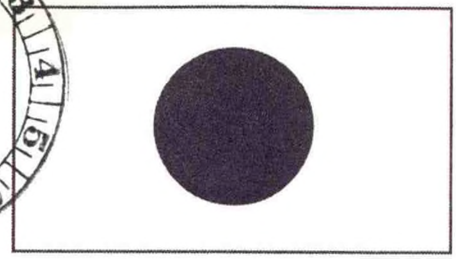

U.S.A.
UJNR
US/Japan Cooperative Program in Natural Resources

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18th MEETING of the U.S. - JAPAN MARINE FACILITIES PANEL

October - November, 1992
Conference Record

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration

18th Meeting of the Marine Facilities Panel of the United States-Japan Cooperative Program in Natural Resources (UJNR)

October - November, 1992

Marine Facilities Panel Charter

The UJNR Marine Facilities Panel consists of senior-level engineers, scientists, and managers from the U.S. and Japan who are involved in advanced technology associated with the research, design, development, evaluation, and operation of marine facilities for a wide variety of applications in the assessment, development, utilization, and management of the oceans and their resources.

The scope of technical topics is broad and includes: ocean and coastal engineering; facilities and techniques for ocean resource exploration and development; shipbuilding and marine transportation; undersea systems, submersibles, and remotely operated vehicles; ocean space utilization; seafloor engineering and offshore construction; port and harbor facility development; ocean environmental measuring and observational systems; and pollution and waste management systems.

Panel members engage in equitable exchanges of technical data and information to avoid unnecessary duplication of ideas; to promote cooperative projects and joint ventures; and to produce mutually beneficial results.

PREFACE

This conference record contains 50 technical papers and special reports presented at the 18th biennial meeting of the Marine Facilities Panel of the Unite States-Japan Cooperative Program in Natural Resources (UJNR), held October 30-31, 1992, Washington D.C.

From October 25-November 10, the Joint Panel toured numerous marine facilities in New England, Washington D.C. Region, Southeast Florida and the San Diego area. A final meeting of the Joint Panel was held November 10 at the Science Applications International Corporation (SAIC), San Diego, CA. A complete schedule and a detailed summary of the meeting and study tour are provided in this report.

The UJNR was established in 1964 to facilitate cooperative efforts and technology exchange in the field of natural resources between key scientific and technical representatives from Japan and the U.S. Seven of the 17 UJNR panels deal with marine science and technology and come under the umbrella of the Maine Resources and Engineering Coordination Committee (MRECC) of the UJNR. The National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce is responsible for leading and administering the marine panels. The Marine Facilities Panel has met 18 times, alternating approximately every 18 months between the U.S. and Japan. Each panel meeting has been documented in the form of a proceeding to provide a permanent record and to facilitate wider dissemination of the technical information presented and exchanged at the meeting.

Participating governmental agencies in Japan have included the Science and Technology Agency; Ministry of Agriculture, Forestry, and Fisheries; Ministry of International Trade and Industry; Ministry of Transport; and the Ministry of Construction. Participating governmental agencies in the U.S. have included the Department of Agriculture; Department of Commerce; Department of Energy; Department of the Interior; Department of Transportation; Department of State; Department of Defense; and the Environmental Protection Agency.

Numerous organizations representing private industry and academia have also participated in past meetings. At this meeting, participants from Japan included: the Japan Marine Machinery Development Association; Ship and Ocean Foundation; Kawasaki Heavy Industries; Sumitomo Heavy Industries; Techno Superliner Association; Research Institute NKK; Hitachi Zosen Corporation; IHI Industries; Niigata Steel Engineering; Taisei Corporation; NKK Corporation; Japan Nation Oil; Mitsubishi Heavy Industries Co., Ltd; Imabari Shipbuilding Co., Ltd.; Mitsui Engineering and Shipbuilding Co., Ltd.; Japan Marine Science and Technology Center; Coastal Development Institute of Technology; University of Tokyo; Nihon University and Yokohama National University. In the U.S., participants included Westinghouse Electric Corp.; Science Applications International Corporation; Martin Marietta Inc.; Deep Ocean Engineering, Inc.; Marine Development Associates; Engineering Service Associates, Inc.; International Maritime, Inc.; University of Hawaii; University of California; Texas A&M University; Massachusetts Institute of Technology; University of Texas; University of Rhode Island; Woods Hole Oceanographic Institute; Harbor Branch Oceanographic Institute; Florida Atlantic University; NOVA University; University of Miami; and Scripps Institute of Oceanography.

Special recognition goes to Mr. Richard Krahl, President, Offshore Consultative Services, for serving as the panel's finance chairman; Ms. Lynne Mersfelder, of the International Affairs Branch, National Ocean Service, NOAA, for making the logistical arrangements for the study tour, and to Mr. John Pritzlaff, of Westinghouse Electric Corp., for providing many of the photographs in this conference record.

Eliot Hurwitz
Editor

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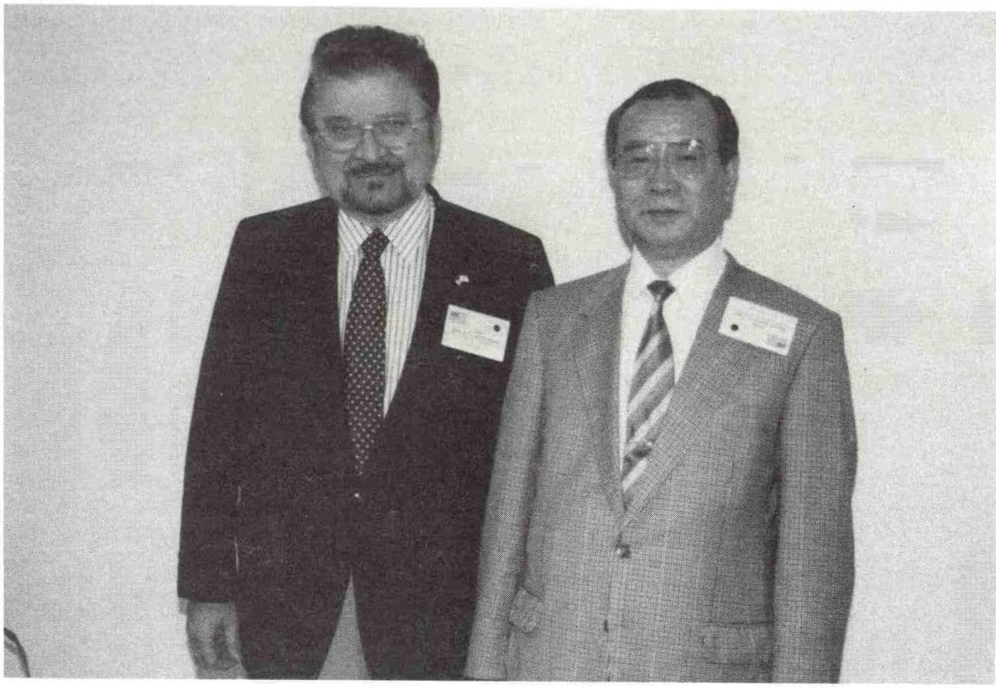


U.S. Panel Chairman J. Vadus and Japan Panel Chairman H. Inoue

Opening remarks by Dr. Robert M. White, President, National Academy of Engineering (left) and Mr. Martin Prochnik, U.S. Chairman, UJNR, U.S. State Department (right)

Opening Remarks

Joseph R. Vadus
Chairman, U.S. Panel

Ohayo gozaimasu, irashaimase, good morning and welcome. Some of us already had the pleasure of greeting most of the members of the Japan Panel in Boston. I hope your visit to New England was interesting and enjoyable.

Once again our U.S. and Japan family is together for the plenary session in Washington DC. On behalf of the U.S. Panel, it is an honor and pleasure for me to extend official warm greetings to Mr. Hajime Inoue, Chairman of the Japan Panel, and to each of the members and advisors of the Japan Panel.

After your gracious hospitality at our last meeting and study tour in Tokyo, Okinawa, Osaka and Kobe, we are delighted to be your hosts for this 18th meeting of the UNJR Marine Facilities Panel. We sincerely hope that your visit to the U.S. is interesting, informative and enjoyable.

Over the years, we engaged in an equitable technology exchange on a wide variety of topics in ocean engineering research and development, and new advances in marine science and technology; developed closer communications between both sides; and engaged in cooperative projects that are mutually beneficial.

I am grateful to Chairman Inoue and the Japan Panel, and to Mr. Yukihiro Narita of JAMDA and the Staff of the Ship Research Institute, for their cooperation in planning and organizing an excellent technical program.

On the U.S. side, I would like to give special recognition to Mr. Richard Krahl, Offshore Consultative Service Inc., for his major effort as Financial Chairman and for his assistance in organizing and planning the program. Other regional chairman include: Prof. Ernst Frankel and Prof. Koichi Masabuchi, Massachusetts Institute of Technology for the Boston area; Mr. Richard Metrey, David Taylor Research Center, Dr. Stanley Dunn, Florida Atlantic University, Mr. Will Connelly, Consultant, and Dr. Tokuo Yamamoto, University of Miami for the Florida Area visits; and Mr. Howard Talkington, Naval Command, Control and Ocean Surveillance Center and Mr. Dan Hightower, Science Applications International, Inc. for the San Diego area.

Regarding all arrangements and program support activities, special recognition is given to NOAA's National Ocean Service's International Affairs Office, especially Lynne Mersfelder, Fatimah Taylor and Adams Miller and to Mr. Eliot Hurwitz for technical programming and editorial services. The superb efforts of all who contributed toward the success of this meeting are greatly appreciated.

As a final note, I would like to say that the U.S. members and advisors cherish the trust and friendship that these meetings have fostered with our Japanese colleagues; and it is our sincere hope that this spirit of mutual cooperation will become even stronger as we strive together to meet the challenges of the 21st Century.

I wish every one of you a pleasant and productive meeting and study tour.

Thank you. Domo arigato, gozaimasu.

Opening Address

Hajime Inoue
Chairman, Japan Panel

Good morning, ladies and gentlemen.

We are very pleased to participate with you in the 18th meeting of Marine Facilities Panel, US-Japan Cooperative Program in Natural Resources here in Washington D.C.

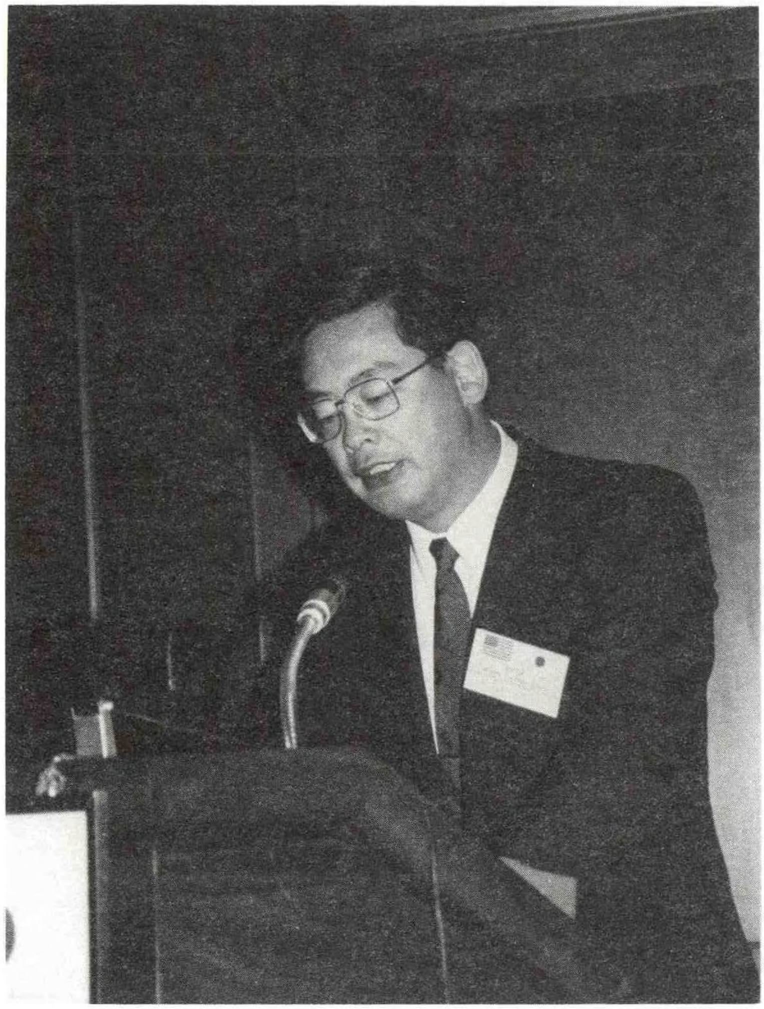
Since I have arrived in Boston, we have met many of our American colleagues, and we have enjoyed a trip from Boston with them, feeling at home.

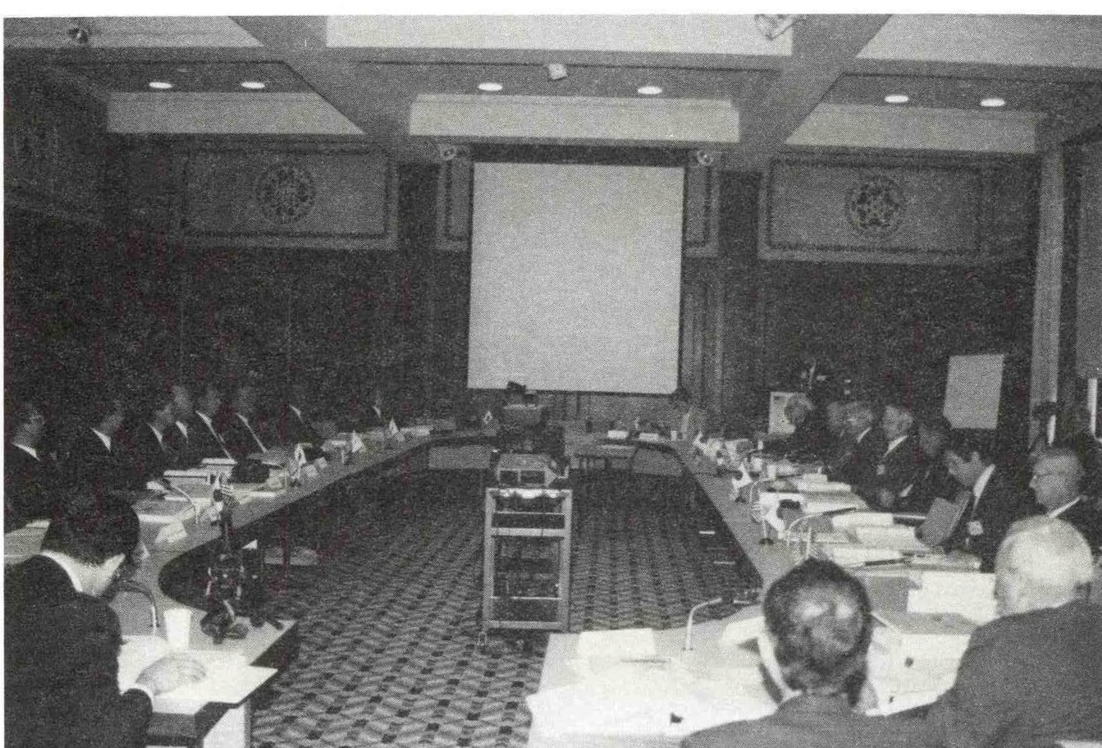
First of all, I would like to thank Mr. Vadus, Mr. Krahl and other people who have assisted in developing the technical program and arranging papers to be presented at the meeting, and preparing an interesting study tour. I am sure that the 18th meeting will be very beneficial and fruitful, and enjoyable, too.

Many papers are presented at the 18th meeting from both the United States and Japan. Two of the Japanese papers are reports of the projects carried out with the cooperation of the U.S. Panel. One is the paper on a database of winds and waves in the north Pacific. The National Oceanic and Atmospheric Administration presented a huge amount of data that greatly contributed to the data base. The other is a paper on a study of an intelligent ship which is a project in cooperation with The Maritime Administration. For this project, Professor Eda of The Merchant Marine Academy of The Maritime Administration came to the Ship Research Institute to work with us, and, in turn, young researchers of the Ship Research Institute visited the Maritime Administration to discuss the research program and its results. These cooperative projects were developed through our Marine Facilities Panel, and I would like to express my sincere thank to the United States Panel.

I believe that this kind of cooperation between the United States and Japan should be increased. One reason for that is that recent technological issues are sometimes so big that they need a large amount of money and a lot of researchers. It is not economical for each country to investigate such big issues separately. One of those issues is the environmental issue. We share the earth. We share the atmosphere and the oceans. It is quite natural that we, all the human beings, endeavor to support the issue with all our might. That is another reason for cooperation.

A lot of international regulations have been proposed from many countries. Some of the proposals were premature and rough drafts. No matter how unreasonable it may be, once a draft is proposed, everything starts with it, and it is very difficult and very expensive to change the initial approach. For avoiding such an uneconomical process, we should discuss the matter in advance to prepare a draft when the issue arises. As far as issues of the marine environment are concerned, I believe the United States and Japan should take the lead. I believe that our UJNR-MFP is an excellent mechanism for cooperation. The Ministry of Transport and Ship Research Institute is in contact with U.S. Coast Guard to exchange information about control of exhaust gas from ships. The Ministry of Transport hopes to propose a regulation about it to The International Maritime Organization in cooperation with the United States in the future. When the scenario is written, we will bring it into the Marine Facilities Panel for discussion. We all share this planet, so let's all work together for the future of human beings. Thank you.





Opening remarks by Dr. Yukihide Hayashi, Counselor for Science and Technology, Embassy of Japan at the Plenary Session (below).

A Tribute to Dr. Noboru Hamada

The Marine Facilities Panel, US-Japan Cooperative Program in National Resources (UJNR), honors posthumously Dr. Noboru Hamada, who died July 10, 1993

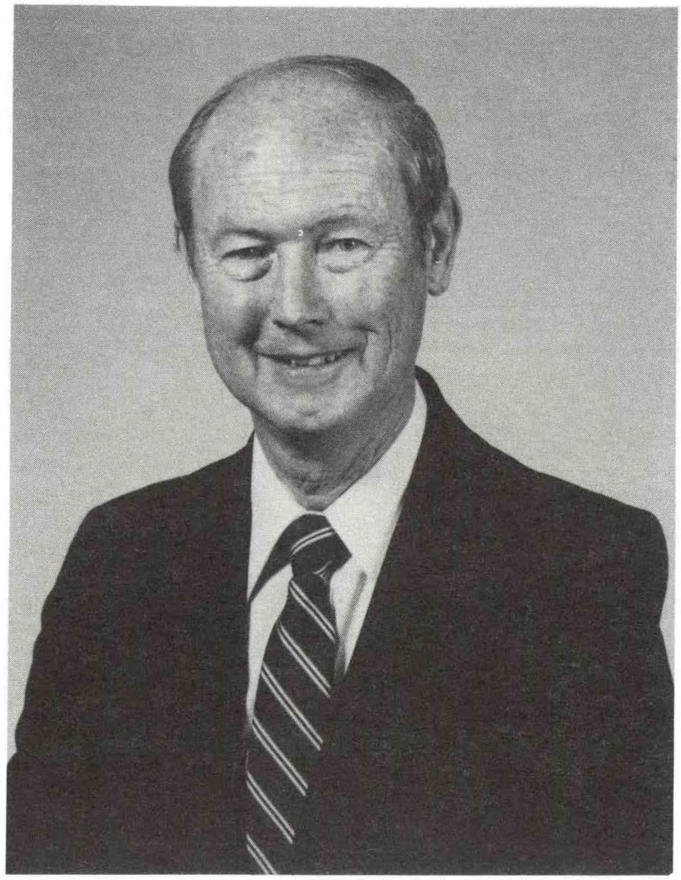
The Marine Facilities Panel owes a debt of gratitude to Dr. Hamada for his many contributions for over two decades. As Director General of the Ship Research Institute, Ministry of Transport, he also served as Chairman of the Japan Marine Facilities Panel; and afterward as President of the Japan Marine Machinery Development Association (JAMDA) he continued to provide strong support as a member. During this long period, his strong leadership contributed greatly to the strengthening and respected stature of the Maine Facilities Panel. Dr. Hamada was a man of great vision, and had contributed very much toward advancement of Ships and Ship Systems development that will project many years into the next century. He has left a legacy of great ideas based on his dreams of the future.

We will always remember Dr. Hamada, and will continue to share in his fervent objectives for development of ships and ship systems for the benefit of mankind. He has been a good friend and colleague for many years. We will miss him.

Hajime Inoue
Japan Chairman

Joseph R. Vadus
U.S. Chairman

Marine Facilities Panel, UJNR



A Tribute to Mr. Howard Talkington

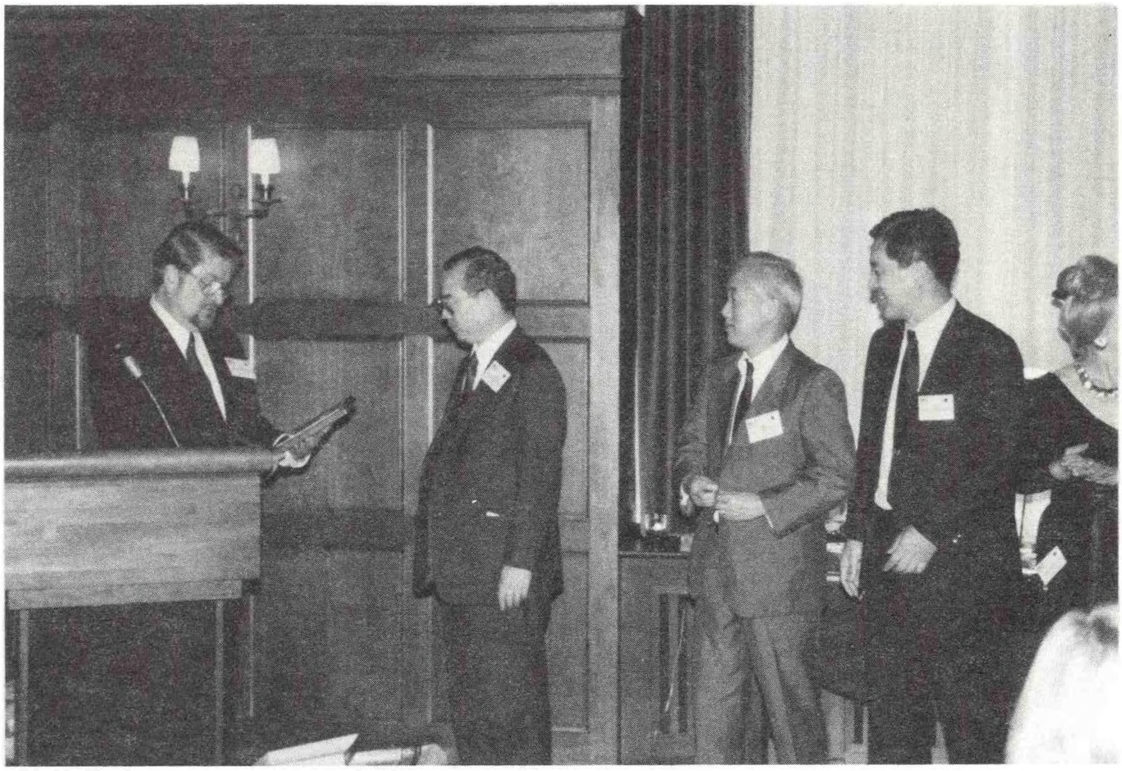
The Marine Facilities Panel, US-Japan Cooperative Program in National Resources (UJNR), honors posthumously Mr. Howard Talkington, who died December 15, 1993

Mr. Howard Talkington was a very active member of the US Marine Facilities Panel for 10 years, while he was Technical Director, Naval Ocean Systems Center and later as Deputy Executive Director of this center, renamed the Naval Command, Control and Ocean Surveillance Center, San Diego, California. He was a highly respected by US and Japan Members for his technical expertise in underwater technology, especially remotely operated and autonomous undersea vehicles. He authored and presented papers and engaged in technology exchange discussions at all of the meetings and hosted the Panel during several visits at the San Diego Facility. Howard and his wife Nula were always in the main stream of our study tours and social events. He will be remembered not only for his many technical accomplishments but for his congenial personality and sincere friendliness. Howard has been a good friend and colleague for 25 years. We will miss him.

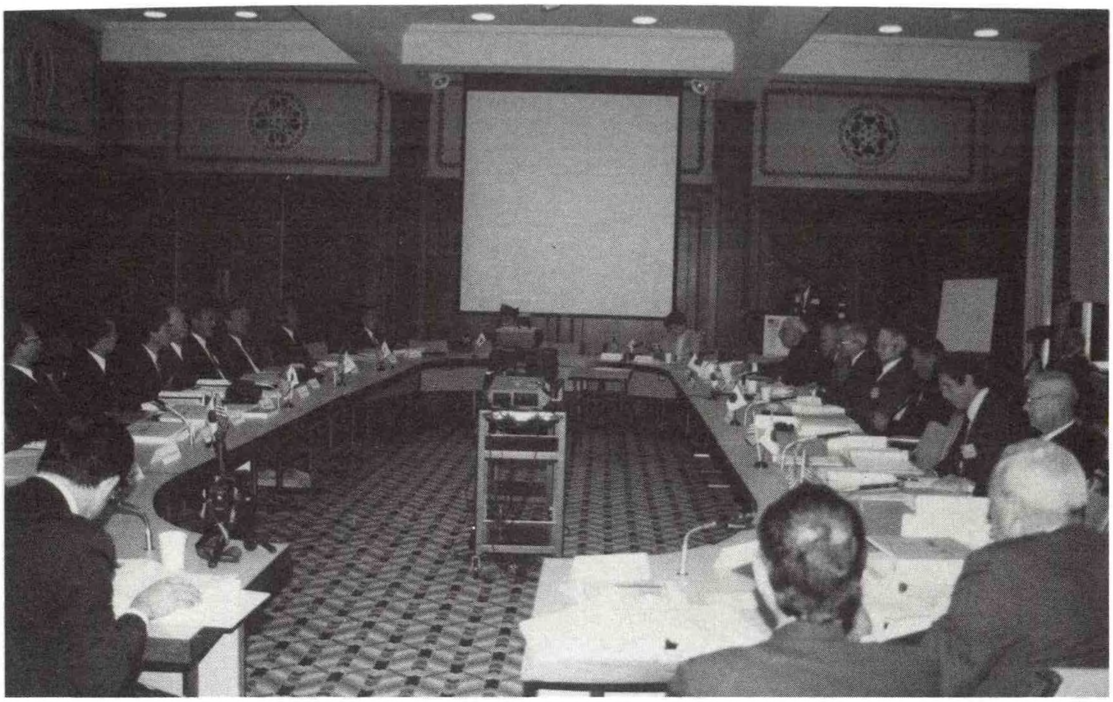
Joseph R. Vadus
US Chairman
Marine Facilities Panel
UJNR

Special Recognition

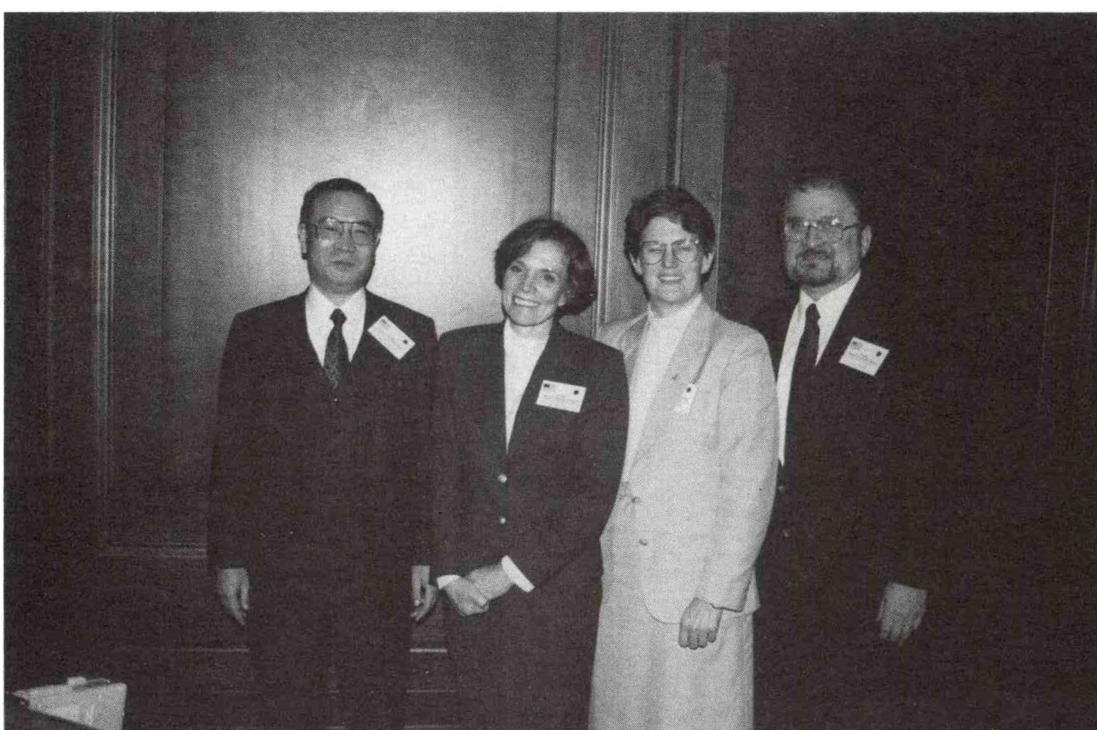
At the National Academy of Sciences on October 30, 1992 Plaque awards presented by US Chairman J. Vadus to Japan Chairman H. Inoue, H. Nakato and Y. Narita (above) and Japan Chairman H. Inoue presenting plaques to J. Flipse and J. Wenzel (below) for their distinguished service and valuable contributions to the Marine Facilities Panel



Marine Facilities Panel at the National Academy of Sciences, Washington D.C.



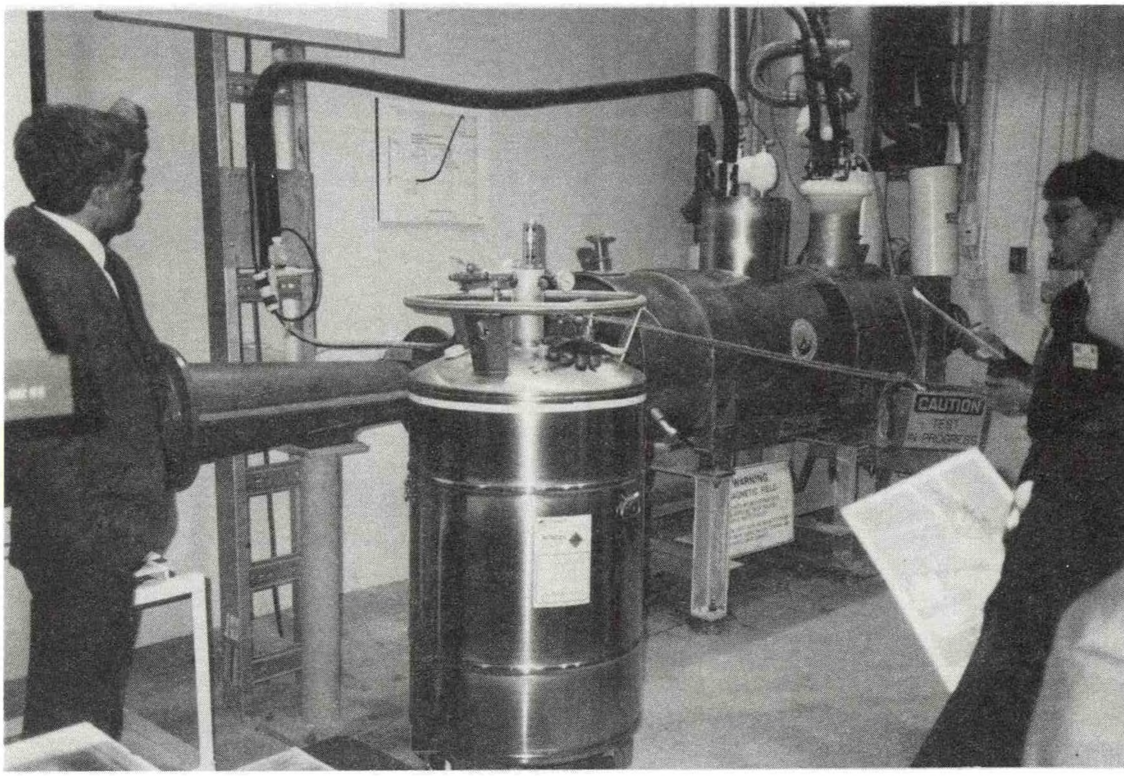
Plenary session at the National Academy of Sciences, Washington D.C.

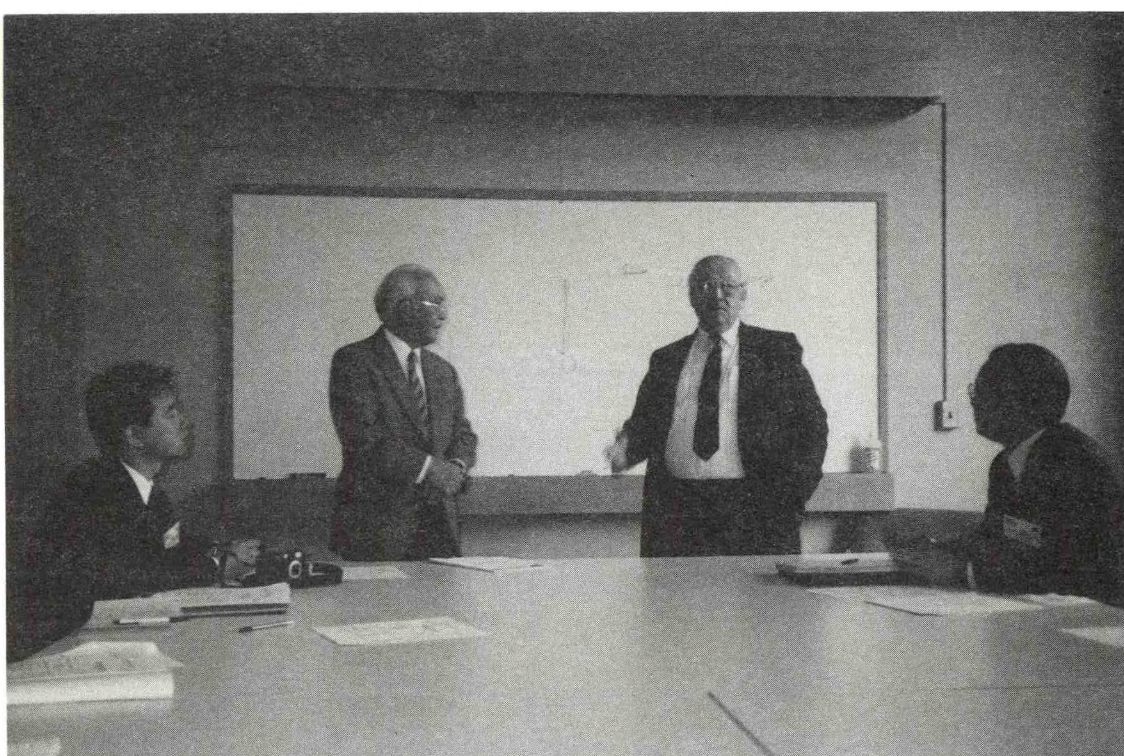


Japan Chairman H. Inoue, Keynote Address Speakers Silvia Earle and Kathryn Sullivan, and US Chairman J. Vadus

US-Japan Reception at the National Academy of Sciences Washington D.C.

U.S. sponsored receptions in Olney, MD (above) and Potomac, MD (below)





Briefings at the Naval Undersea Warfare Lab's MHD Test Facility (above); and by Professors Frankel and Masabuchi at the Massachusetts Institute of Technology (below).

Marine Facilities Panel visiting the U.S. Naval Academy, Annapolis, MD (above) and at the Harbor Branch Oceanographic Institution, Ft. Pierce, Florida (below)

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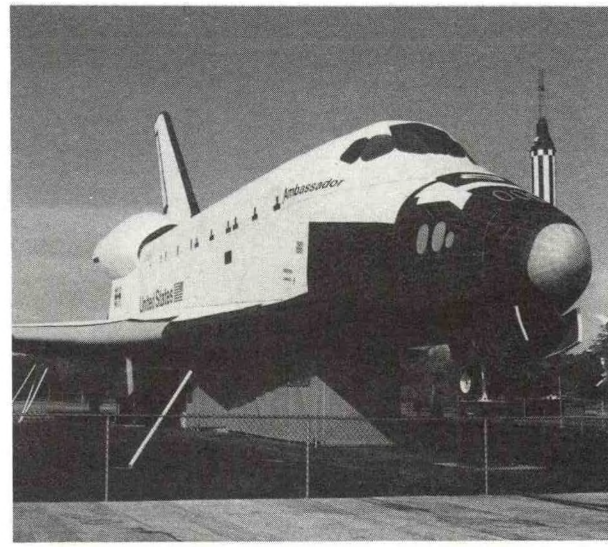
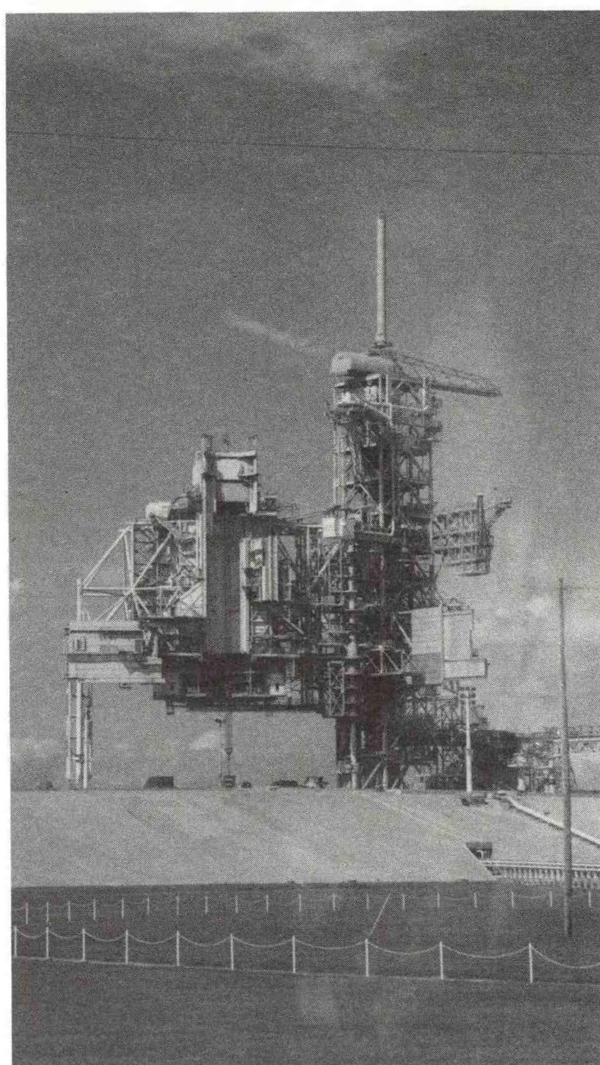
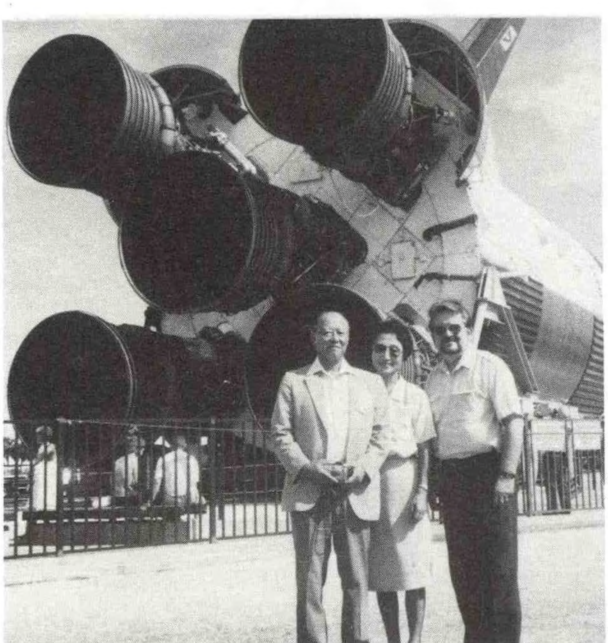
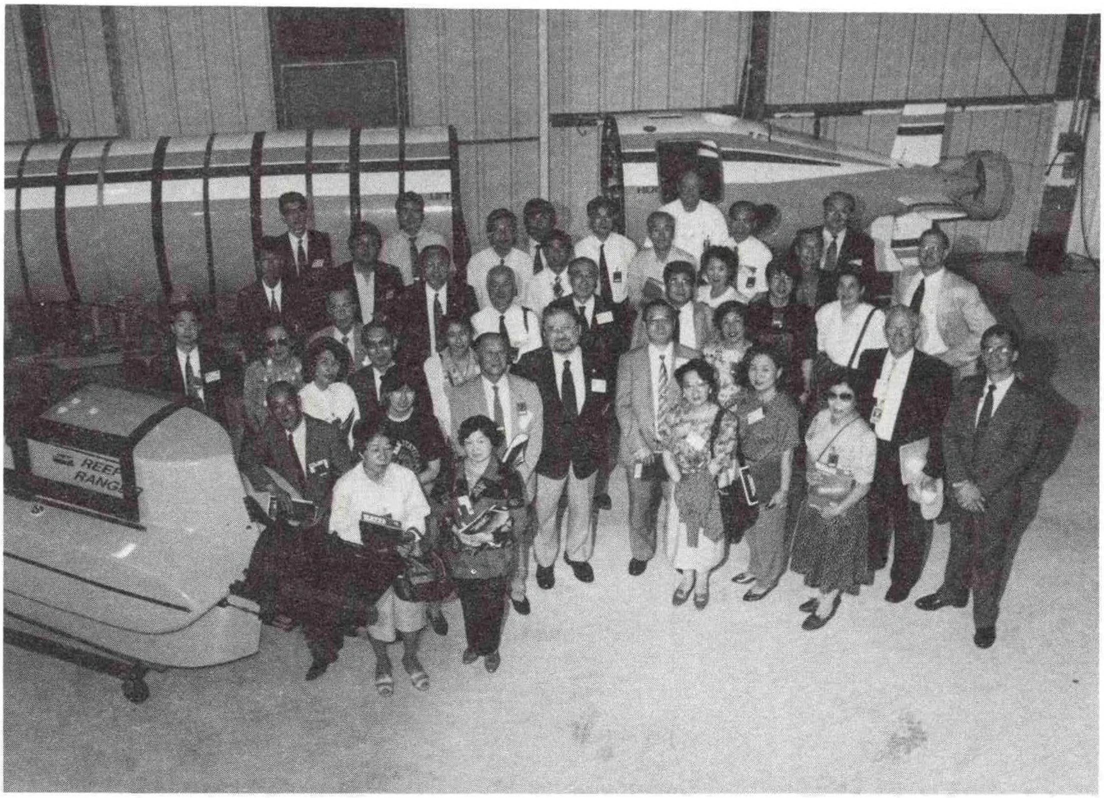






Visit to Kennedy Space Center Cape Kennedy, Florida



Marine Facilities Panel: visiting Perry Technologies Riveria Beach, FL (above); and during visit of Living Seas Pavilion, Orlando FL (below)

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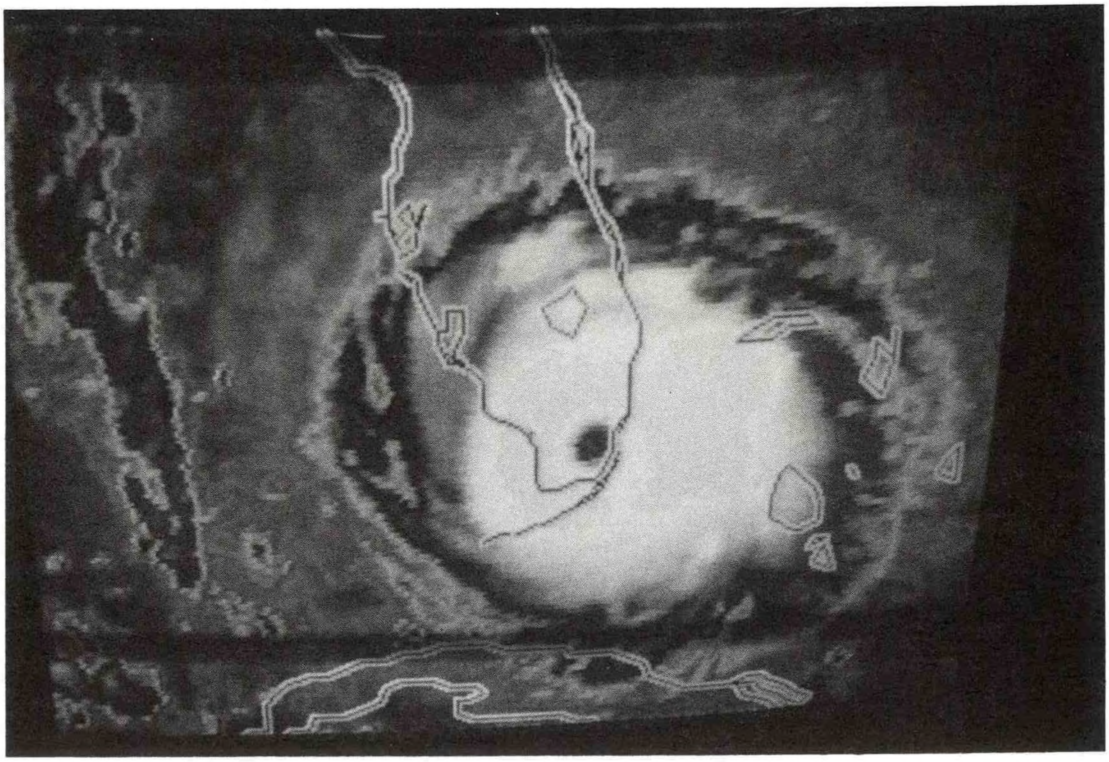


Marine Facilities Panel (above) being briefed at NOAA's National Weather Service's Forecast Office, Miami, Florida on the tracking of hurricane Andrew of August, 1992 shown centered over Miami (below)

Marine Facilities Panel: on deck of the NOAA ship DAVID STARR JORDAN (above); and in session at the final meeting held at Science Applications International Corp., San Diego, California

Itinery: 19th Meeting & Study Tour of UJNR MFP

Preliminary Program:

Oct. 24(Sat)	Japanese arrive	
		Logan International airport
		Hyatt Regency Cambridge 575 Memorial Drive Cambridge, MA 02139
Oct. 25(Sun.)	Free Day	
Oct. 26(Mon)		
	09:00-12:00	Visit Massachusetts Institute of Technology Department of Ocean Engineering 77 Massachusetts Avenue, Room 5-22 Cambridge, MA
	12:00-13:00	Lunch at MIT Faculty Club
	14:30-15:30	Visit Naval Undersea Warfare System Center (Superconducting Electromagnetic Thruster Laboratory) Building 80 Newport, RI
		Newport Marriot Hotel 25 America's Cup Avenue Newport, RI 02840
Oct. 27(Tues)	Attend OCEANS 92 Conference	
		Newport Marriot Hotel
Oct. 28(Wed)	Attend OCEANS 92 Conference	
	12:00 noon	Take shuttle to Providence Airport Fly Providence, RI to Washington D.C.
		Wyndham Bristol Hotel 2420 Pennsylvania Avenue, NW Washington, DC 20037

Oct. 29(Thurs)		
	09:30-12	Visit Naval Surface Warfare Center (Formerly David Taylor Research Center), Annapolis Facility (Superconductive Electric Drive Systems, and Environmental Control Research) Annapolis, MD
	12:30-14:00	Lunch: Harry Browne's Restaurant 66 State Circle, Annapolis, MD
		Free time in Annapolis
	14:00-16:00	Tour: U.S. Naval Academy,Annapolis Naval Academy Guide Service Gate 1 Rickets Hall Annapolis, MD 21402
	17:00-20:30	Octoberfest Reception: Metrey's Home 16710 Batchellors Forest Rd. Olney, MD 20832
Oct. 30(Fri)		
	08:00-16:30	Plenary Session in Lecture Room, National Academy of Sciences (NAS) 2101 Constitution Avenue, NW Washington, DC 20418
	12:00-13:00	Lunch at NAS
	18:00-20:00	Joint Reception at NAS 2101 Constitution Avenue, NW Washington, DC 20418
Oct. 31(Sat)		
	08:30-15:00	Plenary Session at NAS
	12:15-13:15	Lunch at NAS
	19:00-22:00	Reception at: Vadus' Home 8500 Timber Hill Lane Potomac, MD 20854
Nov. 1 (Sun)	Free Day	
Nov. 2 (Mon)		
	7:00	Depart for Airport

08:25-10:47	Fly Washington, DC to Orlando
	"Living Seas" exhibit at Epcot Center
	Disney's Port Orleans Resort 2201 Orleans Drive Lake Buena Vista, FL 32830
Nov. 3 (Tues)	
	Bus to Cape Kennedy
10:00-12:00	"Spaceport USA" tour of NASA Facilities
12:00-12:50	Lunch at NASA
12:50-13:40	IMAX movie of Space Program
15:00-16:00	Briefing on Navy Acoustic Test Facility (formerly David Taylor Research Center) Trials Detachment Bldg. 740 Mullet Road Cape Canaveral, FL 32920
	Bus to Cocoa Beach Hilton Hotel 1550 N. Atlantic Avenue Cocoa Beach, FL 32931
Nov. 4 (Wed)	
9:00-12:00	Bus to Harbor Branch Oceanographic Institution 5600 Old Dixie Hwy. Ft. Pierce, FL 34946
16:00	Bus to Holiday Inn, Singer Island 3700 N. Ocean Drive Singer Island, FL 33404
18:00-21:00	Reception hosted by Perry Technologies
Nov. 5 (Thurs)	
08:15-08:30	Bus to Perry Technologies in Riviera Beach
08:30-11:00	Visit Perry Technologies for overview and tour of submersibles and ROV's 100 E. 17th Street Riviera Beach, Fl 33404
11:15-11:45	Bus to Florida Atlantic Univ. (FAU) in Boca Raton
12:00-13:15	Lunch hosted by Florida Atlantic University Board Of Regents Room, Administration Bldg.
13:30	Florida Atlantic University, Ocean Engineering facilities (AUV, SONAR and Sea Water Corrosion Laboratories)

16:00-17:00	Tour of FAU's beach side engineering laboratory at Gumbo Limbo , Boca Raton
	Bus to Howard Johnson's Hotel 2096 North East 2nd Street Deerfield, FL 33441
Nov. 6 (Fri)	
08:30-09:30	Bus to NOVA University in Dania, FL
09:30-11:00	Tour NOVA University Oceanographic Center 8000 N. Ocean Drive Diana, FL 33304
11:00-12:00	Bus to University of Miami
12:00-12:45	Lunch at University of Miami, RSMAS cafeteria Rosenstiel School of Marine Affairs and Science 4600 Rickenbacher Causeway Miami, FL
12:45-13:30	Visit University of Miami
14:00-15:00	Visit National Hurricane Center, NOAA IRE Building, 6th floor 1320 South Dixie Hwy Coral Gables, FL 33146
Nov. 7 (Sat)	Free day
Nov. 8 (Sun)	
07:00	Depart for Airport
09:00-13:45	Fly Miami to San Diego Bus to International Facilities
18:00	Dinner - Old Town San Diego
	Bus to Embassy Suites Hotel at San Diego Bay 601 Pacific Highway San Diego, CA 92010
Nov. 9 (Mon)	
08:00	Bus to NOAA Ship DAVID STARR JORDAN
08:30-09:30	Tour of NOAA Ship 297 Rosecrans, Nimitz Facility San Diego, CA
09:30-11:30	Bus to Naval Command Control Oceans Surveillance Center (NRaD) (ex-Naval Ocean Systems Center) San Diego, CA Briefing on Navy Systems

11:30-14:00	Lunch NRaD
14:00-16:30	Unified Port District of San Diego 3165 Pacific Highway San Diego, CA
19:00	Dinner at Harbor House Restaurant

Nov. 10 (Tues)

08:30	Bus to Scripps Institution of Oceanography
09:00-11:30	Scripps Institution of Oceanography Stephen Birch Aquarium La Jolla, CA
12:00-13:00	Final Meeting at Science Applications International Corporation, SAIC
13:00	Luncheon Buffet and Reception
14:30	Bus return to Embassy Suites Hotel

Nov. 11 (Wed) U.S. and Japanese Departures

18TH MEETING
OF THE
MARINE FACILITIES PANEL

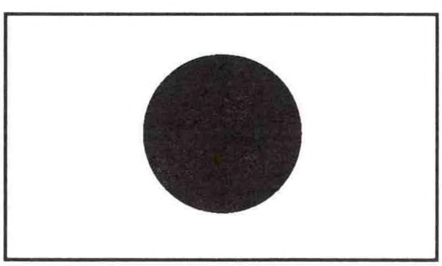
OCTOBER 24 - NOVEMBER 11
1992

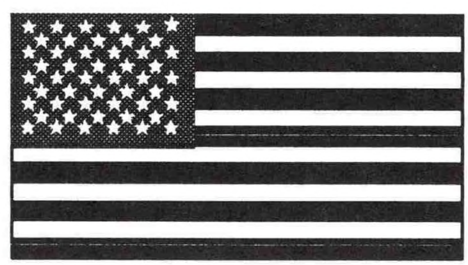
日本

日米天然資源共力プログラム

U.S.A.

UJNR
US/Japan
Cooperative
Program
in
Natural
Resources





STUDY TOUR

BOSTON / NEWPORT
WASHINGTON DC / ANNAPOLIS
FLORIDA
SAN DIEGO

18th UJNR/Marine Facilities Panel Study Tour

Monday, October 26th
Massachusetts Institute of Technology

Prof. Ernst Frankel
Massachusetts Institute of Technology
77 Massachusetts Ave.
Building 5 Room 222
Cambridge MA 02139
tel: 617-253-6763
fax: 617-253-8125

Naval Undersea Warfare System Center (Superconducting Electromagnetic Thruster Laboratory)

Dr. James Meng
Chief Scientist
Naval Undersea Warfare Systems Center
Newport, RI 02841
tel: 401/841-1477
fax: 401/841-7012

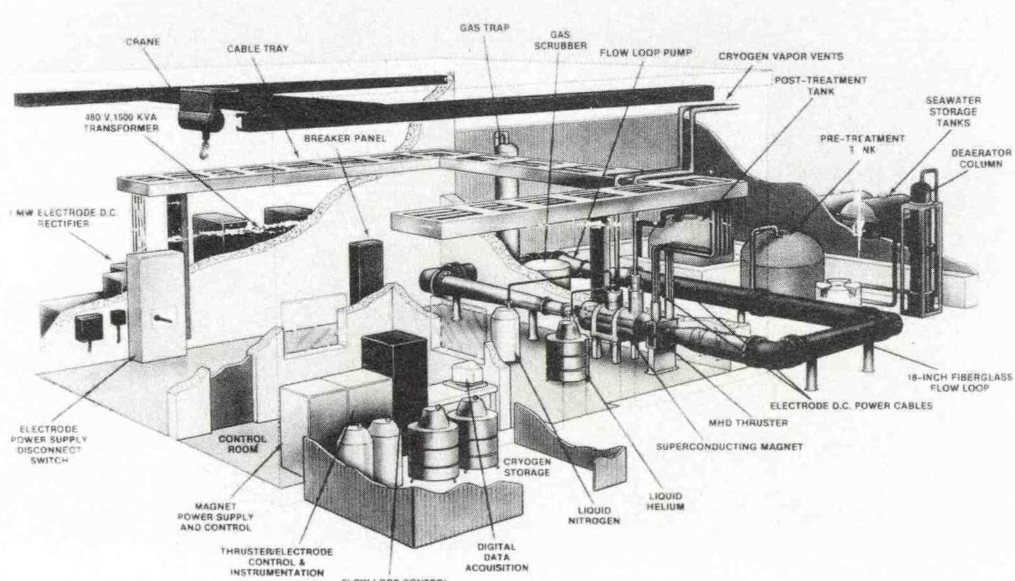
14:30 General Overview and principle of seawater EMT and demonstration - Dr. Jim Meng

14:35 Design and construction of Superconducting Magnet - Dr. Peter Hendricks

14:50 Design and construction of SCMET laboratory and operations 1990 to 1992- Mr. Dana Hrubes and Dr. Charlie Henoch

15:15 Summary of results and future applications with high temperature superconductors - Dr. Jim Meng

SUPERCONDUCTING ELECTROMAGNETIC THRUSTER LABORATORY



Tuesday, October 27th and Wednesday , October 28th

OCEANS 92 - Mastering the Oceans Through Technology
Newport, Rhode Island

Dr. Craig Dorman, Chairman, Oceans '92
Director
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
tel: 508-548-1400x2500
fax: 508/457-2190

With its diverse set of topics, covered by high quality presentations, Oceans '92 promises to be an exciting forum about the cutting edge technology which is helping to drive ocean science into some major new frontiers. Given national and international priorities, the Plenary Session's theme "Global Ocean Observing Systems" is a particularly timely and important example of one of those frontiers, and will provide an appropriate orientation for the rest of the Technical Program. Sessions within that program will focus on such exciting areas as:

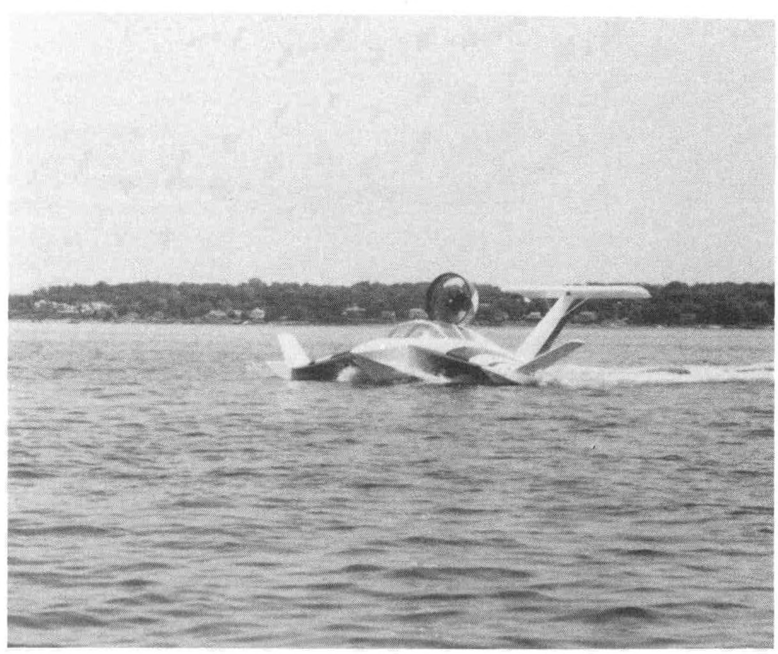
- Computing and Information Management
- Sensing and Processing Technologies
- Communications and Navigation
- Instrumentation, and Measurements
- Technology Advances.

OCEANS 92 MASTERING THE OCEANS THROUGH TECHNOLOGY

Flarecraft Demonstration

Mr. Richard Shamp
President
Engineering Services Associates, INc
9912 Main St.
Fairfax, VA 22031
703-352-7600

A wing and ground effect vessel (boat). It becomes airborne at 40 mph - flies over the water between 75 and 100 mph using 3 gallons of gas per hour. The current model holds three passengers. The size can be expanded to carry many more passengers.



Thursday, October 29th

Naval Surface Warfare Center
(Formerly David Taylor Research Center),
Annapolis Detachment
Environmental Control Research
Annapolis. MD

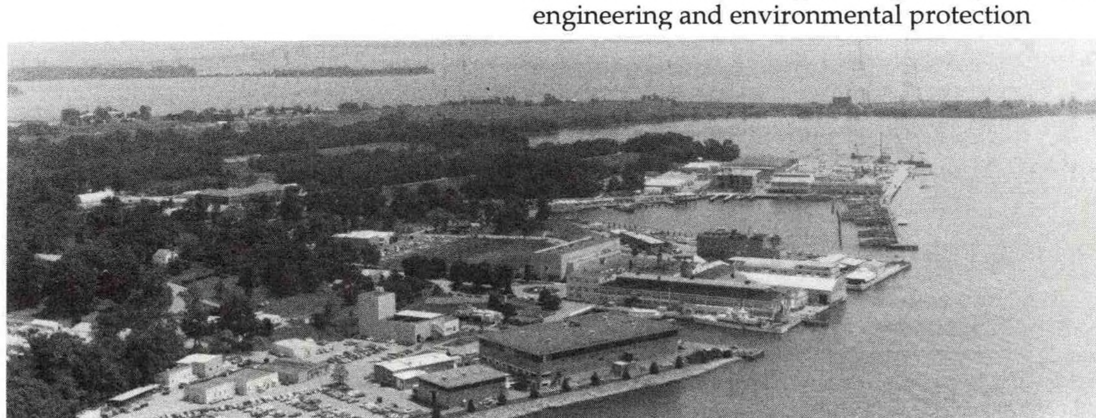
Richard Metrey
Technical Director
Bethesda, MD 20084
tel: 301/227-1628
fax: 301/227-5657

The mission of the Naval Surface Warfare Center (NSWC) is to operate the Navy's full-spectrum research, development, test, and evaluation, engineering and fleet support center for ship hull, mechanical and electrical (HM&E) systems, surface ship combat systems, coastal warfare systems and other offensive and defensive systems associated with surface warfare. NSWC provides the Navy with leadership and expertise in 14 major technical areas and is organized into five divisions. The Carderock Division, with approximately 4,500 employees, is centered at the David Taylor Model Basin in Bethesda MD, with a major detachment in Annapolis, MD. The Division's mission is to provide research, development, test and evaluation, fleet support, in-service engineering and test ranges for surface and undersea vehicle HM&E systems and propulsors; provide logistics R&D; and provide support to the Maritime Administration and the maritime industry.

The Annapolis Laboratory occupies 66 acres on the Severn River, directly across from the U.S. Naval Academy. It employs 950 civilian and military personnel who work in two major technical departments

Developing naval machinery components and systems is the primary function of the propulsion and auxiliary systems department. Research includes auxiliary machinery (pumps, compressors, heating, ventilation and air conditioning, piping and fluid systems), electrical machinery, ship service power (generators, power conditioners, and distribution systems), machinery and electromagnetic silencing, submersible machinery, prime movers (various engine types) and superconductivity applications.

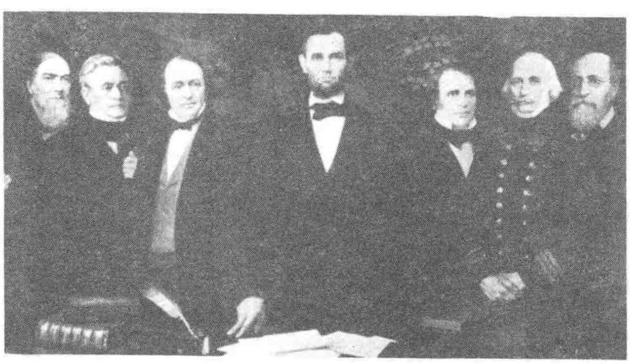
As the Navy' primary source of materials technology for ships, submarines, and advanced naval craft, the ship materials engineering department performs research on naval alloys, metals fabrication, nonmetallic composites, fuels, lubricants, anti-fouling coatings, shipboard fire engineering and environmental protection



Friday October 30th and Saturday October 31st

Plenary Session I and II
National Academy of Sciences (NAS)
2101 Constitution Ave. NW
Washington, DC 20418

Since 1863, when it was chartered by the U.S. Congress, the National Academy of Sciences has given objective and scientifically sound advice to the federal government on difficult matters such as nuclear power, workplace safety, space exploration, agriculture, defense, health care and myriad other issues. Congress was succinct in its charge. It directed the 50 charter members of the Academy to "investigate, examine, experiment, and report upon any subject of science and art,"whenever called upon by any department of the Government. More than 125 years later, this duty is carried out not by one organization, but by four: the National Academy of Sciences, with about 1,550 members; the 1,300-member National Academy of Engineering (home to the Marine Board); the 460-member Institute of Medicine; and the National Research Council, established in 1916, with about 10,000 volunteer committee members, serving in nearly 1,000 different study committees that generate about 300 reports annually. National academies that honor outstanding scientists and engineers with membership are not peculiar to the United States. Most industrialized nations and many developing countries have similar honorary organizations. None, however, has a counterpart to the National Research council, a means of mobilizing science and engineering talent to address national issues.

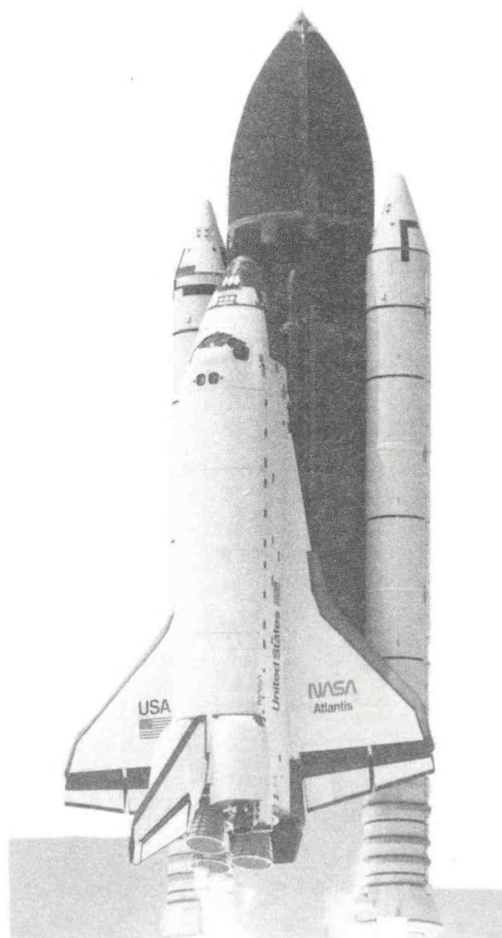


Abraham Lincoln with the Founders of
The National Academy of Science

Tuesday November 3rd

Cape Canaveral, Florida
"Spaceport USA" tour of NASA Facilities

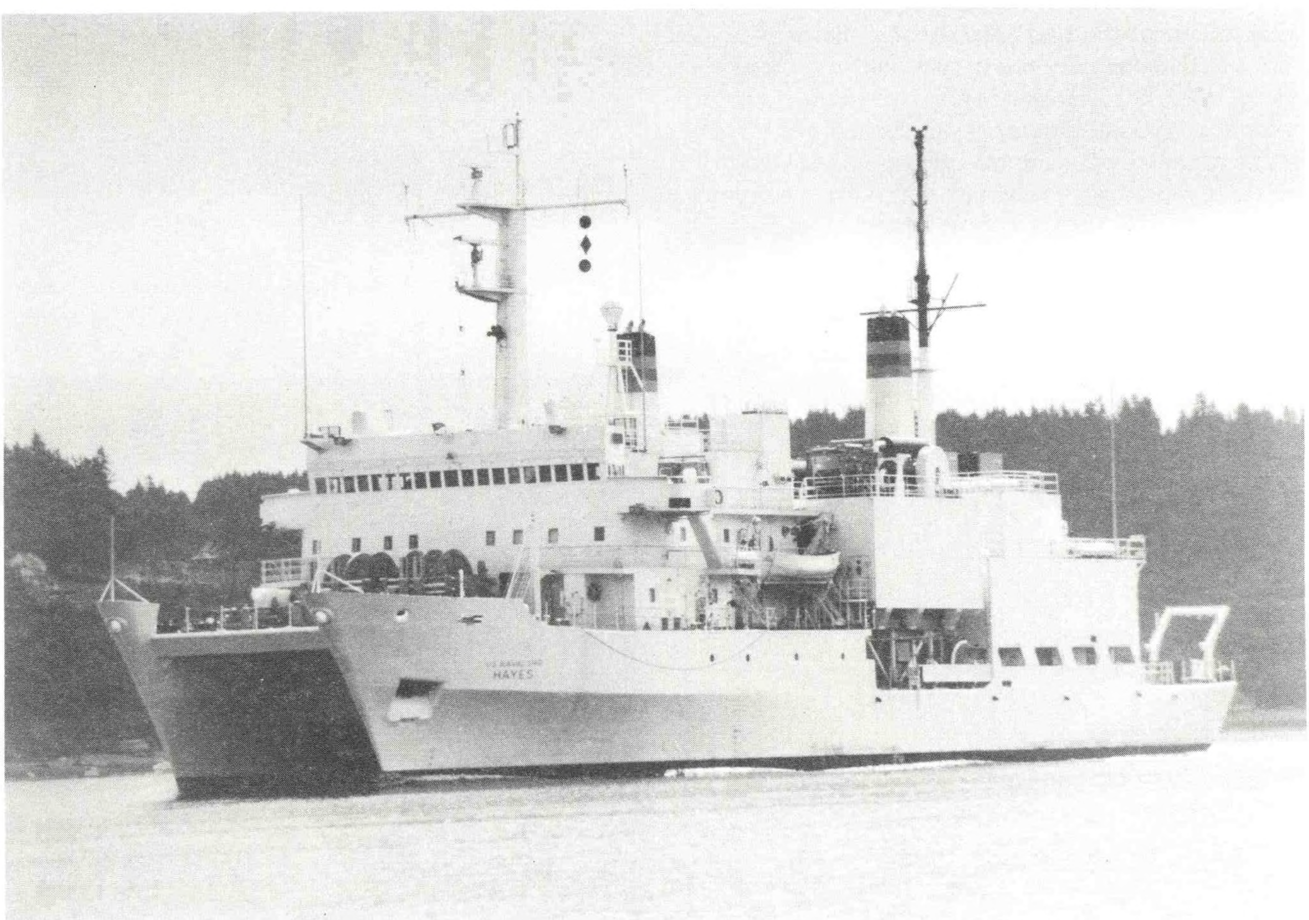
Tour of the Kennedy Space Center including launching pads, Astronaut Training Center and the Canaveral Air Force Station's museums. The Air Force Space Museum has more than 70 missiles and space-launch vehicles on display and is located on the historic Space Launch complex 26, where America's first satellite, *Explorer 1*, was launched. The Valiant Air Command Museum is a historical flying museum, operations center, and headquarters, preserving vintage World War II and post-war military aircraft. Since its formation in 1977, the VAC has collected more than 350 historic warbirds. A highlight of the trip will be the IMAX film presentation, projected on a screen 5 and a half stories high and 70 feet wide.



David Taylor Research Center
Navy Acoustic Test Facility
740 Mullet Road
Cape Canaveral, FL 32920-4504

Mr. Richard Metrey
Technical Director
Naval Surface Warfare Center
(formerlyDavid Taylor Research Center)
Bethesda, MD 20084
tel: 301/227-1628
fax: 301/227-5657

An overview of the Submarine Acoustic Trials program will be provided. The briefing will include the methodology used to measure andprocess submarine acoustic trials data. The capabilities of the acoustic measurement platform, USNS HAYES, its acoustic arrays and data processing systems will be discussed



Wednesday, November 4th
Harbor Branch Oceanographic Institution

Mr. Andrew Clark
Harbor Branch Oceanographic Institution
5600 Old Dixie Hwy.
Ft. Pierce, FL 34946
tel: 407/465-2400x254
fax: 407/465-2446

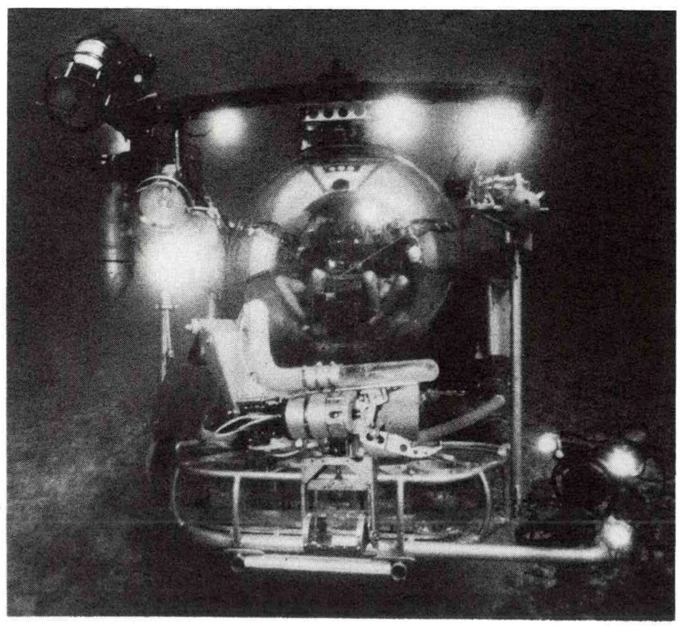
Scientists and engineers of this not-for-profit organization share a commitment to understand and protect the oceans, estuaries and adjacent coastal regions. They are involved in research and education in the marine sciences; biological, chemical, and physical oceanography; natural products chemistry; marine biomedical sciences and ocean engineering, and aquaculture.

Harbor Branch is located in a transitional zone between warm-temperature to the north and subtropical to the south for climate, vegetation, and animal populations. Transitional zones are noted for great diversity, containing species that are characteristic of the two adjacent regions, as well a species that occur only the transitional zone. The campus of harbor Branch encompasses some of the last pristine coastal hammocks on the East coast of Florida, and extends from mangroves on the lagoon, through a red maple-sweet bay magnolia swamp, to scrub ridge on old dunes. Harbor Branch is home to plants and animals that are of special concern, threatened or endangered. This favorable geographic location also lends itself to *in situ* testing of marine materials as well as a year-round testing of oceanographic equipment.

Harbor Branch enjoys a national and international recognition as a major research and study facility. The staff of approximately 200 includes scientists, engineers, technicians, mariners, support and management personnel. One in six holds a Ph. D. degree.

The Divisions of the Institution are:
- Division of Engineering Research and Development
- Division of Aquaculture
- Division of Environmental, coastal and Ocean Sciences
- Division of Marine Operations

Other operations include:
- Biomedical Marine Research
- The Harbor Branch Environmental Laboratory
- The J. Seward Johnson Marine Education and Conference Center
- The Harbor Branch Oceanographic Museum



Thursday, November 5th

Perry Technologies for overview and tour of submersibles and ROV's

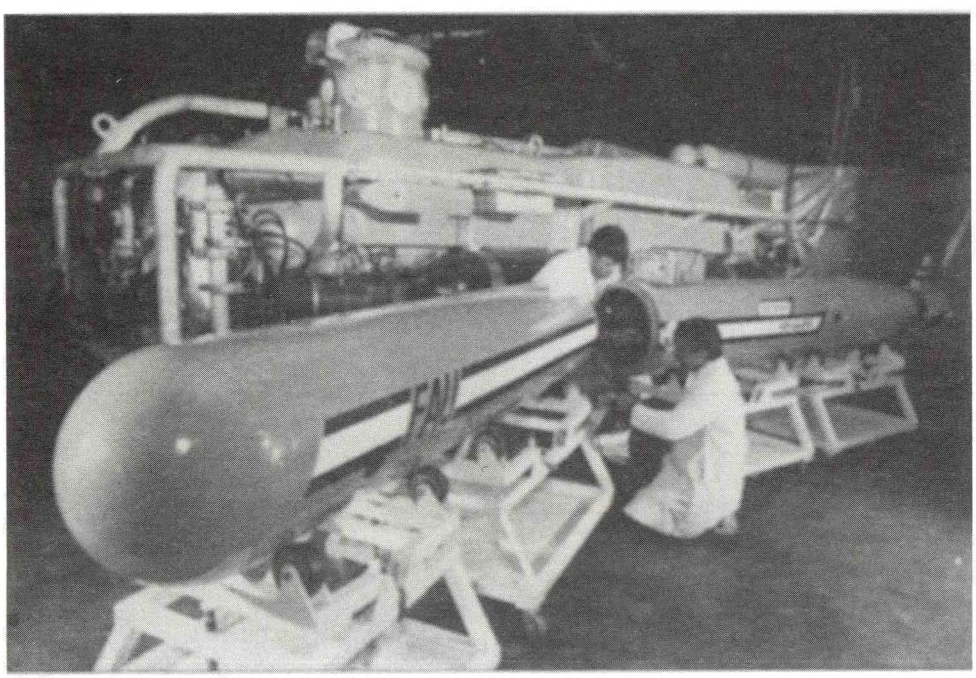
Mr. Mike Mulleavey
100 E. 17th Street
Riviera Beach, FL 33404

Perry Technologies' marine base facility has more than 30 years of experience in the design, protoptyping, assembly, integration, manufacture, test, operation, and support of undersea work systems. The engineering and manufacturing facilities are purpose-built for prototype development and limited quantity production. Engineering and manufacturing experience is in materials, structural, welding, electrical, electronic, software, controls, mechanical, fluid, hydraulic systems, machining, assemble, test and integration, and all the specialties required for undersea work systems. The Perry Technologies has dock space for multiple vessels with an overhead crane for support vessel operations, mobilization, and demobilization. A roof canopy with side curtains extends out over the gantry crane and over the vessel's after deck so that vessels can be loaded and unloaded directly from the manufacturing area. An above-ground test tank, measuring 16.78 meters in diameter and 7.3 meters in depth has been augmented as part of ongoing company research and development to offer ocean heave simulation capability and ROV checkout for realistic verification testing and operator training.

Florida Atlantic University, Ocean Engineering facilities (AUV, SONAR and Sea Water Corrosion Laboratories),

Dr. Stanley Dunn
Chairman, Ocean Engineering Dept.
Florida Atlantic University
Boca Raton, FL 33431
tel: 407/367-3437
fax: 407/367-3885

Tour of FAU's beach side engineering laboratory at Gumbo Limbo, Boca Raton



Friday, November 6th

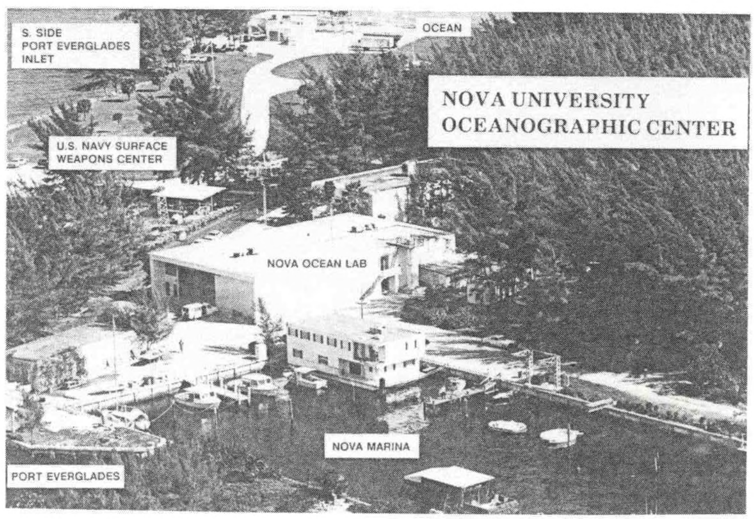
NOVA University Oceanographic Center

Dr. Julian McCreary
NOVA University Oceanographic Center
8000 N. Ocean Drive
Dania, FL 33304

Mr. Will Connelly
1048 S.W. 49th Terrace
Plantation, FL 33317
tel: 305/791-6183
fax: 305/581-4310

The Oceanographic Center is located on 109 acres of land between Fort Lauderdale's Port Everglades and the Atlantic Ocean. Researchers have immediate access to the Gulf Stream, Florida Straits, and the Bahama Banks. Facilities housed in a 20,000 square foot warehouse building include a large bay for experimental staging, a machine shop, wood shop, biological laboratory, several offices, and the Institute for Marine and Coastal Studies administrative area. A newly acquired 10,000 square foot building soon will house 7 laboratories, 12 offices, a museum room, and a conference room. A third, smaller building provides a coral storage room and workshop, a "wet" classroom, and an outdoor wetlab. At present a large 2-story houseboat in the Center's basin holds offices, a conference room and a common area for faculty, staff and students. The Computer Center has a Micro VAX 3600 with magnetic tape unit, two disk drives, a printer-plotter, and 2 array processors plus a keyboard terminal to the university's VAX 11/789 located on the main campus in Davie. A number of microcomputers are available for faculty and student research, and for administrative purposes. The Center's 22-foot Boston Whaler serves as a research vessel and is used for Gulf Stream, nearshore, and wetlands studies.

Research activities in physical oceanography include modeling of large-scale ocean circulation, coastal dynamics, and ocean-atmosphere coupling, as well as experiments in surface gravity waves. Research in biological and chemical oceanography covers coral reef assessment, sea level changes, physiology of marine phytoplankton and zooplankton, calcification of invertebrates, cell ultrastructure, fouling effects, marine fisheries, and nutrient dynamics.



University of Miami, Rosenstiel Campus

Dr. Tokuo Yamamoto
University of Miami,
Rosensteil School of Marine and Atmospheric Science
4600 Rickenbacker Causeway
Miami, FL 33149
tel: 305/361-4637
fax: 305/361-4781

Since 1943 the University of Miami Rosenstiel School of Marine and Atmospheric Science has existed to pursue scientific discoveries and to educate and train subsequent generations of scientists.

Originally founded as a marine biology laboratory by F.G. Walton Smith, the school's basic and applied research interests have grown to encompass virtually all of the marine-related sciences: marine and atmospheric chemistry, geology, geophysics, applied marine physics, physical oceanography, satellite oceanography, meteorology, and marine affairs, as well as marine biology and fisheries, biochemistry, marine biomedicine, and biotechnology.

Located on a 16-acre facility on Miami's Virginia Key in Biscayne Bay, the school offers the only subtropical marine research basin the continental United States. With the Gulf Stream off shore, a vast expanse of living coral reefs just to the south, and the Florida-Bahamas Carbonate Platform to the west, the campus is surrounded by a unique marine laboratory.

The campus facilities include state-of-the-art computer systems, unique chemical and biotechnology/biomedical laboratories, a near-time satellite down-link, seawater aquaria facilities, an experimental fish hatchery, and a full-service science library.

Two ocean-going research vessels are maintained by the school as part of the United States government academic fleet. The 62-foot R/V CALANUS is a shallow water research vessel that operates primarily in local and Caribbean waters. the 170-foot R/V COLUMBUS ISELIN is used for scientific expeditions throughout the world. The school also participates in the Ocean Drilling Program, an international partnership that uses the drillship JOIDES RESOLUTION to explore the structure and history of the earth by collecting core samples from ocean basins and continental margins.

NOAA National Hurricane Center, Miami Florida

Dr. Robert Sheets, Director
Dr. Jerry Jarrell, Deputy Director
National Hurricane Center
IRE Bldg., 6th floor
1320 South Dixie Highway
Coral Gables, FL 33146

The National Hurricane Center is one of three national centers operated by the National Weather Service. The other two are the National severe Storms Forecast Center in Kansas City and the parent National Meteorological Center in Washington, DC. The Hurricane center has public, marine, and aviation forecast and warning responsibilities for the North Atlantic and Eastern North Pacific Ocean tropic and subtropical regions, the Caribbean Sea and the Gulf of Mexico and adjacent land areas. The NHC provides data assimilation, data analysis and interpretation over these same areas, primarily between the equator and 40^{o} N. This responsibility is both national and international in scope. By international agreement, under the United Nations World Meteorological Organization, the NHC also acts as a Regional Center for Tropical Metrology. IN this capacity, analyses and forecast guidance products are provided on a routine basis to the international community of the Caribbean and Central and North America as well as to all United States interest in the region.

<u>*Monday, November 9th*</u>
NOAA Ship
DAVID STARR JORDAN

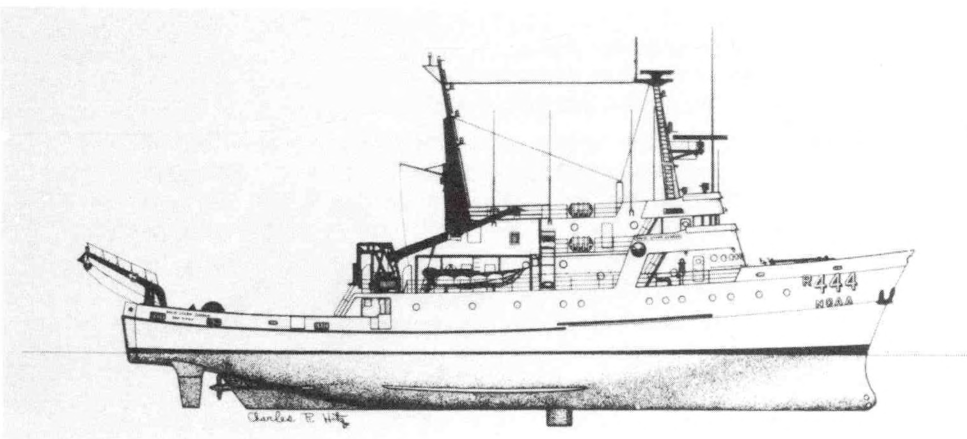
NOAA Port Master
SW Fisheries Center
PO Box 271
La Jolla, CA 92038
attn: Lieutenant Christy Miller

The DAVID STARR JORDAN is one of five Class IV ships operated by NOAA. The JORDAN's primary mission is to study the ocean's living marine resources for fisheries research. The vessel was built by the Christy Corp. in Sturgeon Bay, Wisconson, and was commissioned in January 1966. The vessel is names after Dr. David Starr Jordan (1851-1931) who was the first president of Stanford University. Dr. Jordan was considered the most productive and influential icthyologist of his time in the United States and probably one of the greatest in the history of fisheries science. More than 600 scientific papers attest to his avid interes in fish, including the classic publication "Fishes of North and Middle America"

The vessels principle work areas are off the southwestern U.S. coast and eastern tropical Pacific. This vessel is usually scheduled for 243 days at sea per fiscal year.

Characteristics:

Length overall	171 ft (57m)
Beam	36 ft (12m)
Draft	12 ft. (4m)
Displacement	900 tons
Conservation speed	10 knots
Cruising Range	8,4400 NM
Crew	18
Scientific Complement	13



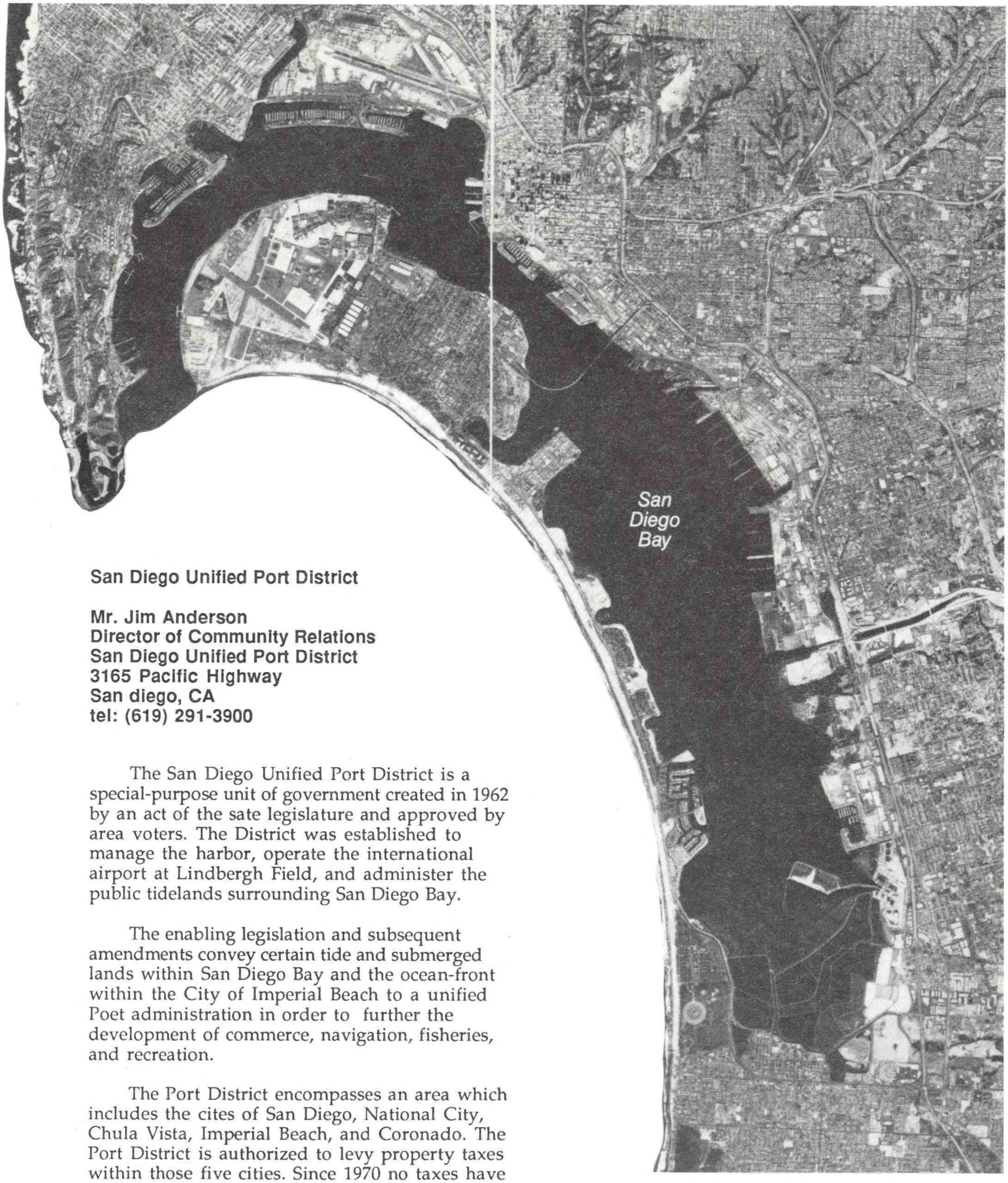
NRaD (ex-Naval Ocean Systems Center)

Mr. Howard Talkington
Deputy Technical Director Code 02
Navy Command Control Ocean Surveillance Center
San Diego, CA 92152
tel:619/553-3020
fax: 619/553-6582

NRaD is the shortened acronym for the Naval Command, Control and Ocean Surveillance Center Research , Development, Test, and Evaluation Division (NCCOSC RDT&E division, official acronym). It represents the principal division of one of the four newly-established Warfare centers, which encompass the large majority of the United States Navy research and development laboratories.

NRaD is staffed by 3,800 people in three locations throughout the country, including Pennsylvania and Hawaii. The headquarters and primary facility is in San Diego, California, with 3,500 people and six technical departments at two sites. The "Topside" site houses facilities primarily concerned with research and development in areas such as command and control, aerial communications and signal processing. The "Bayside" facilities are oriented towards marine sciences, ocean engineering, test range support, mammal training, and undersea surveillance.

The NRaD ocean engineering group is working on robotics, unmanned vehicles, non-metallic marine materials, undersea fiber optics, and sensors. Recently, a 6,000 meter depth remotely-operated work system was developed and build to the Fleet, a 6,000 meter depth autonomous search system was built and tested. lightweight ceramic pressure hulls for full ocean depths have been developed and a 0.76 mm diameter fiber optic micro cable manufacturing process was developed and transferred to industry.



San Diego Unified Port District

Mr. Jim Anderson
Director of Community Relations
San Diego Unified Port District
3165 Pacific Highway
San diego, CA
tel: (619) 291-3900

The San Diego Unified Port District is a special-purpose unit of government created in 1962 by an act of the sate legislature and approved by area voters. The District was established to manage the harbor, operate the international airport at Lindbergh Field, and administer the public tidelands surrounding San Diego Bay.

The enabling legislation and subsequent amendments convey certain tide and submerged lands within San Diego Bay and the ocean-front within the City of Imperial Beach to a unified Poet administration in order to further the development of commerce, navigation, fisheries, and recreation.

The Port District encompasses an area which includes the cites of San Diego, National City, Chula Vista, Imperial Beach, and Coronado. The Port District is authorized to levy property taxes within those five cities. Since 1970 no taxes have been necessary and revenues from the harbor, the airport and property management have supported operations. These include wildlife conservation, construction of cargo facilities, parks and open spaces

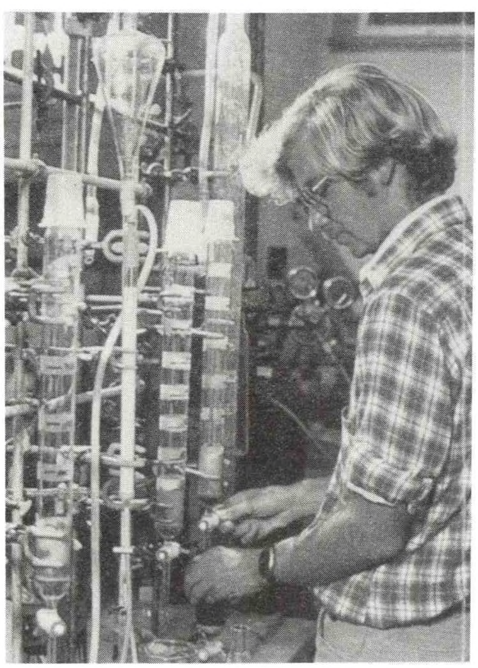
Tuesday, November 10th

Scripps Oceanographic Institute and Aquarium
La Jolla, CA

Dr. Richard Seymour
Director
Offshore Technology Research Center
1200 Mariner Drive College Station, TX
tel: 803-527-6481

Scripps Institution of Oceanography's search for knowledge continues a more than eighty five year tradition of investigating the oceans, the land, and the overlying atmosphere. Its scientists have sailed to tropical islands and adventured under polar ice, observing environments and their inhabitants, collecting rocks and other specimens, and recording myriad data for analysis in the laboratory.

The Institution was founded in 1903 largely through the efforts of Dr. William E. Ritter, a professor at the University of California at Berkeley, and became a part of the University of California in 1912. It was designated Scripps Institution for Biological Research in recognition of the support of Ellen Browning Scripps and E.W. Scripps, the noted newspaper publisher. The program expanded to all aspects of the ocean which was recognized in 1925 when the name was changed to the Scripps Institution of Oceanography (SIO).



Today, a part of the University of California at San Diego, SIO is one of the world's oldest, largest, and most important centers for marine science research, graduate training, and public service. SIO's preeminence in marine-related studies in biology, physics, chemistry, climatology, geology, and geophysics reflects its continuing commitment to excellence in research, modern facilities, distinguished faculty, and outstanding students . . .and the vision continues to grow.

The main campus of SIO is located along the Pacific Ocean, occupying some 65 buildings on 230 acres. The facilities for research are among the most advanced available for marine sciences, ranging from a comprehensive hydraulics laboratory that features a unique ninety-foot, stratified wave-and-current channel to sophisticated analytical facilities with state- of the art scanning electron microscopes and other high precision instruments. The Satellite Oceanography Center enables oceanographers to routinely receive and process imagery from earth-orbiting satellites. The Antarctic Research Center collects data on atmospheric and ice conditions in Antarctica. Another special research facility provides a fully controlled electromagnetic environment for a variety of biological and physical studies. Advanced computer capabilities include a high speed data link to the San Diego Supercomputer Center. In addition, Scripps has one of the major marine science libraries in the world and has a variety of geological and biological collections that serve as resources of data and specimens. Scripps staff numbers about 1,200 including some 190 graduate students.

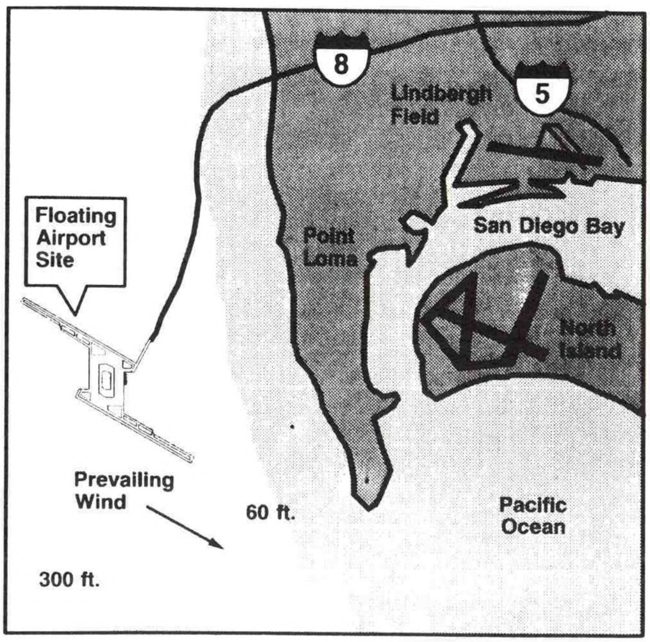
Scripps oceanographic research vessels and research platforms comprise the largest academic fleet in the United States. Two ships have underwater bathymetry survey systems. Cruises vary from local trips to long expeditions that gather data in relatively unexplored areas.

The new Stephen Birch Aquarium-Museum opened this year with exhibits that include an onshore man-made tide pool, marine life tanks, the largest oceanographic exhibit in the US, and displays that portray the research programs at SIO.

Floating Airport for San Diego

Dr. Howard Blood
Chairman
National Ocean Research and Exploration Center
P.O. Box 60472
San Diego, CA 92106
tel: 619-223-6133
fax: 619-222-7188

Proposals for an offshore floating airport for San Diego have been discussed over the last two decades. One concept proposes that the airport be located three miles offshore in water depths of approximately 80 meters. The airport structure would be supported on a floating honeycomb network of 30,000 concrete cylinders each 6 meters in diameter and about 13 meters deep. The cylinders would be formed like an upside-down drinking glass open to the water at the bottom. The airport would have an area of about 250 acres with separate landing and takeoff runways each 4000 meters long. Another concept adds a perimeter of wave power converters to extract energy for use by the airport and to operate a desalinization plant to extract fresh water for use by the airport and for the needs of San Diego County. Proponents of the airport indicate that the offshore location provides safety away from residential areas and minimized pollution over land. Also airport landing and takeoff paths could be oriented to maximize advantages from wind direction and not be hampered by existing structures. There would be no cost for land acquisition and the airport could easily expand. An offshore location would be closer to the center of the area's growing population.



Science Applications International Corporation

Dan Hightower
Corporate Vice President
Science Applications International Corporation
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Employee owned since its inception in 1969, Science Applications International corporation (SAIC) is a diversified high-technology company focusing primarily in the areas of national security, energy, environment, health services, and high technology products.

SAIC's motivated staff, close customer support, and diverse scientific and technical skills base have enabled the company to emerge as a unique problem-solving resource for commercial and international customers. Since 1969, SAIC has grown to one of the largest employee-owned companies in the U.S. with annual revenues of over $1.3 billion and more than 14,000 employees in 300 offices worldwide.

Summary of the 18th Meeting and Cooperative Activities

1. Overview

For the 18th Meeting of the Marine Facilities Panel, UJNR, the Japan Panel arrived in Boston on October 24 to begin a study tour of marine facilities in the New England area and to attend the OCEANS 92 Conference and Exhibition at Newport, RI. On October 28 the panel arrived in Washington DC to continue the study tour and conduct a 2-day plenary session (October 30-31) at the National Academy of Sciences. The total attendance was 66; 27 from Japan and 39 from the US. Other attendees included special guests: Dr. Robert M. White, President of the National Academy of Engineering, who gave the welcoming address;and Mr. Martin Prochnik, US Chairman for UJNR, US State Department and Mr. Y. Hayashi, Counselor for Science and Technology, Embassy of Japan both gave opening remarks. On October 30, a reception sponsored by the US and Japan Panels was held in the Board Room of the National Academy of Sciences and a special awards ceremony was conducted. The US Panel honored the Japanese Chairman, Hajime Inoue, Mr. Hiroyuki Nakato, JAMSTEC and Mr. Yukihiro Narita, JAMDA with testimonial plaques. The Japan Panel honored Mr. James Wenzel, Marine Development Associates and Professor John Flipse, Texas A&M University with special letters of recognition.

Following visits in the Washington DC area, the study tour proceeded from Washington DC.to Orlando, Cape Canaveral, Ft. Pierce, Riviera Beach, Boca Raton, Ft,Lauderdale, Miami in Florida, and then to San Diego and La Jolla in California. The Panel visited about 20 marine facilities operated by government, industries and academia, including laboratories, port and harbor facilities, ships and other coastal developments..

The final meeting took place November 10th at Science Application International Corporation, SAIC, La Jolla, CA.

The 18th UJNR MFP Meeting was very informative and successful. While valuable technical information was exchanged at the plenary session and during the study tour, perhaps equally valuable were the many informal meetings and information exchanges that took place during daily conversation during the course of the itinerary.

A section on accomplishments and benefits is included in the summary to indicate the importance and value of the meetings and cooperative activities between meetings.

2. Plenary Session

The US and Japan Panels each presented a keynote address. Keynote speaker for the Japan Panel was Dr. Naonosuke Takarada, whose paper was titled "Hoping for a Bright Future of UJNR on Effective Utilization of the Ocean." Keynote speakers for the US Panel were Dr. Sylvia A. Earle, the world's most accomplished woman aquanaut and Dr. Kathryn Sullivan, the world's most accomplished woman astronaut, presented a join keynote address titled "Inner and Outer Space Technology for Ocean Observation and Assessment." The themes explored in these keynote addresses set the tone for the technical presentations that followed.

Over 60 papers were prepared for the meeting and are published herein. Of these, about 40 were presented in addition to the two keynote addresses. The papers were divided into 5 topical categories., which cover most of the chartered areas of the Panel:

1. Marine Facilities and Systems for Resource Development and Environmental Conservation,
2. Advanced Ship Technology Development,
3. Offshore and Undersea Technology Systems,
4. Coastal Ocean Space Utilization, and

5. Ocean Measurement, Assessment and Environmental Protection.

It is the practice of the Panel to exchange papers for preview approximately one month before the meeting. Therefore, it was only necessary for each speaker to present a 10 minute summary, thus allowing more time for questions and discussion. This approach has proven to be very interesting, informative and successful. Following the meeting, proceedings are published by both sides and distributed to the respective chairman for distribution to participants.

3. Accomplishments and Benefits

Marine facilities for ocean resources development continues to be a very important category. Technical exchanges have included: platforms for oil and gas exploration and production; facilities for offshore fish ranching/farming and marine mariculture; and techniques for seabottom survey and sampling of deep sea minerals.

There is a growing interest in marine facilities for coastal development and ocean space utilization. Technology exchange and site visits have been mutually beneficial. Japan has made major progress in development of artificial islands and facilities in Osaka Bay including :Port Island, Rokko Island, and a large artificial island for the Kansai International Airport to be opened in 1994.The U.S. is making major improvements in port development, e.g.,Port of Long Beach and World Port Los Angeles, including an inter- modal container transfer facility.

U.S. and Japanese members and advisors of the Marine Facilities Panel were major contributors to planning and participating in International Symposia on Coastal Ocean Space Utilization: COSU II in Long Beach, California April 1991; COSU III near Genoa, Italy, April, 1993. Papers prepared by Panel members were included in the proceedings of each symposium.

There continues to be a strong exchange of information on undersea vehicles, both manned and unmanned. In particular, there is considerable interest in progress and demonstrations of remotely operated vehicles, robotics, undersea work systems, and bottom crawling vehicles. Great emphasis and accelerated mutual interest have developed in remotely operated and autonomous vehicles.

There has been continuing interest and exchange of information on advanced ship technology such as the progression of the Catamaran-type ship development, intelligent ship technology etc. between U.S. Navy, U.S. Coast Guard, Maritime Administration and Japan's Ship Research Institute, JAMSTEC and industry. A close dialogue is maintained on the subject of magnetohydrodynamics and super conducting electric propulsion techniques. In 1991, U.S. members were invited and participated in several sessions of the "First International Symposium on Magnetohydrodynamics for Ship Propulsion" sponsored by Japan's Ship and Ocean Foundation.

The National Research Council, Marine Board (Mr. C. Bookman) received requested information on seamen's education, systems and pilot systems in Japan from the Seafarer's Department, Ministry of Transport and the Maritime Safety Agency. In addition, special arrangements were made for Mr. Bookman and Professor Webster to visit Japanese ship simulator facilities as part of their assessment of existing capabilities.

The U.S. Society of Naval Architects and Marine Engineers (SNAME) Panel on Submersibles, (chaired by Mr. J. Pritzlaff, Westinghouse Electric) is preparing a new book on "Tourist Submersible Operational Safety Guidelines", and obtained significant inputs from the Japanese including: Mr. Kiyoshi Hirata, President, Japan Submarine Tourism Co.; Mr. E. Miwa, Mitsubishi Heavy Industries (MHI) Ltd., Tokyo; and Mr. H. Morihana and K. Sadakuni of MHI, Kobe.

In response to a request from the Ship Dynamics Division (Dr. I. Watanabe), Ship Research Institute, The NOAA Oceanographic Data Center (NODC) provided an extensive data base (1974 to 1988) including:

Meteorological data reported by ships to NOAA in the northeast pacific (east of 170E and North of 0)

Discus buoy data from the North Pacific region

This effort resulted in a comprehensive report entitled "Winds and Waves of the North Pacific Ocean 1974-1988".A paper on this project by Dr. I. Watanabe of SRI was presented at this meeting. This information is useful in ship design and navigation.

The Ship Research Institute (Dr. Y. Murayama et al)and the U.S. Maritime Administration(Messers. P.Mentz and J.Dumbleton) participated in a joint research project on intelligent ship systems. Professor Eda of the U.S. Merchant Marine Academy engaged in joint research at the Ship Research Institute, and researchers of the Ship Research Institute visited with the Maritime Administration to review research and results. Papers describing this research were presented at this meeting. Results of these projects will contribute to major advances in sea transportation.

Information, and technology exchange on offshore facilities and systems for ocean observation and in situ, real time environmental monitoring systems/platforms are becoming increasingly more important. Greater emphasis has been noted in development of the oceans and marine facilities in harmony with the environment. The concept of sustainable development is becoming more prominent in plenary session papers.

There are economic advantages for conducting an equitable technology exchange. Both countries benefit because they don't have to conduct duplicate projects that waste time and limited research funds. Technology can also be advanced more rapidly through cross-fertilization of new research concepts and advanced developments achieving earlier commercialization and economic benefit.

The UJNR provides an excellent mechanism for establishing and maintaining cooperative relationships on an equitable basis. In addition to the valuable technology exchange and cooperative ventures, UJNR also provides an opportunity to understand government-industry relationships and plans and policies for ocean development in each other's countries.

4. Future Cooperative Activities

As noted in the previous section on accomplishments and benefits, several areas have been highlighted and will continue to be emphasized. Future activities on cooperative projects will continue in the following areas:
The Ship Research Institute and the U.S. Maritime Administration will continue cooperative research on intelligent ship system technology and exchange results.
The Ship Research Institute and the NOAA National Ocean Data Center will collaborate in combining their data to produce future issues of Wave Data in the North Pacific.

Members and Advisors of the Marine Facilities Panel will participate in planning and preparing papers for the COSU IV proposed for Japan in May, 1995.

The areas of specific interest noted in the accomplishments section, with emphasis on environmental conservation and development in harmony with the environment, will guide future cooperative activities.

5. Proposal for the 19th Meeting

Chairman Inoue offered a proposal for the next meeting to be held in Japan May 9-25, 1994. The meeting will be held in Tokyo, followed by a study tour which can include visits to the Kansai and Kyushu areas, besides the Tokyo area. Some of the highlights of the visit will include activities at the Ship Research Institute and JAMSTEC; visit to two types of Techno-Superliners, double hull tankers, deep submersibles, new types of marine engines, aquaculture facilities, etc.

Chairman Vadus said that he would confer with the US Panel to provide recommendations for some visits of particular interest. Because of traffic conditions it is necessary to be conservative in establishing a timetable for visits.

Chairmen Vadus and Inoue recognized the valuable contributions make by: all members and advisors, NOAA and SRI Staff as noted in the opening remarks; and the many hosts who opened their facilities and rendered their hospitality along the way. Chairman Inoue concluded his remarks by saying "We are looking forward to seeing you in Japan in May 1994."

Technical Program for the
18th Meeting of the
US/Japan Marine Facilities Panel of UJNR
at the National Academy of Sciences
Washington D.C.
October 30-31, 1992

October 30: Plenary Session I

8:30	**Welcome** Robert M. White, President, National Academy of Engineering
8:35 to 9:00	**Opening Remarks and Introductions** Joseph Vadus, US Panel Chairman Hajime Inoue, Japan Panel Chairman Martin Prochnik, US Chairman, UJNR, U.S. Department of State Yukihide Hayashi, Counselor for Science and Technology, Embassy of Japan
	Program Commencement • Apointment of Chairman & and Co-chairman • Acceptance of Agenda • Start of Meeting
9:00 to 9:20	**Keynote Address: Japan** Title: Hoping for a Bright Future for UJNR Activities on Effective Utilization of the Ocean Author: Naonosuke Takarada, Sumitomo Heavy Industries Co., Ltd.
9:20 to 10:00	**Keynote Address: USA** Title: Inner and Outer Space Technology for Ocean Observation and Assessment Authors: Sylvia A. Earle, President, Deep Ocean Engineeering, and Kathryn Sullivan, NASA Astronaut, and NOAA Chief Scientist Designate
10:00to 10:15	**Coffee Break**
	Technical Program Follows

note: Ten minutes are alloted for summary presenations of each paper, plus two minutes for questions.

I - Marine Facilities and Systems for Resource Development and Environmental Conservation

10:15 Deep Ocean Water Utilization in Japan

Hisaaki Maeda, Institute of Industrial Science, Univ. of Tokyo
Kohzou Kitani, National Research Institute of Fisheries Science
Takenobu Kajikawa, Shonan Institute of Technology
Toshimitu Nakashima and Takayoshi Toyota, JAMSTEC
Haruyoshi Makita, Niigata Steel Engineering

10:30 Open Ocean Mariculture

Patrick Takahashi, The University of Hawaii

10:45 The Development of Electrical Screen System for Marine Ranching Formation

Seiji Otani, Hitachi Zosen Corporation
Gentaro Kai, JAMSTEC
Tsuneo Fujimori, Kumamoto Prefecture
Speaker: Eifu Kataoka, Hitachi Zosen Corp.

11:00 Marine Mining: Status and Future Potential

John Padan, Minerals Management Service

11:15 Ocean Mineral Survey by Acoustic Coring

James G. Wenzel, Marine Development Associates

11:30 LNG FPSO Unit Applying Self-Supporting Prismatic Tanks

Eiichi Isobe, Ishikawajima-Harima Heavy Industries Co. Ltd.

11:45 Shirashima Floating Oil Stockpiling Terminal

Eifu Kataoka, Hitachi Zosen Corporation

12:00 LUNCH

13:00 Progress in Deep Ocean Oil Recovery Technology

Richard J. Seymour and John E. Flipse, Offshore Technology Research Center

13:15 Oil Spill R&D in the U.S.: Plans and Challenges

Donald W. Perkins, Associate Director, Marine Board, National Research Council

(R) = For Reference

13:30 Study on Protection of Oil Spill from Crude Oil Tankers

Yasukatsu Yamauchi, Maritime Technology and Safety Bureau
Chikara Nakagawa, Association for Structural Improvement of the Shipbuilding Industry

13:45 Systems Study on Sending CO_2 into Deep Ocean for CO_2 Recovery and Ocean Storage

Masahiko Ozaki, Nobuaki Murakami, Yuichi Fujioka, and Yoshihiro Suetake, Mitsubishi Heavy Industries Co., Ltd.
Speaker: Eiichi Miwa, Mitsubishi Heavy Industries Co., Ltd.

14:00 Research in the US and Japan on Pendular Wave Energy Converters: Multi-Product Applications

George Hagerman, SEASUN Power Systems, Inc.

14:15 Antifouling Systems for Ship Hull by Electro-Conductive Coating

Masahiro Usami, Kenjo Ueda, and Kiyomi Tomoshige, Mitsubishi Heavy Industries Co., Ltd.
Speaker: Eiichi Miwa, Mitsubishi Heavy Industries Co., Ltd.

Study on the Wave Power Device "MIGHTY WHALE" (R)

Takeaki Miyazaki, JAMSTEC

Japan Mining Collector for Manganese Nodules (R)

Yohichi Kimoto, Sumitomo Heavy Industries Co., Ltd.

Utilization of the Exclusive Economic Zone: Challenges for the Future (R)

Armand J. Silva, The University of Rhode Island

Deep Ocean Water for Agriculture: Theory and Practice (R)

John Craven, Common Heritage, Inc.

(R) = For Reference

II - Advanced Ship Technology Development

14:30 A Tentative Analysis of the Sea Trials of the Superconducting MHD Ship "YAMATO—1"

Yohei Sasakawa,Sasakawa Foundation
Seizo Motora, and Setsuo Takezawa, Ship and Ocean Foundation

14:45 Experimental Study of Sea Water Superconducting Electro-Magnetic Thrust at 3.3 Tesla

James Meng, Naval Undersea Systems Center

15:00 Feasibility Studies on Displacement Type Mono Hull High Speed Ship

Naonosuke Takarada and Shuichi Nagamatsu, Sumitomo Heavy Industries Co., Ltd.

15:15 Fleet Modernization Program of the Oceanographer of the Navy

Robert. S. Winokur, Office of The Oceanographer of the Navy

15:30 Advancement of Techno-Superliner Program

Kazuo Sugai, Technological Research Association of Techno-Superliner

15:45 Shipboard Piloting Expert System

Paul Mentz and John Dumbleton, Maritime Adminstration

16:00 Intelligent Ship as a Large System

Yujiro Murayama, Fujio Kaneko, Masayoshi Numano, Yasuyoshi Itoh, Kunihiko Tanaka, Nobuo Arimura, Nobuo Kiriya, Junji Fukuto, and Keiko Miyazaki, Ship Research Institute, Ministry of Transport

New Developments and Testing of Production Models of the High Speed Flare Craft (R) (Demonstration in Newport, R.I.)

Richard Shamp, Engineering Service Associates, Inc.

(R) = For Reference

Saturday, October 31st - Plenary Session II
8:30 am

III - Offshore and Undersea Technology Systems

8:30 The Legal Restraints Limiting Marine Facility Developments in the U.S.A.

John E. Flipse, Offshore Technology Research Center, Texas A&M University

8:45 A High Resolution Sub-Bottom Imaging System

Robert F. Ballard, Richard C. McGee, and Robert Whalin, U.S. Army Corps of Engineers

9:00 "KAIKO"—10,000 meter Deep Sea Research ROV

Hiroyuki Nakato, and Shinichi Takagawa, JAMSTEC

9:15 Transformation of NOSC into NCCOSC/NRaD and Its Effect on Ocean Programs

Howard R. Talkington, Naval Command, Control, and Ocean Surveillance Center

9:30 Recent Activity/Advances in Remotely Operated Vehicles

John A. Pritzlaff, Westinghouse Oceanic Division

9:45 Development of Collection, Isolation, and Cultivation System for Deep-Sea Microbes Study

Masanori Kyo and Ikuo Nakazaki, JAMSTEC

10:00 The Navy's Unmanned Untethered Vehicle (UUV) Program

John Freund, Navy UUV Program Office

10:15 OCEAN VOYAGER: An Unmanned Underwater Vehicle

Barry Steer for S. Dunn, J. Cuschieri, K. Ganesan, J. Kloske, L. LeBlanc, A. Pandya, A. Shein, S. Schock, S. Smith and K. Venugopal, Florida Atlantic University

10:30 Annotated Map Building for Autonomous Underwater Vehicles

K. Ganesan, S. Dunn, G. Rae, and C. Vasudevan, Florida Atlantic University

10:45 Development of an Autonomous Vehicle with A Closed Cycle Deisel Engine

Tamaki Ura, and Hisaaki Maeda, Institute of Industrial Science, Univ. of Tokyo
Hiroshi Tabuchi, and Takashi Obara, Mitsui Engineeering and Shipbuilding Co., Ltd.
Hiroyuki Yamato, Faculty of Engineering, University of Tokyo
Speaker, Hitoshi Narita, Mitsui Engineeering and Shipbuilding Co., Ltd.

(R) = For Reference

11:00 Development of Dextrous Manipulators with Telepresence

Mike S. Shimamoto and Douglas W. Murphy, Naval Command, Control, and Ocean Surveillance Center

Precise Navigation and Control of an ROV at 2200 Meters Depth (R)

Dana R. Yoerger and David A. Mindell, Woods Hole Oceanographic Institution

A High Relolution 3-D Sub-bottom Image System "Kite" (R)

Tokuo Yamamoto and Andrew Rogers, University of Miami, Rosensteil School of Marine and Atmospheric Science
Howoong Shon, Geophysical Sensing Laboratory, Pai-Chai University, Korea

The Robots are Coming to the Ocean (R)

Norman Caplan, National Science Foundation

Submersible Safety: New Developments in Shallow Water Submersible Rescue Equipment and Techniques (R)

Tim Askew, Harbor Branch Oceanographic Institution

A Look at ROV's (R)

Howard R. Talkington, Naval Command, Control, and Ocean Surveillance Center

Manned Submersible-Based Scientific Research: Enabling Technologies (R)

Andrew M. Clark, Harbor Branch Oceanographic Institution

Recent Technical Considerations for Tourist Submersible Construction and Operation (R)

Don Walsh, International Maritime Inc,

Tourist Submersible Safety Considerations (R)

John A. Pritzlaff, Westinghouse Oceanic

Non-Linear Dynamics in Ocean Engineering (R)

Steven E. Ramberg, Office of Naval Research

(R) = For Reference

IV - Coastal Ocean Space Utilization

11:15 Aiming at Port and Harbour Technology Mild to Human Beings and the Earth

Isamu Tamura, Bureau of Ports and Harbours, Ministry of Transport

11:30 Environmental Management of Port Development

Ernst G. Frankel, Massachusetts Institute of Technology

11:45 Challenges for Huge Floating Platform: Results of Field Test of Prototype Floating Platform

Reisaku Inoue and Shoichi Hara, Ship Research Institute, Ministry of Transport

12:00 Fiber Reinforced Polymer Honeycomb Materials for Marine Floating Structures

Clifford McLain, Consulting Services

LUNCH 12:15

13:30 Development of the Submersible/Surfacing Type Artificial Sea Bed Floor "MARINE—AYA NO.1"

Mineo Okamoto, JAMSTEC
Shin-ichi Tomita and Naoyki Takatsu, Kawasaki Heavy Industries, Ltd.

13:45 A Floating Offshore Satellite Launching Facility

Takeo Kondo, Nihon University, Tokyo
Joseph R. Vadus, NOAA

14:00 Behavior of a Floating Body in Multi–Directional Waves

Hisaaki Maeda, Hyo Jae Jo, and Shogo Miyajima, Institute of Industrial Science, Univ. of Tokyo

14:15 Inspection and Maintenance for Very Large Floating Structures—Lessons Learned by Experience and Prospects for Future Technology

Hirohiko Emi and Toshiro Arima, Research Institute of Nippon Kaiji Kyokai

14:30 Mooring Ships in Harbour During Rough Water

Shigeru Ueda, Port and Harbour Research Institute, Ministry of Transport
Masahiro Kubo, Coastal Development Institute Technology Center
Seiichi Takanashi, Mitsui Engingeering and Shipbuilding Co., Ltd.

(R) = For Reference

14:45 Mooring Facility Based on Single Pile Structure

Shigeru Ueda and Kunio Takahashi, Port and Harbour Research Institute, Ministry of Transport
Satomi Kiuchi, Taisei Corporation
Toru Tamura, NKK Corporation

Estimation of Encounter Probability of Sliding for Probabilistic Design of Breakwater (R)

Tomotsuka Takayama and Naota Ikeda, Port and Harbour Research Institute, Ministry of Transport

Creation of Calm Sea Area by New-Type Offshore Breakwater (R)

Kazunori Yoshioka and Mamoru Koarai, River Bureau , Ministry of Construction
Takaaki Uda, Public Works Research Institute, Ministry of Construction

(R) = For Reference

V - Ocean Measurement, Assessment, and Environmental Protection

15:00 Ships and Oceanographical Observations

Hajime Inoue, Ship Research Institute, Ministry of Transport

15:15 US Navy Research for Environmental Protection

Richard Metrey, David Taylor Research Center

15:30 The Technology of Remote Ecological Monitoring of the Seafloor—REMOTS

Donald C. Rhoads, Joseph D. Germano, and J.D. Hightower, Science Applications International Corporation

15:45 New Seafloor Swath Mapping Technology at Texas A&M University

Thomas W.C. Hilde and R.L. Carlson, Geodynamics Institute, Texas A & M University
Donald B. Hall, Institute for Pacific Asia, Texas A & M University

16:00 Supercritical Water Oxidation- Technical Assessment

Earnest Gloyna and Lixiong Li, University of Texas

16:15 On Database of Winds and Waves of the North Pacific

Iwao Watanabe, Ship Research Institute, Ministry of Transport

16:30 Technology Needed to Enhance the Global Ocean Observing System

Paul Kilho Park, NOAA

16:45 Remote Sensing of Ocean Processes for Engineeering

Steven Ramberg and Frank W. Herr, Office of Naval Research

US Marine Electronics Agenda (R)

James Broadus, Woods Hole Oceanographic Institution

Nationwide Network of Coastal Wave Observation and Its Application to Wave Prediction (R)

Isamu Tamura, Bureau of Ports and Harbours, Ministry of Transport
Takeshi Horie, Tomotsuka Takayama, Chiaki Goto, and Toshihiko Nagai, Port and Harbour Research Institute, Ministry of Transport

Porosity, Permeability, and Shear Strength (P*2S) Cross-Well Tomography Experiments of a Noisy Foundation (R)

T. Yamamoto, T. Nye and M. Kurui, Rosensteil School of Marine and Atmospheric Science, University of Miami
T. Sakak, O Hashimoto, and I. Okumura, Kawasaki Steel Corp., Japan

(R) = For Reference

Review of Research Works of Corrosion and Its Prevention by Paint Coating at Ship Research Insitute (R)

Masayoshi Arita, Ship Research Institute, Ministry of Transport

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List of Technical Presentations

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Open Ocean Mariculture

The Development of Electrical Screen System for Marine Ranching Formation

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"KAIKO" - 10,000m Class Deep Sea Research ROV

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The Merchant Shipping (Submersible Craft) Law 1991

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Development of Submerging/Surfacing type Artificial Sea Floor "Marine-AYA No. 1"

Floating Offshore Satellite Launching Facility

Behavior of a Floating Body in Multi-Directional Waves

Inspection and Maintenance for Very Large Floating Structures

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Estimation of Encounter Probability Design of Breakwater

Creation of Calm Sea Area by New-Type Offshore Breakwater

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Ships and Oceanographic Observations

US Navy Research for Environmental Protection

The Technology of Remote Ecological Monitoring of the Seafloor - Remotes

New Seafloor Swath Mapping Technology at Texas A&M University

Supercritical Water - Oxidation - Technical and Economic Assessment

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UJNR

United States/Japan
Cooperative Program in
Natural Resources

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Marine Facilities Panel

Technical Presentations

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Deep Ocean Water Utilization in Japan

Hisaaki Maeda
IIS, University of Tokyo, Tokyo

Kohzou Kitani
National Research Institute of
Fisheries Science, Fisheries Agency, Tokyo

Takenobu Kajikawa
Shonan Institute of Technology, Fujisawa

Toshimitsu Nakashima and Takayoshi Toyota
Japan Marine Science and Technology Center, Yokosuka
and
Haruyoshi Makita
Niigata Engineering Co., Ltd., Tokyo
Japan

1. Introduction

It is well known that deep ocean water is nutrient-rich, cold and pathogen-free which can be used to sustain mariculture operations, which is useful for cooling and air conditioning, and which is available for electric power generation.

Since 1982, the laboratory at Keahole Point in Hawaii Island has been the center of Deep Ocean Water Utilization as a land based mariculture system. A lot of information and knowledge/know-how have been accumulated for Deep Ocean Water Utilization, however, there are still many problems remain from the stand point of ocean engineering and marine biology.

In order to catch up the Hawaii's activity(1)(2)(3), Japan began two multi-year projects on the subject, which are an ocean based mariculture system in Toyama Bay and a land based system at Cape Muroto in Kochi. The outline of these projects is described in the following section.

Adding the standpoint of Global Environment to the results we concluded in the above maintained projects, we propose the new ocean based mariculture system which will be not only useful for developing mariculture, natural energy, marine mining, but also advantageous for mitigation of Global Warming and conservation of Global Environment.

2. Research of deep ocean water utilization technology

2.1 Research of ocean based deep ocean water utilization

2.1.1 Experimental facilities

It is well known that J.H.Ryther(4) divided the ocean into three regions as oceanic region, coastal region and upwelling region where deep ocean water (Deep Ocean Water) rises, and he estimated bio-productivity of each region as 0.16×10^6tons, 120×10^6tons and 120×10^6tons respectively. We can easily understand the magnitude of natural deep ocean water upwelling effect by comparing the ratio of each region's area (90%, 9.9% and 0.1% respectively) with the estimated value of bio-productivity.

A program for research and development of ocean-based mariculture-OTEC was carried over from 1986 to 1990 supported by the Special Coordination Funds of Science and Technology Agency of Japanese Government and the experimental examination was realized from 1989 to 1990 at Toyama Bay, Sea of Japan(5) (Table 1). There were two major objectives in this program, one was to evaluate the effect of artificial upwelling of nutrient-rich deep ocean water on enhancement of marine bio-productivity for an ocean-based mariculture system and another was to optimize energy supply system as the self-sustaining ocean-based mariculture system (Photo1).

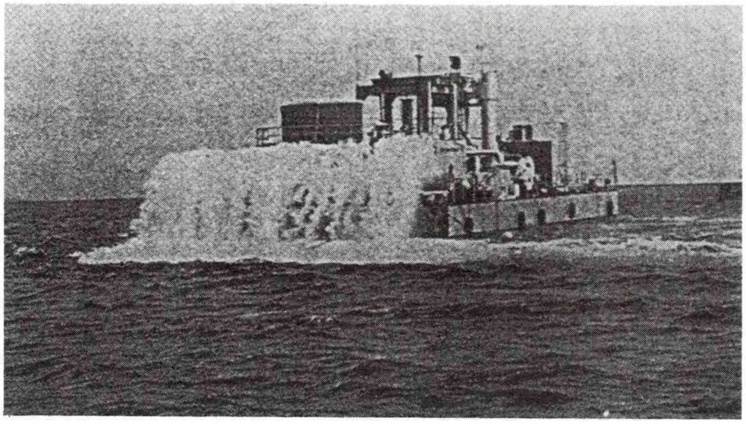
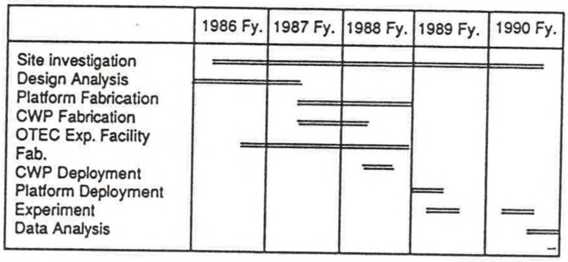


Photo 1 Experimental Facility "Houyo" in Operation at Sea

The most difficult subject to realize the first experiment of mariculture system was to pack all the necessary costs and expenses in the budget of about three million U.S. Dollars. Various contrivance and efforts were made to overcome the economical restriction so that the experimental facility could be not too far from the desired conditions but it was still not satisfactory in some aspects.

Table 1 Master Schedule of Ocean-based Deep Ocean Water Utilization System



The volume of deep ocean water to quantitatively estimate the effect by enhancing marine biological productivity was decided to be approximately $0.3 m^3/sec$ (= $26{,}000 m^3/day$) based on economical condition. The deep ocean water was pumped up to spray onto sea surface together with warm surface water to make the volume triple at maximum.

The mixing of deep ocean water and surface water was done to keep cold and heavy deep ocean water in euphotic zone longer and to reduce the lag period of phytoplankton growth (6).

Approximately one-tenth of deep ocean water was branched and charged as the cold energy source to the small scale OTEC experimental facility (OTEC Module) and the almost same quantity of the surface water was also charged as the warm energy source to the OTEC module. These two kinds of water were mixed and piped to spray at mariculture experiment.

The ocean-based mariculture-OTEC experimental facility consisted of four major sub-system, viz. platform, cold water pipe (Cold Water Pipe), OTEC Module and two-catenary mooring system(Fig. 1).

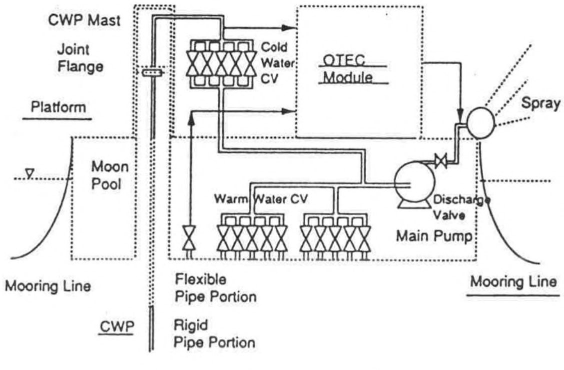


Fig.1 Concept of Experimental Facility

2.1.2 Movement of cold-nutrient water[7]

In the experiment, the flow rate of upwelled deep ocean water from about 300m depth is $0.3m^3/sec$ and the flow rate of surface warm water taken from the intake of the bottom of the platform is $0.6m^3/sec$. The deep ocean water was mixed with surface sea water and discharged on the sea surface. In order to analyze quantitatively a bio-production enhancement of plankton utilizing rich nutrients contained in deep ocean water, there are many items investigated. Among them, one of the most important items, movement of cold-nutrient water is described here.

As the experimental site is close to shore, sea water characteristics of both deep water and surface water varied widely during the experimental period. However, we could investigate the movement of upwelled deep ocean water introducing the tracers of the sea water characteristics especially coldness of discharged water.

The temperature of deep ocean water which was about 3°C rose up to about 5°C after upwelling to the surface through a cold water pipe. The temperature of the deep ocean water mixed with double volume of surface warm water was around 18°C ~ 20°C. When this mixed water was sprayed over surface water with 23°C ~ 27°C, dilution happened rapidly within rather small horizontal region. While dilution and diffusion depend on instantaneous current state and water system in the experiment region, diffusion occurred roughly along the spray direction due to inertia force of sprayed water as shown in the infrared image of air-borne remote sensing in Fig.2. Afterwards the diffusion corresponded to instantaneous current. In other words, diffusion occurred slowly along down stream, and detectable region for diffusion due to temperature difference of sprayed water covered 2-300 meter downstream after spray point and also 2 - 30m upstream.

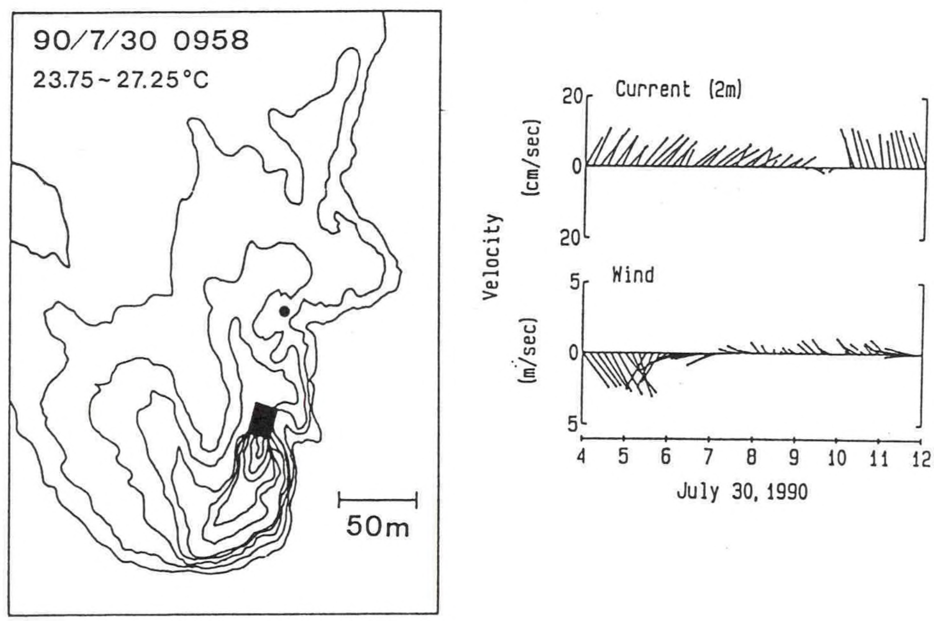


Fig.2 Infrared Image on the Experimental Area (Left) and Current and Wind at the time when the Infrared Image was got by Airplane (Lower). Solid Box in the Upper Panel shows the Experimental Facility "Houyou".

The vertical effect of sprayed water was also investigated, the region of which was limited to about 5 meters below the spray point. The vertical diffusion hardly occurred. Meanwhile in 10m layer, 20m layer and 30m water depth layer at the experimental site, cold water region which was not originated by sprayed water was observed quite often. The reason for this phenomena was considered to be due to local sea water movement derived by kinetic energy of continuously sprayed mixed sea water. That is to say, subsidiary vertical flow might occur to compensate steady flow in surface layer that moved away from the experimental facility (the offshore structure).

Because dilution occurred very rapidly in small limited region as mentioned above, it was not easy to investigate the chain process from nutrient to phytoplankton qualitatively.

It was found that it was necessary to enlarge the total volume of upwelled deep ocean water which would be sprayed if we wanted to investigate qualitatively the fertilization of open mariculture area and detect the effect of nutrient water on phytoplankton in such a sea environmental condition as Toyama Bay.

The estimated necessary flow rate of deep ocean water which will be used for qualitatively reliable experiment is 30 to 300 times of the number in this experiment, that is, 10 - 10^2 m^3/sec, which is derived by introducing diffusion coefficients, division rate and detectable concentration of phytoplankton.

2.2 Research of land based deep ocean water utilization(6)

Characteristics of Deep Ocean Water are "rich-nutrient", "cold" and "pathogen free", which are all advantageous for utilization. Development of technologies for utilizing deep ocean water to bio production or energy recovery is quite expected. The Science and Technology Agency of Japan supported Research Project of deep biology and support technology under the special coordination funds, in which a system of pumping 320m deep ocean water ashore for the purpose of cultivating fish, shellfish and algae was completed in march 1989 at Cape Muroto and the research had continued for two years. The capacity of water supply was 460m^3 per day, in other words, 0.005m^3/sec.

The particular design specifications of this system are as follows: depth of deep ocean water 320m; length of the pipe, 2650m; inner diameter of the pipe, 125mm; pipe material, high density polyethylene with steel wire armor; pump installation height, 2.7m below low water level; pump material, polyvinyl chloride; pump power, 7.5kw.

The specified items for the research are as follows:

[1] Properties of deep sea water influencing biological production
  [1.1] Chemical speciation of bioessential trace metals in artificial upwelling water
  [1.2] Evaluation of Muroto deep ocean water using algal growth potentials and supplement of growth factors or detoxication by bacterial activity
[2] Cuture of planktons using deep ocean water
  [2.1] Effect of deep ocean water on marine diatom growth
  [2.2] Effect of various environmental factors on β-carotene production by Dunaliella salina in deep ocean water
  [2.3] Effect of deep ocean water on nutrit ional quality of plankton
[3] Rearing of marine organism using deep ocean water
  [3.1] Rearing of deep sea fish and culture of macroalgae in deep ocean water
  [3.2] Disease and immune response of fish reared in the deep ocean water
[4] Operation experience of the deep ocean water supply system

It was found that deep ocean water is effective for culture of diatom, rearing of deep sea fish and rearing of cold water fish.

On basis of these prototype experimental results, Japan Marine Science and Technology Center tries to put the technology of land based deep ocean water utilization system to practical application.

2.3 Research of OTEC Technology(7)

2.3.1 The outlines

The objective is to establish a technology for supplying power to self sustaining ocean based mariculture system. In order to obtain necessary fundamental data for optimum design of self-sustaining / self-supply system in which interaction of biofouling and fertilization are considered, the relation between sea environmental conditions and, system or control characteristics was investigated in detail.

The experimental facility is as follows. The system was designed with the minimum capacity considering all the necessary components for practical self-sustaining energy system. The power output of electricity is 3kw(mechanical output is 5.0kw) using one tenth of the amount of total upwelling deep ocean water. Particular specifications of OTEC experimental facility is listed in Table 2. Particular features for this facility are as follows. 1) Condenser consists of spiral drainage type heat exchanger tubes with drainage gutters developed by Electrotechnical Laboratory of MITI. The basic form is a 1mm deep fluted tube, which has spiral type 1.5mm deep drainage with 30mm pitch for removing condensed fluid along longitudinal axis and which has drainage gutters around a circle. Material is aluminum alloy A6063. Sea water side of the condenser is coated by resin. 2) Evaporator is a hybrid type in which upper part is responsible for spray type evaporation and lower part for pool type boiling. Heat exchanger tubes of a spray type evaporator are made of aluminum alloy with pinned fins. Those of a pool type boiling are porous fluted tubes coated by Nickel plasma spray. 3) Turbine is equipped with double stage revolution control system, that is, quick fluctuation is controlled by exciting current of a generator, and slow fluctuation with large amplitude is controlled by by-pass flow rate.

Table 2 Particular Specifications of OTEC Experimental Facility

Evaporator	Shell 520φ x 4.350 l Sprayed/Pool Hybrid Type Tube 21.5φ OD (16 ID) x 3.500 l 150 tubes A6063
Condenser	Shell 500φ x 4.860 l Spiral Drainage Fluted Tube Tube 21.5φ OD (16φ ID) x 4.000 l 140 tubes A6063
Turbine	Single stage axial flow Rated speed 1.500 rpm PCD 400mm Sectional area of nozzle 2.03 x 10^{-3} m^2 (12φ x 18 holes)
Generator	Synchronous generator, separately excited type three-phase alternating current 200V (50Hz) Rated output 5kW
Load device (Primary)	Main resistance 20－60Ω 5Ω intervals Three-phase interlocking variable resistance for fine adjustment 5Ω Three-phase resistance for balanced adjustment 5Ω each phase
Load device (Auxiliary)	700W mercury lamp 5 lamps 500W incandescent lamp 1 lamp
Working fluid	R114 ($CClF_2-CClF_2$)

The experiments were carried out two times from July 18th until September 7th in 1989 and from July 10th until August 7th in 1990. In the first year, the characteristics of powder output at real sea state were investigated during the long term operation. In the second year, performances of each component of the OTEC system and control methods with small loss were investigated.

2.3.2 Results

1)Interaction between discharged plume and OTEC System

Since the plume remains horizontally under 7 - 20m water depth according to the numerical simulation and the water depth of intake for surface sea water is 1.5m, the intake hardly absorbed the discharged plume, the behavior of which was considered to depend highly on direction of onshore current. The measured current velocity and its direction, the time history of surface temperature difference and OTEC power output are shown in Fig.3. In the case of the direction of current south or south-west comparing the current direction with the location of intake, the temperature of intake water and OTEC power generation were stable and the effect of sprayed water could not be observed.

However, in the case of the direction of the current north or east, and also in the case of weak current velocity, the temperature of intake water and the OTEC power output were unstable and varied widely. The reason is considered that some part of discharged plume was taken again through the intake.

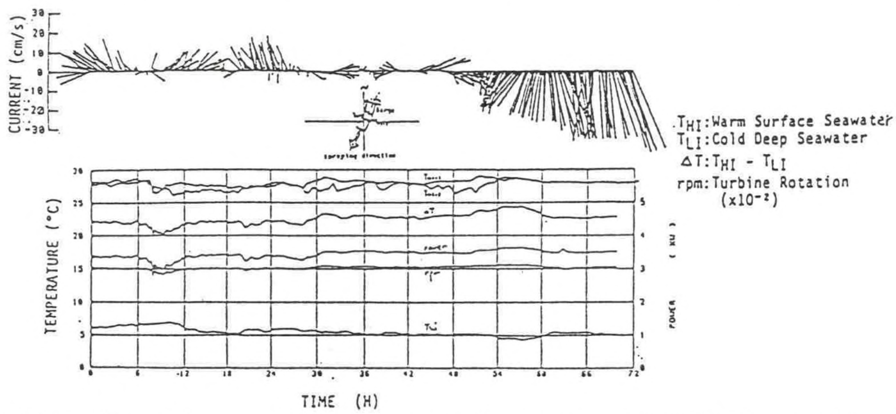


Fig.3 Tim Dependency of Oceanographic Conditions and OTEC Power Generation

2) Fluctuation of temperature and OTEC system control

In Toyama Bay, the fluctuation characteristics of surface sea water were 0.6°C, which varied from 22.1°C to 21.5°C in 10 minutes, that of power output was 0.2kw(5.7%). Maximum fluctuation of surface sea water in 30 minutes was 1.4°C which varied from 25.9°C to 27.3°C, and that for deep ocean water was 0.7°C which fell down from 5.8°C to 5.1°C. The corresponding fluctuation of power output was 0.7kw(18.4%). Two kinds of control methods were adopted in order to make turbine revolution steady against these kinds of input fluctuations.

Figure 4 shows the characteristics of OTEC power output due to two types of turbine rotation control methods. It was found that the exciting current control method was effective for taking out maximum OTEC energy, and the bypass control method was advantageous for stability even though steady loss was not so small.

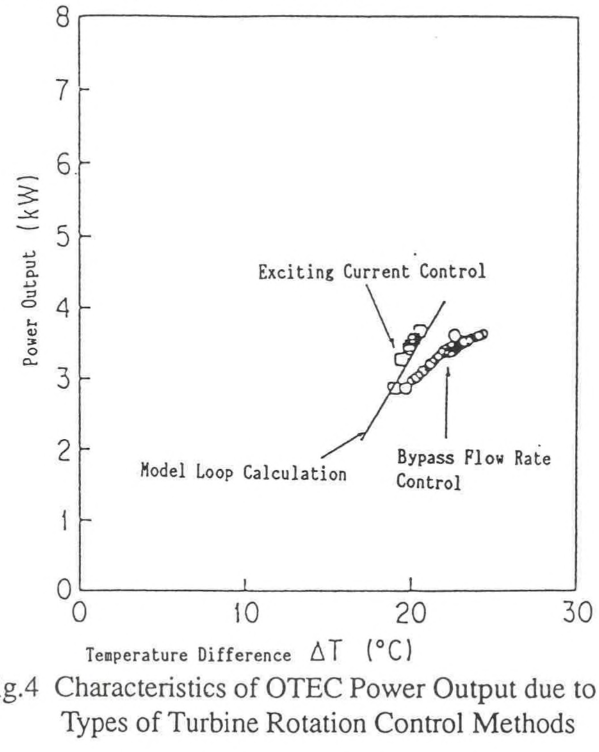


Fig.4 Characteristics of OTEC Power Output due to Two Types of Turbine Rotation Control Methods

3) Energy self-sustainability

According to the experimental data and numerical model, the energy self-sustainability was investigated, assuming that the system was enlarged ten times of the proto type model and all the amount of charged deep ocean water was used only for OTEC power generation. The results were shown in Fig.5. The water head of pressure loss of pipes and heat exchangers in the system was 8.5m. The results show that in the case of 27°C of surface sea water, power output of 20kw is available even through discharging water consumes 2m water head of pressure loss.

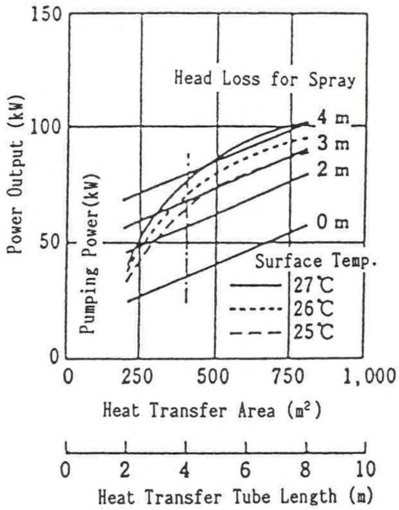


Fig.5 Self-sustaining Condition of Ocean-based Mariculture System "Houyou"

4) Performance of Components

In situ experimental data were obtained for characteristics of evaporator, condenser and biofouling. They were all compared with those in the corresponding laboratory tests. The design specifications about these subjects are almost all satisfied. New knowledge of durability of the material aluminum alloy was also obtained in the OTEC power generation system.

2.3.3 Outlook of OTEC system with multi-purpose

1) Establishment of total system for energy self-sustained OTEC

A deep ocean water utilization system which fertilizes open mariculture sea area requires several kinds of power, for instance, powers for intake and discharging water, power for control system and sometimes power for position keeping. It is quite reasonable to use OTEC energy as on-site energy for generating power and to supply them to a self-sustaining deep ocean water mariculture system from the stand point of minimizing impact to natural environment and also saving running cost of the system. It is confirmed by this experiment that this kind of an energy self-sustaining system is feasible and stable. In future we have to consider the balance between size of a mariculture system and amount of power generated from deep ocean water as OTEC. When a size is enlarged, there must be surplus of generated power, application field of which we have to consider at the same time as we design a large scale of a deep ocean water utilization mariculture system.

In the experiment of Toyama Bay, OTEC system was sometimes affected by cold discharged plume because of a limitation of the two point mooring system. And we also observed remained discharged plume near the barge, measuring temperature of surrounded water area. There must occur a problem of interaction between discharged plume and OTEC when a size of the system is enlarged. Then it is necessary to design a new intake-discharge system in which we consider a separation of power generation part from fertilized sea area.

2) Subject of components for a future study

Since marine bio-productivity is affected very sensitively by concentration of a specified heavy metal ion, special consideration should be paid for materials of components in order that fertilization system due to deep ocean water coexists with energy self-sustaining OTEC system.

In order to make a system more economical, aluminum alloy as material of a heat exchanger is considered to have some potentiality. However there have been only few experimental data on aluminum alloy used in an in situ system. Experimental data in Toyama Bay suggest the necessity of more detail investigation of monitoring concentration of metal ion around experimental site and the adoption of double prevention system of aluminum alloy against sea water.

2.4 Dynamics of a facility of ocean based deep ocean water mariculture system(10)

The facility of ocean based deep ocean water mariculture system consists of main floating platform, cold water pipe and mooring line. The platform made of steel is 25m in length, 11m in breadth, 2.5m in depth and 1.2m in draft. The cold water pipe is vertically hung up by a tower located at the center of the platform through a moon pool. The depth of intake of deep ocean water is about 230m. The cold water pipe consists of two pieces of 10.5m flexible hose and the others, the steel pipe joined by a 11m rigid piece. The outer diameter of the cold water pipe is 0.45m which allows either maximum $0.3m^3/sec$ of the flow rate or $1.9m^3/sec$ of the deep water velocity flow. The thickness of the cold water pipe is 7mm.

A two point catenary mooring system is applied and about 150m excursion circle is expected by about 40ton initial tension for the line. The distance between two anchors is about 2,400m, the each anchor is installed at about 320m and 250m in depth respectively. Each catenary line has a 20ton mooring buoy for easy operation for relief and remooring of the removable platform without anchoring works. While non experimental term, the platform does not locate at the site, the cold water pipe is hung up by the supporting buoy.

During two year insitu experiments, many valuable measured data were collected not only under calm and moderate sea conditions, but also under typhoon sea condition. Through the experiments, characteristics of dynamics of two point moored platform, behavior of cold water pipe and mooring force characteristics are clarified.

We developed 3D numerical simulation programs for predicting dynamics of a two point moored floating platform with long cold water pipe and behavior and bending moment of cold water pipe in time domain. It is confirmed through comparisons between the experiments and calculations that the developed simulation programs give reliable estimation(Fig. 6). So long as the weight ratio of a platform versus cold water pipe is 10:1 or over like our experimental case, it is found that dynamics of a floating body and behavior of cold water pipe can be simulated separately introducing the interaction forces only as external forces.

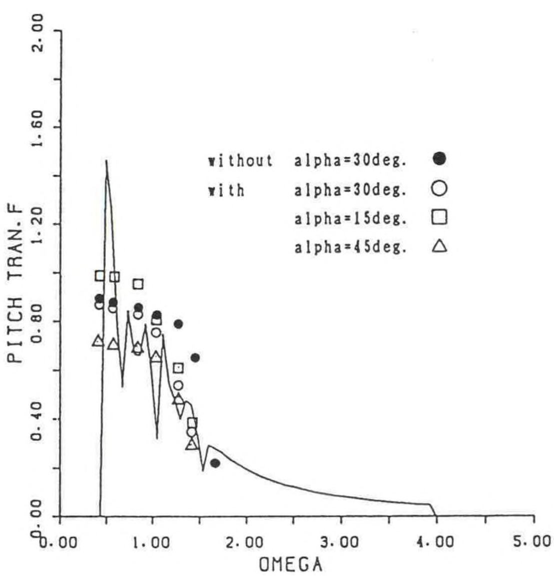


Fig.6 Comparison between Experiment(solid line) and Calculation(marks) of Pitch Transfer Function of the Platform

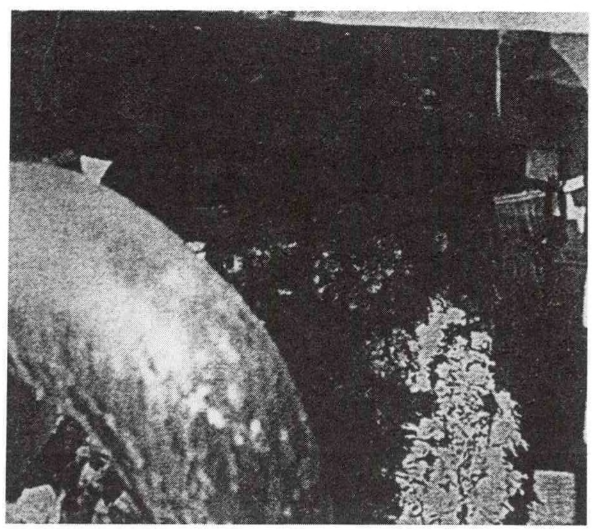


Photo 2 Broken Cold Water Pipe in Typhoon Sea Condition

The prototype facility of ocean based mariculture system was designed to survive up to the sea state of significant wave height 3 m. However, in the summer of 1989 when typhoon attacked Toyama Bay directly, it was impossible by some reasons to escape(to disconnect the platform from the cold water pipe and mooring system and move it to the harbor) and finally the joined point of cold water pipe to the platform was broken. The strong interaction between the platform and cold water pipe was considered to occur (see Photo 2).

Moreover in future when we design the phase two ocean based deep ocean water utilization mariculture system, we must enlarge the capacity of upwelling deep ocean water at least ten times of the present one. Then the weight ratio between a platform and cold water pipe may be less than 10:1 that means interaction between a platform and cold water pipe can not be neglected.

Therefore it is important in the next stage to develop a simulation program which consider the direct dynamical interaction between a platform and cold water pipe and also mooring lines.

And also it is important to develop a design method of mooring system which is based on reliable prediction method of low frequency motions.

3. Outlook of deep ocean water utilization technology

3.1 Consideration of ocean based deep ocean water utilization

3.1.1 Expected effects

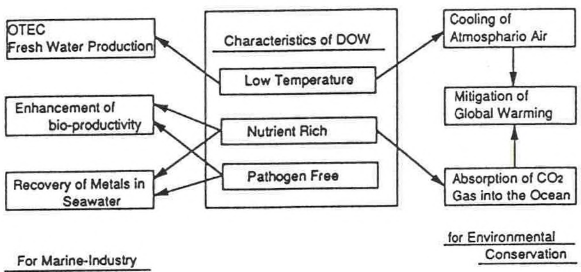


Fig.7 Major Utilization of Deep Ocean Water

There are three major characteristics of deep ocean water viz. low temperature, nutrient rich and pathogen free. By utilizing these three major characteristics, deep ocean water can be used not only for mariculture and OTEC, but also for mitigation of Global Warming.

Figure 7 shows the following effects which are brought by the artificial upwelling of deep ocean water.(8)(9)

1) Electric power generation is expected by OTEC utilizing temperature difference between surface water and deep ocean water, and fresh water production is also expected if Open- cycle OTEC is employed. OTEC generates energy without producing CO_2.

2) Enhancement of bio-productivity originated from phytoplankton growth is expected by utilizing rich nutrient of deep ocean water for photosynthetic activity.

3) Marine mining is expected by utilizing a huge amount of sea water which is mechanically transported for OTEC and / or mariculture. The selective bio-concentration function of Mollususca will be added on the technology to recover metals in sea water.

4) Mitigation of Global Warming is expected by cooling down of atmospheric air temperature utilizing low temperature energy of deep ocean water of OTEC, mariculture and marine mining. Cooling of air temperature links to minimize the melting of glaciers and/or frozen ground surfaces, and the minimizing for these melting means to minimize the increasing of water volume in the ocean. Sea level rise will be minimized as the result of minimizing of increasing of water volume in the ocean. And then high density of sea surface water due to cooling by deep ocean water will affect to shrink surface water volume that means to minimize Sea water Level Rise.

5) Mitigation of Global Warming is expected by increment of CO_2 absorption into the ocean from atmosphere utilizing photosynthetic activity by phytoplankton and chemical reactions by low temperature of surface water and enclosed CO_3^{2-} in surface wate.

Figure 8 shows the detail of the structure of mitigation and countermeasure of Global Warming(11)(12).

3.1.2 Remarkable points

The following points should be remarked before starting the study of the above mentioned

expected effects of deep ocean water artificial upwelling.
1) Deep ocean water upwelling does not produce good fishing bank when the effect is judged by short time-scale as a few months.

It is considered that low dissolved oxygen (DO) and low water temperature disperse fishes from the point.(13)

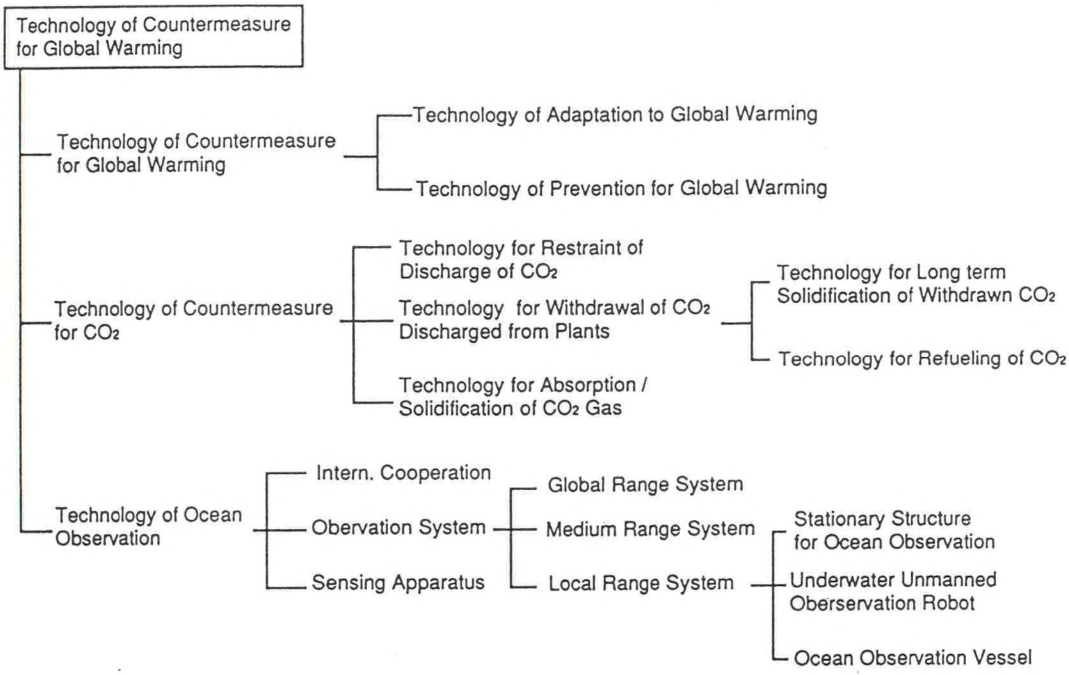


Fig. 8 Structure of the Mitigation for Global Warming

2) Good fishing banks made by natural upwelling of deep ocean water are summarized using the figures of 10 to 50 Km in width, 10^{-3}cm/sec in average vertical upwelling speed and 10^{2}cm/sec in horizontal dispersion speed. Relatively slow upwelling speed leads higher bio-production.(13)
3) When a change of food link in the ocean is foreseen, careful action should be taken considering the undesirable change in the natural system. As an example, along with rearing of useful diatoms in phytoplankton, silicon (Si) may become short which could invite the increase of unuseful living things like jellyfish.(14)
4) The formation of organic carbon in the ocean eliminates CO_2 from atmospheric air, but formation of inorganic carbon (C_2CO_3) means CO_2 generation against atmospheric air. And the ratio between two formations and the accumulation and/or dissolving process are one of the study theme of chemists.(15)
5) Generally, total carbon (TOC) in deep ocean water is higher than that in surface water. There is a possibility that the amount of CO_2 increased by deep ocean water transportation exceeds the amount of CO_2 decreased by the effect of phytoplankton.

3.2 Trend of ocean based deep ocean water utilization technology

3.2.1 Experimental study

To establish a theory for utilization of deep ocean water for environmental conservation and food production, it is necessary to take theoretical approach from various fields as biological, physical, chemical, fishery, geology and meteorology.
Small scale experiments on-site should be realized as soon and speedy as possible because it is not practical to collect all the necessary phenomena from nature. Backup of the experimental study by

engineering function is necessary, while research and development should be continuously made for the realization of artificial Deep Ocean Water upwelling.

It is recommended to organize and international research and development program including experimental studies for Deep Ocean Water utilization technology with view points of the following.

1) The program should be multi purpose to get various data from the ocean as much as possible both for fields of science and engineering.

2) The ocean-based mariculture system should be the first object of research and development and the system should be sustained itself by "Clean Energy" like OTEC.

3) The site should be selected from the sea to enable to charge from "CO_2 Source" to "CO_2 Sink" considering environmental conservation even for a small scale.

3.2.2 Investigation of economy

Regarding utilization of deep ocean water, various unique ideas such as onland application, fixed-bed type upwelling installations and super scale trade wind cooler are also proposed. All the beneficiaries of the Deep Ocean Water utilization are many and unspecified, therefore it should be considered as public workings organized by the United Nations, and the work should be economical to reduce burden of each nation.

In case of ocean-based Deep Ocean Water utilization, the first experiment in the world mentioned in 2.1.1 shows that $0.3m^3/sec$ of deep ocean water volume for artificial upwelling is not enough to judge quantitatively enhancement of primary production under conventional observation methods. When the figure of 1 m^3/sec, the minimum size of natural deep ocean water upwelling, is applied on the experimental study, the diameter of cold water pipe (Cold Water Pipe) is about 60 m with $10^{-3}cm/sec$ of vertical upwelling speed. Such Cold Water Pipe dimension will disturb the project. Therefore artificial upwelling facility should provide a function to cover primary production by such as bio-reactor to rear phytoplankton and its eater before spreading deep ocean water to surface water and reduce the amount of deep ocean water upwelling. And, even if we use optimized artificial DOW upwelling facility, attention should be paid on the powerful observation network and the prevention and countermeasure of any accident which requests to interrupt the experiment and to restore the site to the former conditions.

Moreover, ocean mining which utilizes biologically selective concentration function should be studied in parallel with recovering metals in sea water. Then we can sell the recovered metals from internal organs of such as Common Octopus, Menke and Sea-squirt and at the same time we can sell marine products of Common Octopus, Menke and Sea-squirt themselves toward a self-supporting accounting system.

3.2.3 Experimental facility in future

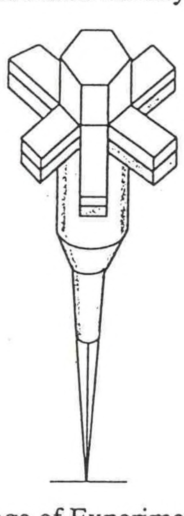


Fig. 9 Image of Experimental Facility

The image of an international experiment facility for development of ocean-based deep ocean water utilization technology is shown in Fig.9. Considering investigation of carbon circulation, the facility is assumed to be installed in the sea at more than 2,000 m depth, and deep ocean water at more than 300 m below from sea surface is pumped up to get specified deep ocean water characteristics. The facility is a single point mooring floating unit, and six auxiliary experiment module barges are joined just like space laboratory. The cold water pipe will be assembled in the mooring line.

A main floating unit and six auxiliary experiment modules are used for the research and monitoring the effect to the ocean and atmosphere by the artificial upwelling of Deep Ocean Water, research of food link including the facility such as bio-reactor for enhancement of primary production, research of optimization of OTEC/floating facility and research of biological concentration function.

4. Concluding remarks

In situ experiments for deep ocean water utilization as prototype experiments have been completed as five year project in two sites of Japan, one in Toyama Bay of Japan Sea, and another at Cape Muroto in southern Pacific side of Japan.

An ocean based artificial upwelling experiment, in which nutrient-rich deep ocean water flow rate was $0.3m^3/sec$ and upwelled deep ocean water was mixed with surface sea water and was sprayed to sea surface, was carried out in Toyama Bay in order to obtain basic data for a future artificial upwelling system using deep ocean water. It is confirmed that upwelled deep ocean water is effective for multiplication of phyto- and zoo-plankton according to the laboratory bag tests, and that discharged deep ocean water stay in photosynthetic zone. However it was difficult to validate the fertilization in open mariculture field because the amount of discharged deep ocean water was too small and mixed and diluted so rapidly. Meanwhile it was first time in Japan that energy self-sustained system(with 5kw OTEC system) succeeded in generating electric power and attained continuous 412 hour power generation. Moreover measured data for behavior of two point moored floating platform and cold water pipe were collected under not only moderate but also typhoon sea conditions. The corresponding numerical simulation methods were also developed.

A land based artificial upwelling experiment was carried out at Cape Muroto. It was found that deep ocean water is effective for culture of diatom, rearing of deep sea fish and rearing of cold water rich.

Considering the above mentioned results and adding the new concept of mitigation of Global Warming and conservation of Global Environment, we propose the next phase of ocean based deep ocean water utilization mariculture system which will be not only useful for developing mariculture, but also advantageous for prevention of Global Warming and conservation of Global Environment. We wish this new proposal will be an internationally cooperated project.

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OPEN OCEAN MARICULTURE

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Introduction

"Engineering Research Needs for Off-Shore Mariculture Systems Workshop" a National Science Foundation-sponsored workshop hosted by the University of Hawaii and East-West Center, brought together a cross-disciplinary international group of experts from academia, industry, and government to discuss the current state of mariculture, project trends for the future and develop research priorities. We brought together diverse areas of engineering (mechanical, chemical, and electrical) and environmental and oceanographic sciences (biological, chemical, and physical), with fisheries experts, mariculturists, and technologists. The workshop participants identified engineering research needs and delineated the technology requirements to enhance the production of open ocean fisheries, either free in the sea or in containment systems (technology barriers — fencing, pens, trees, baskets, electrical, thermal, chemical, photic, and/or acoustic), such that by the year 2010, global commercial stocks may be maintained on a sustainable yield basis, with a growing share coming from some of the next generation fisheries discussed at the gathering.

The workshop participants envisioned three types of ocean-cultured fisheries:

(1) loose on the range with an emphasis on improving the quality and production of the range through enhancement technologies and ocean systems engineering to maximize sustainable development; (2) enclosed in ocean engineering culture systems under similar operational philosophies as a cattle feed lot; and (3) in blue water, off-shore, utilizing upwelled nutrient-rich deep ocean waters to create a total system where the natural environment would provide feed and structures avoided through the use of temperature or nutrient barriers.

Recommended Priorities

Four prioritization groups were formed on materials/construction, anchoring/mooring/positioning, operations and deep ocean water.

One of the primary requirements of the off-shore mariculture industry is the absolute necessity that our structures and systems withstand the oceanic environment for extended periods of time. The ocean cycles of wind, waves, currents, and biological and chemical reactions dictate the regimen of inspection and maintenance that is possible. For some systems, there will be no second chance.

At present, there is an absence of any code of design standards. Establishment of proper codes, design standards, factors of safety, and design information requires additional information on the properties of the materials which may be used, as well as a better understanding of the environment (chemical, biological, and physical) to which they may be subjected. In addition there needs to be a better understanding of available marine materials and new materials for service in the off-shore marine environment.

The following research programs to understand and utilize materials in the open ocean marine environment were recommended:

1. better characterize the environment and forces acting on commercial-size structures;

2. study the degradation of materials and changes in their properties as a result of service in the marine, and environment; and

3. develop in situ testing techniques for determining the properties of the materials and the component age relative to their expected service history is needed.

The conferees further suggested that these programs should be carried out with a defined policy of international cooperation and information exchange to make use of the experience of all involved.

With respect to anchoring, mooring and positioning, the priorities are:

1. improved understanding of pen system dynamics;

2. long-term deployment in exposed sites;

3. low-scope, taut mooring systems;

4. development of low-cost, easily installed anchors;

5. intelligent mooring systems for survival in extreme conditions; and

6. techniques to determine bottom characteristics.

Two workshop groups combined to form one on biological and engineering aspects of operations, and then defined "operations" as "need, breed, seed, feed, weed, succeed, and greed (financial success)." Matrices based on this list of operational topics and others based on containment versus open systems were also discussed.

The top five research topics selected were to:

1. develop non-mechanical confinement and herding technologies;

2. develop upwelling technologies that could be used both for small- and large-scale open ocean farming;

3. develop cloning and other propagation methods for cultivated organisms that ensure both their genetic isolation from native stocks and product uniformity;

4. develop comparative testing of the operations of various pens and support structures; and

5. study pelagic species (tuna), considering the biological, engineering, marketing, and economic factors.

The fourth group met to consider options for coordinated, collaborative efforts capitalizing on the resource represented by nutrient-enriched deep ocean waters and to propose the means of tapping that resource. All attending the conference recognized the importance to the future of mankind of increased marine productivity. The task before us was identification of the means of achieving that increased productivity in an environmentally acceptable and a cost-effective manner. As the focus of our research in Hawaii with respect to open ocean mariculture is utilization of the deep ocean fluids, we will provide added details on this subject.

Ideas were subdivided into categories:

1. natural upwelling systems,

2. engineering needs for upwelling and mixing processes,

3. ocean ecosystems modeling, and

4. marine bioproduction.

The first category recognized the need for a better understanding of naturally occurring areas of high biological productivity, zones of natural upwelling. Unless and until we better understand the nutrient biogeochemistry and the biological productivity of these zones, we have little hope for the responsible manipulation of large-scale oceanic systems or of predicting the behavior of artificially created zones of high biological productivity. Listed were those topics judged necessary for the characterization and classification of natural systems. Improvements in remote sensing were also listed as necessary for accomplishing these ends. Participants additionally recognized that site selection would be a critical factor for both investigations and for experimentation and manipulation, as energy requirements may prove to be an overriding consideration in any real world application.

Topic area two, engineering needs for upwelling and mixing processes, addressed the devices and structures which will be required for experimentation and manipulation. Topic three, ocean ecosystem modeling, addressed the need for a significant modeling effort to complement experimental observation and engineering design. Models can help to summarize findings and will provide the means for evaluating design and deployment options and projected impacts prior to actual construction of full-scale, open ocean mariculture facilities.

Marine bioproduction was the fourth category. Here, workshop participants identified and summarized those considerations with respect to systems design, species selection, and site selection. This broad area was both the target for the workshop as a whole, as well as being the topic that best brought forward discussions delineating a research plan, a plan including on-shore stock enhancements, as well as near-shore and off-shore field experiments.

The following topics/actions toward increasing marine biological productivity by the use of deep ocean water were recommended:

1. Natural upwelling systems
   a. characterization and classification
      1) size,
      2) dilution,
      3) energetics, and
      4) nutrient dynamics
         a) biogeochemistry
            (1) major and trace elements
            (2) carbon flux rates
         b) limitations;
      5) community structure;
   b. remote sensing; and
   c. site selection.

2. Engineering for upwelling and mixing of deep ocean water
   a. upwelling devices
      1) diffuser design
      2) effluent discharge design
      3) OTEC;
   b. cold-water pipes;
   c. support structures;
   d. remotely operated vehicles (ROV);
   e. engineering control and operation;
   f. deployment; and
   g. instrumentation.

3. Ocean ecosystem models
   a. physical oceanography (hydrodynamics)
      1) far-field behavior (Steady-state/ transient conditions)
      2) transport and mixing (near-field behavior);
   b. biochemical transformation
      1) C/H/N flux
      2) reaction kinetics;
   c. summed ecosystem model; and
   d. model applications
      1) open ocean mariculture
      2) site selection
      3) evaluation of scale and selection
      4) environmental impact and experimentation systems failure
      5) global CO_2-flux
      6) economic evaluation.

4. Marine bioproduction
   a. systems considerations
      1) containment systems
      2) ranching/stock enhancement
      3) ecosystems modification
         a) near-shore
         b) off-shore;
   b. species considerations
      1) stock selection
         a) characterization
         b) cultivation

2) biotechnology/genetic manipulation; and
c. site-specific characterizations
  1) selection
  2) field experiments
    a) near-shore
    b) off-shore.

Summary and Conclusion

The 60 participants from Hawaii, the U.S. mainland, Canada, Monaco, Norway, Sweden, Japan, and Taiwan each brought a wealth of experience and knowledge to the proceedings. Topics ranged from the merits of high tech fish cages and materials, to the use of waste materials to build artificial reefs, to the use of artificially upwelled sea water for fish cultivation. One fact became very evident: the United States is lagging behind the more progressive fisheries nations.

Despite this disappointing domestic situation, the expectation is that interest in, and support for, open ocean mariculture will grow because of overfishing, near-shore pollution, and rising demand for seafood in this country and elsewhere. Among the work needing to be accomplished includes the modelling of artificial upwelling systems as a source of nutrient-rich sea water for ocean ranches, genetic engineering for optimal species and systems, and a particularly close look at a revenue attraction pelagic species, such as tuna, integrating biological, engineering, and economic factors.

Much work remains to be done, but the workshop was highly successful in identifying and recommending the research needed to foster the growth of open ocean mariculture. While only the beginning, there is promise that the gathering has stimulated the genesis of an important international partnership to develop solutions to meet our common marine protein needs.

As the results of the workshop were the combined product of the participants, attached is the list of conferees.

List of Participants

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The Development of Electrical Screen System for Marine Ranching Formation

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1. Impact of which Japan's fissheries faces and the direction of fisheries reform

Along with 200 nautical miles system is steadily recognized, overseas fishing ground of Japan's fisheries' is reduced and its catch has decreased sharply. Also, in the recent years a catch in the high seas of which no country has the fishery direct control right is tend to decrease, besides, from the point of protection of wild creatures and preservation of marine ecology, fishery control is strengthened and which spurs on the decrease of a catch.

While, in the domestic, a symptom of the decrease of a sardine group resource which accounts for most of the catch, has begun to be seen, which gives an impact to breeding, feed, fish oil manufacturing industry, at the same time, the decrease trend of fishery resource of mainly bottom fishes live in the coast area can be seen. In this way, under the serious change of fishery production environment, it is the present condition that our country's consumption of marine products is still powerful and anuual total consumption amount is 14 million-tons, which accounts for 40% of animal protein supply amount.

In this background, in 1985, Fisheries Agency planned Marinovation concept (marine-inovation, marine production inovation) to aim at planning synthetic arrange-development of the coast area and offshore area as fishery as a core and planning of stable supply of the fishery products and promotion of the fishery area. Based on this principle, each local government has established the concept making the best use of local characteristic and planned the basis plan for realization that numbers are 55 areas in the whole country.

The sea area interception system by the electric screen system introduced this time, is a technical system located in Kumamoto marinovation concept as one of 55 areas mentioned above, and since 1985 in which basic experiment of a stimulus performing a school of fish behaviour control, at the present, it is proved that the electric screen is effective for interception of a shool of fish as a result of interception experiment of red sea bream fries by the demonstraion plant constructed on the actual sea area.

2. The resource management fishery system and the technical subjects

Kumamoto-prefecture marinovation conception is to develop a resource management fishery system in Shiranui-kai which is the closed sea area, as an object.

The conception of system development is shown in fig. 1 and the general idea figure is shown in Fig. 2.

◆After liberation, protect-rearing, and feeding and staying of a big volume of seeds (red sea bream bastard halibut, black porgy, etc.) in Shiranui-kai	→	The resource management fishery system in the closed sea area
↓		
◆For that, rearing the seeds in the natural sea and liberating	→	The sea area barrier system (construction of an intermediate breeding area)
↓		
◆Increasing the natural bait in this sea area	→	The natural bait propagation system
↓		
◆Establishing the offshore aqua culture facility inside the production fishing ground and utilizing for rearing, staying of the fishes along using for culture	→	The big scale offshore aqua culture system
↓		
◆Surveying the fishing ground environment and mainly the fishes resource, and managing whether the purpose is achieved	→	The fishing ground environment monitoring system

Fig. 1 The Kumamoto marinovation conception

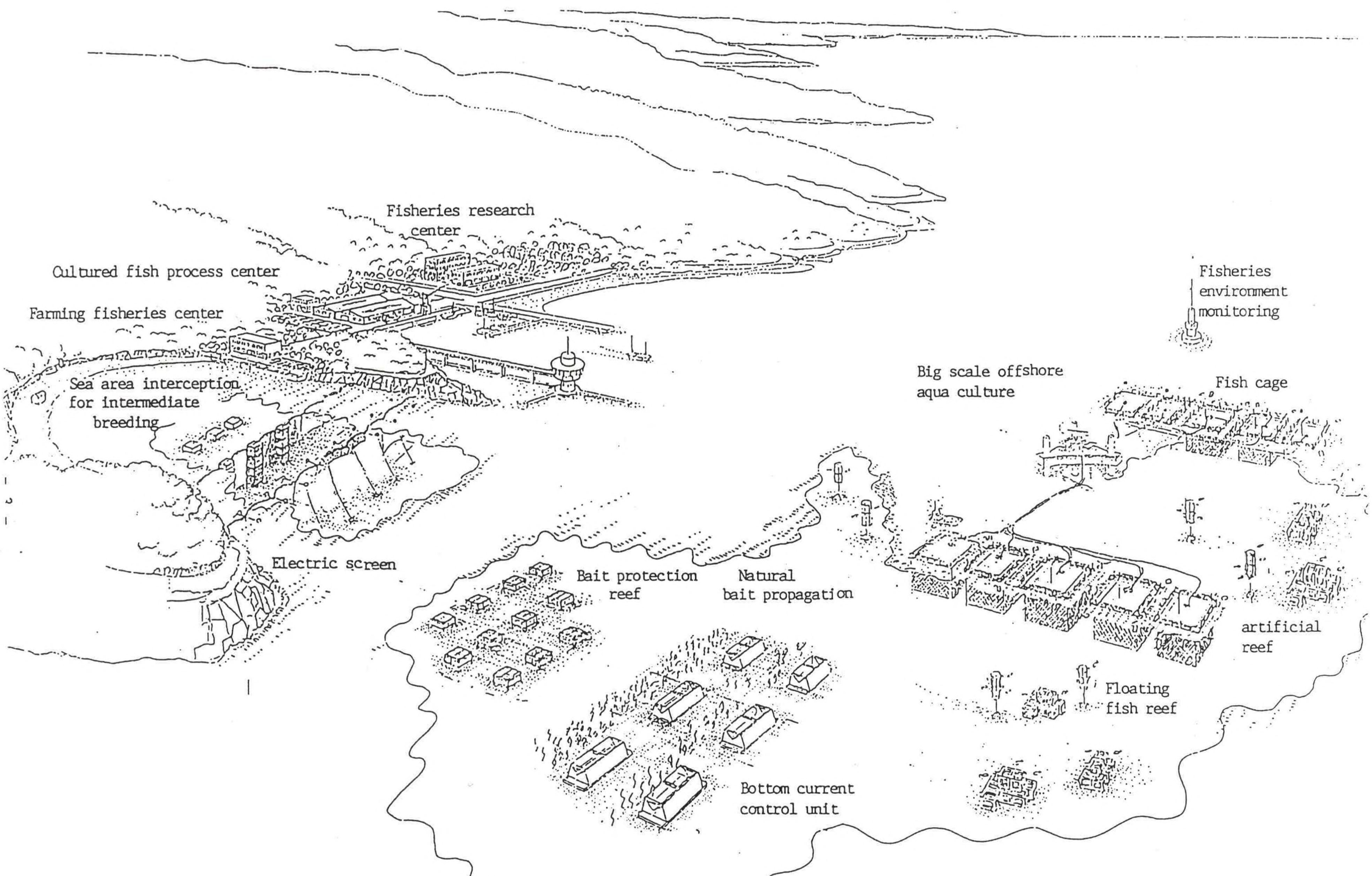

Fig.2 Kumamoto Prefecture. Marinovation

This conception is to manage from the birth of species to the catch and harvest along controlling the fishes and shellfishes behaviour at the coast sea area in the possible range, in Japan. it is called as The resource management fishery system, and this conception is taken into above mentioned 55 areas marinovation conception in the whole country in common. In the country, generally it is called as the marine ranching and has become familiar.

Generalizing this fishery system being developed now in Japan and showing fishery production process in the Table 1, and evaluating the establishment degree of technology at the present stage.

Table 1 The fishery production process(fishes)

Production	Contents	Establishment degree of Japan's fishery technology	needs
(1)Artificial seed production	Egg removal from a parent fish hatching rearing		
(2)intermediate breeding /liberation	Move to the actual sea area, accustom to the natural sea. Breed up to the size to evade predation.	breeding in the bay ○ breeding in the small fish cage ◎	Expecting to produce a big volume of healthy seeds effectively in the natural sea
(3)Protection and rearing of fry and juvenile fish	Protection and rearing fry, juvenile fish in the shallow sea (shalower than 7-8m) by such protection/ rearing reef, sea weed reef. Securing incipient feed. Protection from the foreign enemy.	◎	
(4)Guidance to production fishing ground	Move fishes to the deeper natural reef, artificial reef as their growth Guide fishes to the aimed sea area	×	
(5)Staying/ baiting at production fishing ground	Stay and breed fishes at aimed sea area	×	Expecting to avoid scattering of the adult fish grown from artificial seed and expecting to raise the recapture rate as possible
(6)A capture, a harvest	Fishing gill net, longline, sea bream surrounding seine, trawl net, etc.	◎	

◎: technology is established ○: under development ×: technology is unestablished

Table 2 Main fishes classification seed liberation volume

classification	annual seed liberation amount							for liberation	for seeding
	unit	total	1983	1984	1985	1986	1987		
<artificial seed>									
salmon	1,000	712,740	99,585	107,576	154,733	168,781	182,065	30	-
bastard halibut	1,000	31,892	3,261	4,810	5,087	8,217	10,517	50	31
flat fish	1,000	7,396	1,106	2,495	1,572	1,080	1,143	11	-
red sea bream	1,000	85,747	15,820	15,311	13,990	17,265	23,361	40	37
abalone	1,000	104,747	19,456	19,521	21,248	21,853	22,669	73	10
giant ezo-scallop	1,000	10,172,715	1,574,416	1,642,656	2,083,250	2,058,229	2,814,164	6	1
kuruma prawn	1,000	1,785,032	356,030	329,905	336,547	353,765	408,785	44	14
offshore greasyback prawn	1,000	143,153	19,837	27,741	35,722	25,208	34,645	10	-
sea urchin	1,000	45,016	7,806	7,123	8,472	9,228	12,387	28	1
<natural seed>									
abalone	1,000	5,027	1,204	1,168	1,057	845	753	..	..
hard clam	1,000	135,657	6,863	10,728	6,282	8,397	103,387	..	..
little clam	1,000	53,623,955	8,544,465	6,969,990	9,268,232	10,933,214	17,908,054	..	..
giant-ezo scallop	1,000	-	-	-	-	-	-	..	..

source: Agriculture, Forestry and fisheries statistics (up to november 1988)

As fishery resource in Japan's adjacent sea tends to decrease, producing seeds artificially of prime fish mainly, and the development of this technology is remarkable. The seed liberation volume of main fishes is shown in the Table 2.

Next one is preparation for liberation. Hatchig in the ashore water tank, moving breeded seeds to actual sea area, .and accustoming to the sea, and rearing in the net cage to the size to evade predation by the·foreign enemy. By this method, it cannot produce healthy seeds in large quantity.

Therefore, the method of intermediate breeding of the seeds utilizing of natural bay is considered. In this case, the technique of intercepting the bay entrance to prevent the fries dispersing without making worse the sea area environment, is required. This technique, at the present, is Japan's main technology subject, and also the main theme of this papers.

In the sea area called nursery where liberating the artificial seeds and protecting and rearing the seeds added naturally, requires to secure an incipient feed for the fry and jevenile fish and to take into consideration how to protect from the foreign enemy, in this point, in Japan, such technology of the natural bait propagation, the protection rearing reef, the sea weed bed creation has been developped and project is performed.

The fishes move to the natural reef of the artificial reef in deeper sea area along their growth, and are caught in this sea area. These sea areas called production fishing ground is almost fixed at the coast area in or country, but, the technology to conduct the fishes of a production object to this sea area staying breeding has not been established in Japan's fisheries.

It is reported that recapture rate of the acoustic feeding system for the red sea bream is also under 20%. Because the red sea bream move to deeper offshore natural reef when the temperature goes down in winter time. The most difficult point for the construction of large scale marine ranching utilizing the natural sea is in this situation.

At the present, in Japan, the regulation project for the fishing ground is steadily proceeded corresponding to the fishery production process mentioned above, Fisheries Agency reported "fishing ground regulation rate" of deviding the area of used/regulated fishing ground until 200m depth by the total area of the fishing ground to be able to use by regulation development is 10%.

Hereafter, it is expected that fishing ground development and its regulation of Japan's coast will progress by taking the result of technology development with marinovation basic plan in 55 areas of whole country as a leading part.

3. The development trend of the control technology of a school of fish behaviour

To establish resource management fishery system at the coast, control of objective fishes behaviour to favorable condition for the fishing production, is emerged as a big dream. In Japan, fishes behaviour control is already performed as can be seen in squid angling with light and pacific saury stick-held dip net, and this is the example of applied for fishing catch method. As for the application for the fishes production process, only acoustic conditioning system is available, therefore, the technology development in this area is greatly expected for the future. comparing to the animals on land, at the present situation, life history and detailed study of mode of life of marine creature is behind which causes to delay the development speed of a school of fish behaviour control technology, but, many cases of this development come to be seen. In the contents of these study, the method of behaviour control is classified roughly into three of interception (prevention of dispersion, protectionfrom foreign enemy), guidance, staying, baiting (conditioning).

Purpose, corresponded technology and establishment degree of technology by every method are indicated in the Table 3.

At the present, each research organization proceeds research-development energeticly, but, especially important point is to study the relation between stimulation (technique) applied for controlling of objective fishes behaviour and physiologicalreaction patiently, and to establish accurate stimulus condition, and also to design the hard system.

4. Sea area interception technology by electrical screen method

The most important formation factor to construct intermediate breeding ground producing seed in the natural sea area, is the fence for the ranch, that is, sea area interception technology, interception by the net as the conventional method requires small mesh which causes to damage the sea water circulation by stuffed with the submarine creatures, also to be damaged/lost by the tidal current. Paying attention to this point, the interception method in the natural sea comes to a netless barrier (formless barrier) which does not affect to thesea water natural circulation.

As considerable measure, next method for behaviour control by stimulating the phisiology of the fish can be raised.

① sound:	sound the disgusting sound on the screen
② light:	surprise by the color, flash light.
③ electricity :	form weak electric field which fishes feel slightly.

Among these stimulations, sound and light have the problem of loosing their effect gradually by practice. But electric method is the most reliable one, for it shows the effect to the most fishes and the fish never get used to it. But, in spite of

Table 3 The development situation in the control method of a school of fish behaviour and thecorresponded technology

Control method	purpose/usage	corresponded technology (stimulation)	establish-ment degree
interception	①sea surface seed production (mainly intermediate breeding) ②bay aqua culture ③protection from foreign enemy ④fish preserve/fishing pond, etc. ⑤prevention of fishes entering (all kinds of water intake)	· net · electricity, light, sound, screen · air bubble · water mass temperature control	◎ ○ △ △
guidance	①guide liberated fish to production fishing ground ②guide migratory fish to production fishing ground ③catch	· sound · light · bait	○ △ ◎
staying /baiting	①catch in the production fishing ground	· sound · light · bait · structure such as reef	○ ◎ ◎ ◎

◎: under opration ○: under development △: planning stage

the method with electricity has been examined from days gone by, it has not been made practicable yet. Especially, application for marine ranch is equal to none. This may be because that it was difficult to form electric field inside the sea water besides electric stimulation condition for the fishes was unknown. Moreover we cannot miss when realizing the electrical screen in the actual sea area with several hundreds meters bay entrance, requires huge amount of electric power.

"The electrical screen system sea area intercepting method" introduced as follows is developed for aiming at controlling a school of fish behaviour surely by clarifying above subjects.

4.1 Electric shock reaction and behaviour control condition of the fishes

The fish shows the electric shock reaction depending on its strengh when it is released in the electric field. Table 4 shows the electric shock reaction in the case of strenghening the electric field gradually on the fish as the red sea bream for an example.

The electric shock reaction and its condition is different depending on the sort of fish or the body length, but, any of them can be divided into some areas from the condition of weak electric field in order. That is, the area of which showing light shock and incompatibility in the weak electric field, but possible to swim (the condition of able to evade), the condition for impossible to swim by opening gill or bending the body (weak paralysis condition), and cramp, stiff, state of suspended animation (strong paralysis condition).

Table 4 electric shock reaction of the red sea bream fry and electric shock division

electric field	electric shock reaction	a reaction standard	electric shock division
weak	Dorsal fin stands. Moves eyes and pectoral fin heavily.	The area that feels electric shock, but possible to swim.	The area of able to evade.
↓	Pectoral fin stands and gill opens. (stops breathing)	The area that cannot swim freely by electric shock paralysis, but back to normal when goes out the screen.	The weak parlysis area
middle	Moves up in the water in cramping. Looses the sense of equilibrium. Sinks to the bottom of water and falls sidelong.	The area that impossible to swim by paralysis by electric shock and even if goes out the screen cannot be back to the normal condition soon.	The strong paralysis area.
↓ strong	The body becomes stiff.	The area that falls into state of suspended animation by electric shock and then some fish stop breathing or die by the shock.	The fatal area.

The electrical screen is the method of trying to realize the fish behaviour control by a single electric shock area or combining as in the fig. 3. For example, the combination in the fig. 3(c) is the structure of setting the condition of able to evade in only ranch side with considering of finance and setting the weak paralysis area in the outer sea side. By this method allows to put back the released fish invading to the screen with less harm to the ranch side, and paralyse or reject the enemy fish in the outer sea immediately.

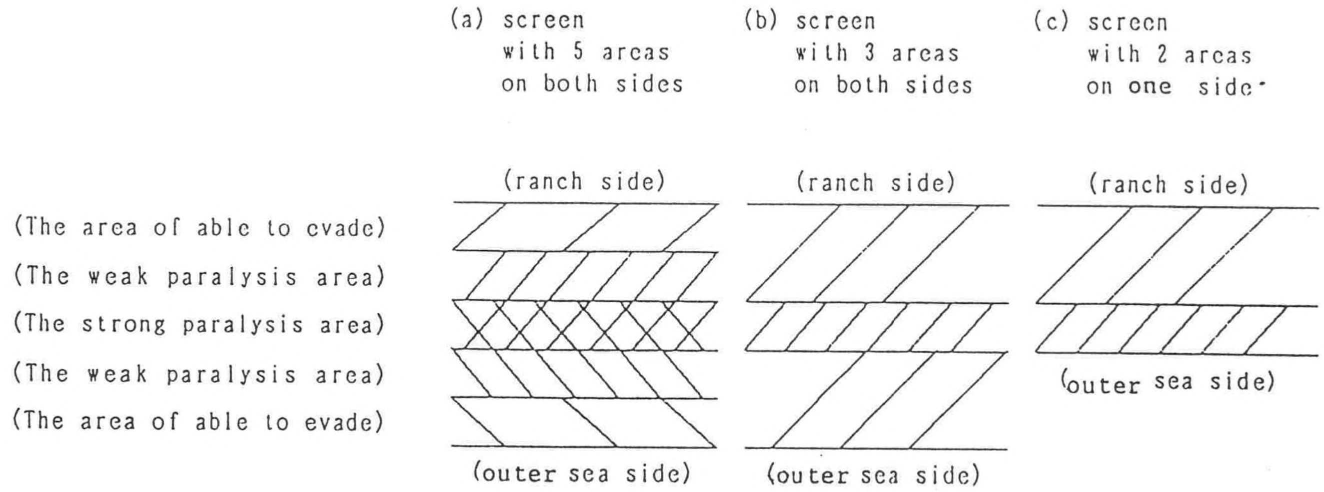

Fig. 3 various ideas of the electrical screen

4.2 The formation of the electrical screen

The electrical screen including two electric shock areas in beltform can be formed by combining such bar electrodes. But, to construct electrical screen in the actual sea, requirés to give cosideration to the next phase of safety and practice.

①Not to leak the electric field from screen to the outside. (electric field confined)

②Easy to set and control the electric barrier. (electric field control)

③Reduction of consumption of electric power. (saving electric power)

One example of the electrical screen developed with considering these points is "3 pole-2 potential-form electrical screen" shown in the fig. 4. This is the structure of arranging bar electrode line in 3 lines, providing P_1 pole of ranch side and P_3 pole of outer deaside as a standard potential and giving fixed potential to middle P_2 pole. By this, allows to obtain 2 potential inclining from P_1, P_3 poles toward P_2 pole inside the screen, besides the degree of this inclining, that is strength of the electric field can be set independently each by changing the distance between each pole X_{12}, X_{23}. The current I and applied voltage V and consumption power P of this 3 pole-2 potential-form electrical screen is figure out by next expression.

$$I=(E_{12}+E_{23})\cdot S\cdot \rho^{-1} \quad (1)$$

$$V=E_{12}\cdot X_{12}\cdot \alpha_{12}^{-1}=E_{23}\cdot X_{23}\cdot \alpha_{23}^{-1} \quad (2)$$

$$P=DF\cdot V\cdot (E_{12}+E_{23})\cdot S\cdot \rho^{-1} \quad (3)$$

However, E_{12}, E_{23}: the strengh of the electric field, S: interception area, ρ: sea water electric resistance rate, α_{12}, α_{23}: barrier form coefficient by electrode construction, DF: Duty Factor by power reduction measure.

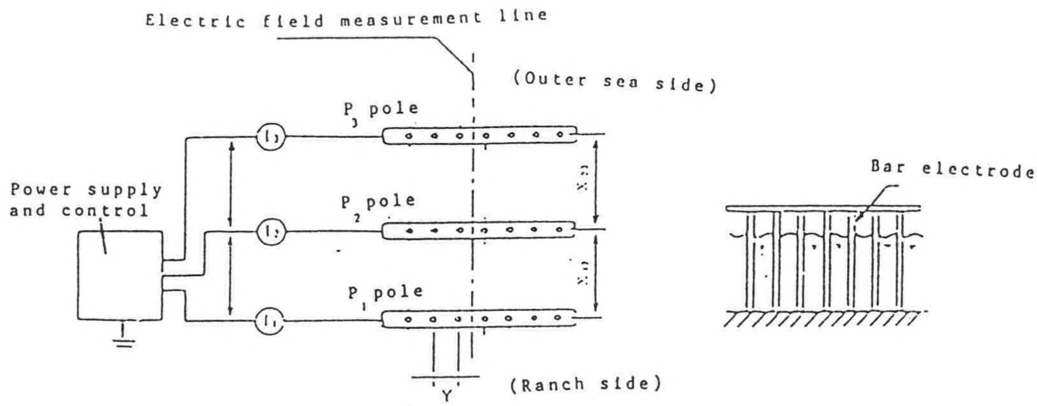

Fig. 4 "3 pole-2 potential method" electrical screen basic structure

4. 3 The interception performance by a small scale marine ranching system

Fig. 5 is complete view picture of a small scale marine ranch constructed for trial inside a big water tank (28x7m). The electrical screen is the 3 poles potential system with 2 electric field areas of the area of able to evade and the weak paralysis area. The width of the area of able to evade on the ranch side X_{12} is as 1m for the relation between swimming speed of an objective fry (a red sea bream) and electric shock character, and the paralysis area X_{23} arranged on outersea side is set as 0.5m. Total length of screen is 20m and presents track form, and the ranch area is 60m² scale. Also, a trial screen equips with a function of formation barrier feedback and controlling power supply automatically and a program control function of continuous barrier pattern. Besides, a barrier formation function linkaged to a fish finding signal.

Fig. 6 shows the result of calculating the fish numbers rush in the screen after liberating 10cm lengh class red sea breams inside the trial ranch and researching the change of the number of the fish paralysed in the paralysis area in the passed time. The reason why the paralysed fishes are concentrated in the first stage of liberation is considered as by the change of environment such as feeling free and surprising when released to a large area suddenly. But, in several hours after liberation, fishes tend to become in a school gradually and migrate in keeping a fixed distance without invading to the screen. Fig. 7 shows its situation. It is imagined that this migratioin results in the study the existance of screen by the experience in the first stage of liberation.

Fig. 8 shows the research of interceptive character by discontinuous barrier with noticing learning ability of the fish. As the barrier formation pattern, performing series of barrier for the first 3 hours of liberation as a learning term, after entering migration condition, starting by 5 seconds ON-2 seconds OFF, finally as a discontinuous barrier of 5 seconds ON-10 seconds OFF. As its result, a school of fish entering the migration condition rarely rushed into the screen. Further, checking up the time from release of barrier in the migration condition to invasion to the screen was 3 minutes.

Fig. 5 a trial small scale ranch(inside the big water tank)

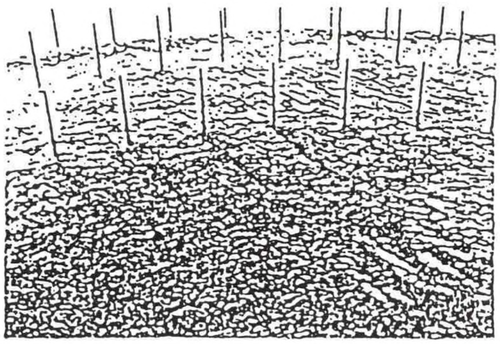

Fig. 7 a school of fish migrating along the screen

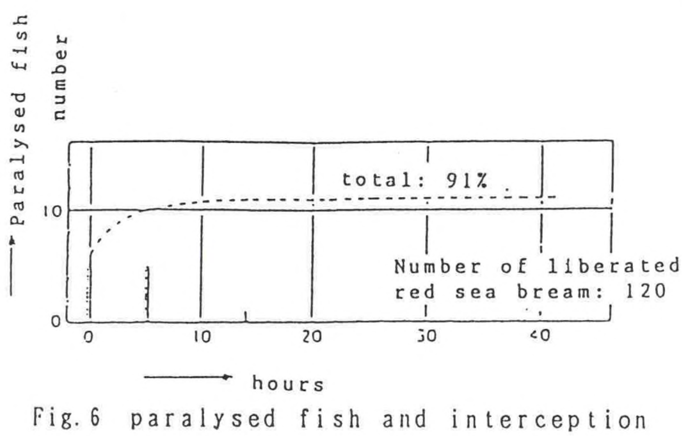

Fig. 6 paralysed fish and interception performance in the first stage of liberation

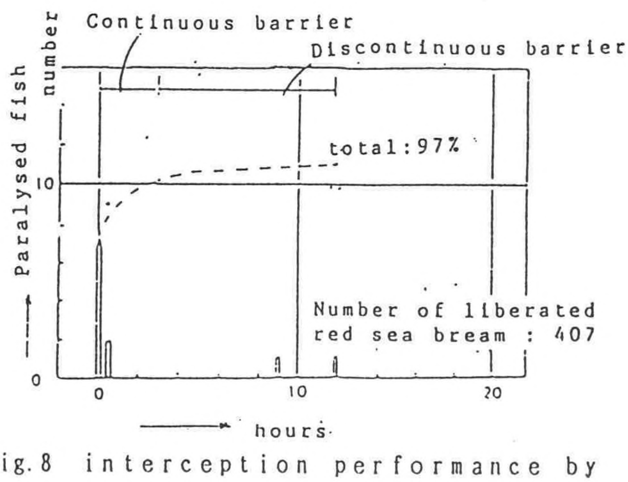

Fig. 8 interception performance by discontinuous barrier

5. The demonstration experiment of the electrical screen system in the actual area

5.1 The characteristics of the system

As it is prooved that by the basic experiment mentioned in then former chapter, by control the strength of the electric barrier irrelative the sort or the size of the fish allows to intercept the behaviour, so confirmed the performance in the actual sea area. And as the character of this system, the followings were considered.

(1)Intercepting the bay entrance by the electrical screen by which changes inside into huge "natural crawl" and allows to breed various kinds of fishes.

(2)Conventionally, using the net to intercept the sea, but the sea weed and the shell fish adhere and grow up and stuff the net which causes the difficulty with sea water get through, but, as the electrical screen is formless barrier, so it does not prevent the sea water exchange.

(3)As sea water goes in and out freely inside "natural crawl" which allows to keep interior natural environment in the good condition. By this, not only secure the good nursery environment for the fish, but also it is very useful for nursery of the plankton and the benthos.

(4)As the fish swims freely taking the natural bait inside the bay, which allows to be possible to breed equal to the natural fish.

(5)In the case of intermediate breeding the fish seed, it becomes wild, as the result, allows to produce artificial seeds in healthy.

5.2 The purpose of the experiments

To confirm the character mentioned above, also to try system and proceed technical method research-development and extract the improvement point as a main purpose, we decided to raise the following purpose and proceed.

(1)confirmation of the interception performance of the fish behaviour

(2)establishment of a mass breeding method of the fish inside the bay, especially effective breeding method

(3)sea water exchangibility and observation of environment from the point of fisheries

(4)observation of the fish life and behaviour habit inside the bay

(5)evaluation of the fry as a healthy seed

(6)finace and workability relating with construction of system support and management

5.3 The demonstration plant

Experiment was taken place in Tsunagi-cho of Kumamoto prefecture (Fig. 9). The layout of the demonstration plant is shown in Fig. 10.

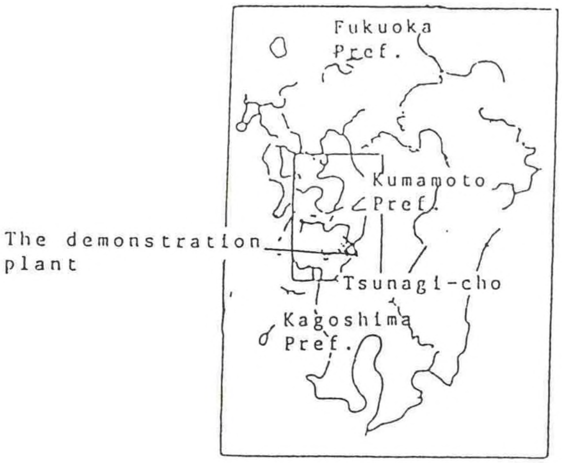

Fig. 9 The place of experiment

Fig. 10 The demonstration plant layout

The demonstration plant is constructed as follows and the explanation is added to main points.

- interception line
  - electrical screen part
  - sectional net (fish net)
- power supply device
  - control power supply device
  - submarine power line
- control and monitoring room
  - operation of the electrical screen
  - environment monitoring
    - · monitoring the fish behaviour (under water TV). (collection of each kind data)
    - · electrode applied voltage, current, electric intensity
    - · tide level, wave height
- protection device
  - on the sea ····· protection net
  - on the land ····· off limits fence

5.3.1 The interception line

Setting 6m width electrical screen unit on the total 3 places of the center and right and left of 130m interception line by separating by 30m, and closing except this place, with fishing net (Fig. 11)

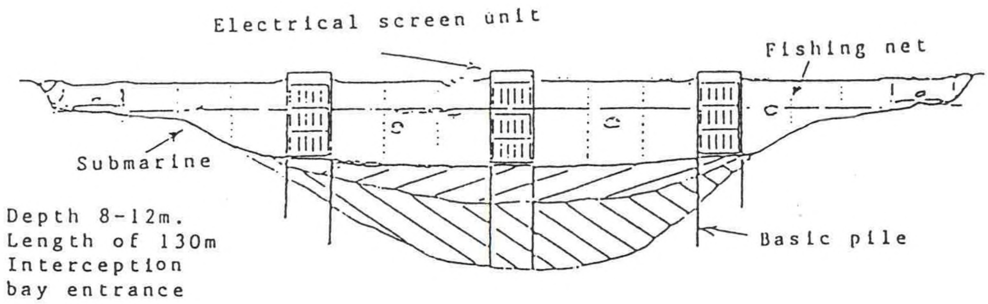

Fig. 11 the structure of interception line

To form the whole interception line with the electrical screen is not a good measure from the financial point and as submarine landform near the coast is complicated and shallow. Also, the electrical screen part, as Fig. 12 shows, is made in unit, and manufactured in the factory and carried to the spot and fitted to the pile striked in the submarine which allows the construction easily.

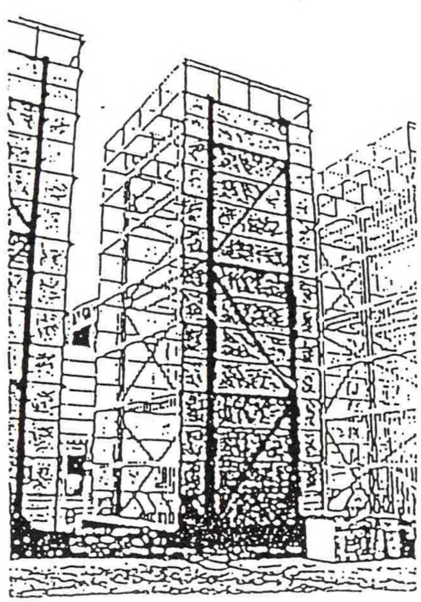

Fig. 12 The electrical screen unit

5.3.2 The electrical screen part

In the basic experiment, interception succeeded by using the 3 pole-2 potential form electrical screen cofining the electric field, was mentioned above. By this method, as barrier strength on the stage is formed, which causes to give a sudden shock to the fish and as by arranging the poles in right angle with flow direction which becomes the obstruction in the running passage and is damaged by such driftwoods. Therefore in the experiment in the actual sea area, applied the parallel form screen arranging the poles line in the flow direction(Fig. 13).

This method applys voltage(Vp) making each electrode as alternate polarity. As this method is the leak electric field form as Fig. 14, 15, barrier strength shows mountain form distribution in the flow direction with the pole center part as a peak, which does not give a sudden shock to the fish. Also, as the pole is arranged in parallel with the flow direction which has a character of less obstruction against taken water.

The structure of electrode unit

- the distance between elecrodes ········· 1m
- the width of electrode ················· 0.6m
- the electrode pole pitch ··············· 0.12m
- the height of electrode ················ 11.5m
- the number of electrode ················ 6 poles
- the setting number of electrode unit ··· 3 places
- the electrode material ················· copper tube

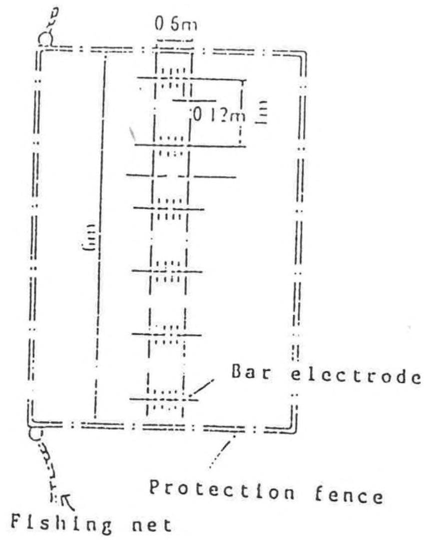

Fig. 13 arrangement of the electrodes

Setting the protection fence near the electrodes for safe as people cannot stop by. In Fig.14, electric intensity decreases enough inside the protection fence, on outside, it never harm people.

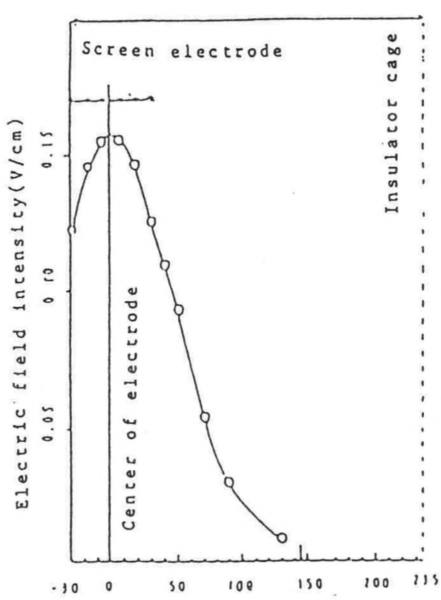

Fig.14 electric intensity distribution at the center part between electrodes

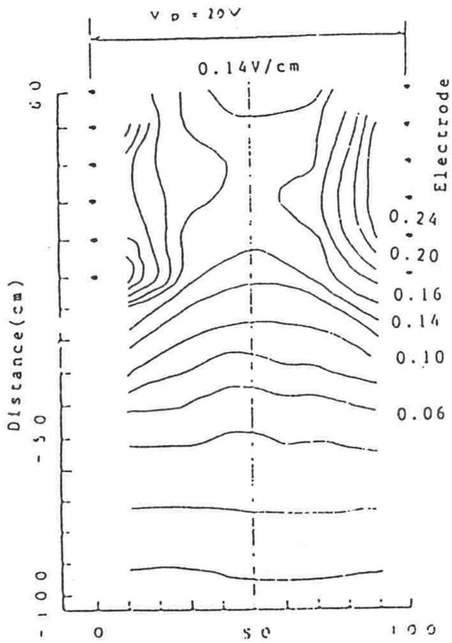

Fig.15 electric intensity distribution in the horizontal direction

While, between the electrodes, over 0.11 V/cm electric intensity area exists, by the result of basic experiment, the red sea bream fry over 4cm cannot get through this area.

5.4 The contents and the result of experiments

As mentioned above, Kumamoto prefecture has an intention to utilize this system in intermediate breeding of red sea bream seed. Then, in August 1990, 150 thousand 4cm red sea bream fries were liberated, in July 1991, 500 thousand as same red sea bream were liberated to the experiment plant, and continued the experiment refering to the purpose. The outline of the result is introduced as follows.

5.4.1 The behaviour of a school of red sea bream in the bay and interception performance

Immediately after liberation, by the observation with the under-water camera, a big volume of red sea bream crowded to interception line and near the electrodes. Especially in the day time, when the tide flew into the ranch, the highest density school was recognized. But, after 1 week, in this area, the red sea breams were seen less even in the daytime, and none was seen in the night time. This is because they moved from middle level to bottom level in the bay. After that, the red sea breams formed 3 groups and lived in the bay.

One of the groups lived near net cage with feeding machine set in the center of the bay, the second one lived in the coast, the other lived near the inerception line, but the biggest numbers distributed near net cage.

By the observation through the under water camera fitted near the electrode of the electrical screen, in the case of the red sea bream invaded into the electric field area, the situation of turn back was observed, the interception effect of the electrical screen was confirmed.

5.4.2 Replacement of sea water and monitoring of the water quality environment

We investigated the condition of tide current and replacement of sea water inside the bay with tidal current measure, electromagnetic current measure, sea water replacement simulation program.

When dividing whole interception line in the bay decreased about 60%, but by setting 3 gates of electrical screen which allowed to prevent by about 20% decrease.

Also, sea water flow to the bay was 16% at barrier part in the condition of open bay without setting section net, but when setting net, increased to 44% which prooved the effect as the gate by determination.

While, as a result of calculation by in putting flow measuring data in sea water replacement simulation program, in the case of dividing the bay entrance with the net, when the net is stuffed, the sea water replacement function decreased remarkably, but when setting the opening part with the electrical screen, even in the case of whole net was stuffed, the condition of sea water replacement was the same as the opening bay after some time has passed, was conducted. Also, we must notice how the water quality in the bay changes by setting the structure at the bay entrance, operating electrical screen, besides liberating large volume of the red sea bream fries. Therefore, we analyzed ①temperature of water, ②concentration of salt, ③concentration of hydrogen ion, ④residual chroline, ⑤dissolved oxygen, ⑥dissolved oxygen saturation, ⑦chemicaly oxygen requirement, ⑧total nitrogen, ⑨total phosphorus, ⑩transparency, ⑪suspension, ⑫settling particle, ⑬bottom sediment, etc., but special change was not seen during the experiment.

5.4.3 Health of the seed

In the case of liberating the seed produced artificaially, it becomes the subject that first of all how many can survive and grow, also, the speed of growth. That is, the quality of the seed is called health of the seed or character of the seed, but the measuring method has not been established yet.

In this experiment, refering to the evaluation of the character of the seed at Japan Sea Farming Association Hyakushima experiment, ①aerial exposing test, ②paralysis test, ③low oxygen test, ④the fish behaviour at the time of liberation were researched.

In this result, we could not find conspicuous difference between the red sea bream liberated in the bay and the red sea bream breeded in the small net cage. The possible reason for this, the red sea bream breeded in the small net cage had been feeded sufficiently, so they grew well, on the contrary, liberated fish in the bay had not been feeded sufficiently, so they grew poorly, which prevented the moderate comparison. Hereafter, we need to compare after take consideration into the growth of the fry by both methods.

5.5 Conclusion

By this time experiment, as for the research from the technical aspect of facility, especially behaviour interception performance of the red sea bream by the electrical screen was confirmed, simultaneously improve-items were fixed and also obtained good results.

Hereafter, the subjects to research the effective feeding method in the bay, to establilsh the evaluation method of health of the seed, and to perform the inspection, are left.

MARINE MINING: STATUS AND FUTURE POTENTIAL

A Presentation to the
18th Meeting of the UJNR Marine Facilities Panel
Washington, D.C.

by

John W. Padan

Chairman, UJNR Marine Mining Panel

This brief report represents the situation as I see it, from the point of view of the UJNR Mining Panel. How nice it is to be asked to address the joint meeting of a sister panel. If this trend continues, we'll be accused of coordinating! But, trends seldom continue...a theme to which we shall return before I close.

The Mining Panel has historically been composed of Federal employees whose agencies have involvement in some aspect of marine mining. This can range from the conduct of in house research, in the case of the Bureau of Mines, to regulatory authority, in the case of the National Oceanic and Atmospheric Administration (NOAA) as well as the Minerals Management Service (MMS). From time to time, we also have included advisors from universities and observers from private firms.

Our charter has been to define clearly our agencies' interests in marine mining and then make sure that we work with our Japanese counter-parts to learn what they are doing in those areas of investigation. Our counter-parts have been extremely cooperative with us in this quest, often developing inter-agency relationships among themselves that otherwise would not have evolved.

During the 20-something years the Mining Panel has been in existence, joint activities have taken three forms: cooperative research; exchanges of personnel; and, joint meetings such as the one you are conducting this week. Our most important cooperative research has focused on environmental concerns, as seems fitting for government-funded research. For example, the NOAA's New England Offshore Mining Study (NOMES) Project in Massachusetts Bay identified the discharge plume issuing from a hydraulic dredge as the most serious concern associated with marine sand and gravel mining. Through the UJNR Program we learned that the Japanese had developed an Anti-Turbidity Overflow System to reduce the magnitude of the surface plume from channel dredgers. Unable to test the system in the United States, due to Jones Bill constraints, we worked out an inter-agency test in Japan. The results were published in 1989. Should the Minerals Management Service ever have to consider mitigation measures for a sand and gravel operation on the Outer Continental Shelf, data will be there for industry and government to share.

In a similar vein, both countries recognized that the discharge plumes associated with future commercial manganese nodule mining operations were cause for concern, even though the concerns were fairly well examined during the NOAA'S Deep Ocean Mining Environmental Study (DOMES) Project. Through the UJNR Program, Japan's Metal Mining Agency, acting on behalf of the Ministry of International Trade and Industry, has been working with NOAA since 1990 on a joint project. Basically, Japan is concentrating on the upper water column and NOAA the effects of the benthic plume. Recently Japanese cooperation and funding have been extended to an examination of potential benthic effects in the Japanese license site in the Western portion of the North Pacific "nodule belt." The findings will augment what is being learned about benthic effects at the United States Preservational Reference Area in the Eastern portion of the belt.

Exchanges of personnel have been a one way street. Four Japanese researchers have been in the United States for one year tours of duty at Federal and university facilities. We have not yet been able to accept the repeated offers of the Japanese Panel to place U.S. researchers in the marvelous facilities in Tsukuba, Japan's "Science City."

Finally, we too have had our meetings, although we tend to view them as a means to an end...cooperative investigations being our goal. Joint Panel meeting #1 was held in Japan in 1970. Meeting #14 was conducted in June of this year in the United States.

There have been many changes in the status of marine mining during this period. I won't recap them now. Anyone who wishes to can refer to numerous papers on the subject, including two "history" type papers I prepared for the Center for Oceans Law and Policy and the Underwater Mining Institute which were published in 1988 and 1989, respectively.

Because of these changes, during the recent joint panel meeting we agreed to take a hard look at where we are going. Commercial marine mining of most commodities of mutual interest looks ever further in the future, except for sand and gravel mining. Although that is a vast industry in Japan, in general the United States is finding it environmentally acceptable to recover seafloor sand only for beach replenishment. The notion of "mining" will not sell in most coastal areas. Over the short-term, I am trying to arrange for the Marine Minerals Technology Centers (MMTCs) at the Universities of Hawaii and Mississippi to become involved with Japanese research through the exchange program.

What is the future for marine mining? As recently as 20 years ago we used to worry about demands for minerals outpacing the ability to produce. The pressures to keep up with demand were supposed to become exponential as world population increased at the same time standards of living improved. Technology was supposed to be one key to keeping up, so research and development were well funded.

Well, world population is increasing as predicted but the world is having trouble paying for the items needed even to maintain its standard of living, let alone increase it. Demand is flat and production, which was "king" in the '50s, now is taken for granted. Environmental fears cause government regulators at all levels to be extremely cautious with regard to marine sources of minerals in the absence of market demands forcing them to be otherwise.

Will this trend continue? Probably not. Someday, the world will need to turn to the current "resources for the future" such as manganese nodules. Until then, it behooves the national governments of the world to continue to fund, even modestly, research aimed at the eventual utilization of these resources.

In the United States, the continued funding of the MMTCs would be the most logical method of accomplishing this. Access to the manganese nodules for U.S. industry can be assured if NOAA will continue to cooperate with the U.S. Deep Seabed Mining consortia by helping to keep their licenses active.

In closing, let me just state that the Mining Panel recommends that the United States Government continue to develop legal mechanisms so that when certain marine mineral resources are needed the private sector will be able to obtain rights needed for development. We should continue to work with developing countries and the newly emerging democracies to encourage them to operate in a market economy. We should continue to address environmental, socio-economic, and safety issues and share the information globally so that when production once again is demanded it can be accomplished with predictable effects.

Acoustic Core Technology
A Major Promise for Ocean Mineral Exploration

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Introduction

Research conducted in the early 1970s led to the development of a procedure, whereby surface sediments could be classified by the relationship between the acoustic impedance and the geotechnical properties of the sediments. Caulfield Engineering's Acoustic Core System has extended the above techniques to the identification of these subbottom sediment layers. The system concept is highly flexible, making applications to marine surveys for seafloor dredging, marine mineral prospecting, and buried object detection highly attractive and cost effective.

Due to its major interests in improving the efficiency and reducing costs associated with dredging operations, the U.S. Army Corps of Engineers (USACE) has conducted detailed testing of the Acoustic Core Technology. In order to verify the accuracy of the Technology's ability to identify subbottom materials, the USACE made direct comparisons of acoustic predictions with physical seafloor core data. These "ground truthing" exercises were conducted in the Gulfport Ship Channel, Mississippi, and in the Mobile Ship Channel, Alabama. The results showed that the acoustic predictions were accurate to within 1 percent. The impressive success of these tests has resulted in continuing development funding being provided by USACE to Caulfield Engineering, for purposes of further improvements in efficiency and extension of this exciting technology.

The following information will summarize the existing technology, and outline both near-term applications of the Acoustic Core System and future additional developments.

Summary - Acoustic Core Technology

There currently is very little existing technology within Industry for post-acquisition processing of shallow marine seismic data. Black and white hard copy data are usually produced on-site, and used to interpret the acoustic results. The data is rarely digitized or transformed into the frequency domain for spectrum analysis, and no attempt is made to directly relate acoustic reflections from a layer to the specific type of sediment involved. In addition, geophysical coring operations, utilized as an alternative, are highly costly. Many operations do not utilize acoustic methods at all, and provide spotty data of varying quality.

Figure 1 illustrates a typical shallow seismic reflection system with the reflected echoes returning from an ideal layered subbottom structure. The depth of pene-tration is usually dependent on the frequency and source power. Lower frequency sources penetrate deeper, and higher frequency sources provide for better resolution. The Figure shows that the reflections occur when the layers have changes in acoustic impedance. The right portion of the figure illustrates the stratigraphy as would be normally determined by a geophysical core.

As summarized in Figure 2, the Acoustic Core System uses digital acquisition technology and seismic software to maximize the information available from traditional acoustic data. The system estimates the density versus depth of marine sediments via a mathematical model and statistical processing of shallow subbottom seismic data of good signal to noise quality. Information available from standard acoustic devices, such as subbottom profilers and hydrographic survey equipment, have been greatly improved and are related directly to the geophysical properties of the sediment.

This empirical technique effectively treats all the subbottom layers as if they were the topmost reflective layer until the signal to noise ratio is approximately 5 decibels. The Caulfield model compensates for absorption losses in each layer as a function of frequency and utilizes classical multi-layer reflective mathematics to compute equivalent reflection coefficients of the sediments as if they were surface layers, thereby classifying the lithostratigraphy (Hamilton, 1972; Caulfield, et al, 1984).

Figure 3 is shown to illustrate a hypothetical echo sounding or seismic pulse impinging on the bottom and subbottom. It shows that the pulse has a finite time width (t) and will have different return amplitudes based on the acoustic impedance (z) and the absorption ( ) of each layer. It is this information that is fed into the computational algorithm to generate the expected density plots. Note that, because the bottom echo has a finite length, some averaging of the bottom layers occurs. This averaging increases as the frequency is lowered.

Quality core data is important for calibrating the acoustic impedance prediction system to insure that all equipment is properly working. For most projects, it is highly recommended that selected standard marine sediment model cores be taken from the actual surveyed area, and the geophysical data from these cores be used to calculate the calibration constants.

The steps of the system in practice are illustrated in Figure 4. It can be seen that there are three major calibration factors. These are; the source level (total energy incident on the bottom); the absorption terms; and the relationship between impedance and velocity for that region. The first two terms are utilized in computing the most accurate estimate of the impedance. The last terms are used in relating the impedance to density. The Acoustic Core program allows for inputting local variations in these relationships based on local core data.

The Acoustic Core System can also be described as having three major components, as described in Figure 5. These components consist of the initial system calibration for quality control, a proven mathematical model that estimates sediment density and impedance versus depth, and an extensive geophysical data base which supports the mathematical model by determining the density and material type from empirical tables. Color video and color hard copy playback options are available for analysis at each step in the process.

The complete survey system, incorporating the Caulfield Acoustic Processing System, is shown in Figure 6, as utilized by the U.S. Army Corps of Engineers. The technical specifications and hardware definition of all major system elements are presented in the accompanying Table shown in Figure 6. Modifications to these specifications and hardware are feasible. However, the potential impact of such changes on the operational system output, needs to be determined for the specific survey application.

Application to Beach Sand Exploration

The State of Hawaii had expressed great concern over deterioration of the tourist beaches at Waikiki, which have become seriously depleted of sand. The options for acquisition, transportation and placement of sand on the beaches were examined by the Marine Minerals Technology Center (MMTC), with respect to feasibility and cost. Acoustic surveys to date have experienced major difficulty in distinguishing between acceptable offshore calcarous sand deposits and those which have become chemically solidified on the sea floor, making continuation of the current survey approach non-viable. It appeared to MDA that the use of the Caulfield acoustic coring technology could resolve this problem.

A brief feasibility study of this possibility was conducted in 1992 by Marine Development Associates and Caulfield Engineering, for the Marine Minerals Technology Center. The purpose of the program was to conduct initial calibration, modelling, and analysis of both sandy and calcified sand deposits acoustic data, to examine their impedance characteristics relative to standard marine sediments, and determine the feasibility of distinguishing between them with the basic Caulfield Acoustic Core System.

Based on this model study, it was clear that acoustic technology, such as the Caulfield Engineering Acoustic Core System, can be used to positively identify the desired carbonate sands that can be dredged for use for beach refurbishment. Further, it has been shown that in order to properly do this, that the CE Digital Field Acquisition System must be used in order to properly calibrate the survey system. With this calibration, even the present survey techniques can be markedly improved.

Marine Applications

The proven Acoustic Core Technology can provide shallow marine seismic survey data for utilization in the immediate applications shown in Figure 7. Addi-tional detail and value of the above applications can be summarized as follows:

- Harbor Dredging

The acoustic impedance of bottom and subbottom materials is directly related to the material type and its density, which in turn are factors related to the degree of difficulty and the contract cost of seafloor dredging operations. By incorporating the virtually continuous coverage of the subbottom materials with digital terrain modeling techniques, rapid and accurate computations can be made of the volume and material-type to be removed by dredging. By obtaining such data prior to approval of dredging contracts, quality control and significant cost reductions can be obtained in the subsequent required dredging operations. Complete and detailed 3-dimensional descriptions of material to be removed can be obtained, with the specific materials defined in color. Special cuts, through the deposit can be made at any angle, and the view rotated at will. In addition, a detailed data base will be established for project monitoring and long-term planning of future requirements associated with the safety of major ship operations.

- <u>Bathymetric Survey and Mapping</u>

The use of the Acoustic Core's Digital Field Acquisition System allows legal quality monitoring during bathymetric surveys. Improved signal-to-noise quality improves overall interpretability of the data and reveals subtle geologic features and bottom characteristics that may be significant to living resource habitats (fishing Industry). When bathymetric systems are supplemented with lower frequency sound sources, monitoring of changes in sediment distribution and type of material deposited, due to seawater currents, will provide valuable long-term planning information regarding future dredging needs and requirements. The addition of lower frequency sound sources also permits definition of the thickness of below-sediment hard layers, as required for the foundations of structures to be mounted on the seafloor.

- <u>Detection and Mapping of Buried Pipelines or Mines</u>

Due to the significant differences in the acoustic characteristics, density, and other physical properties of man-made objects, from that of seafloor sediments, the detection and precise location of subbottom pipelines or undesirable and hazardous materials, such as buried mines, can be clearly identified for subsequent repair, modification, removal or destruction. Periodic surveys of harbors and coastal shallow waters, utilizing Acoustic Core Technology, can provide the information necessary to ensure safety of vessel mooring and shipping traffic. The same value is provided for location of non-explosive sunken obstructions and wreckage.

- <u>Location of Shallow Gas Deposits</u>

The Acoustic Core Technology provides critical data for acoustic frequency versus depth below bottom analysis. This capability enables the absorption characteristics of the subbottom sediments to be revealed, aiding in the identification of unique material types. Shallow gas deposits have a characteristically high absorption pattern, permitting definition of commercially-viable deposits, or identification of small deposits that would be troublesome to subsea construction foundations.

- <u>Exploration for Construction Mineral Deposits</u>

Seafloor sand and gravel deposits, for use in onshore construction projects, is a direct and immediate application of the Acoustic Core System. Survey operations to locate such deposits in near-project shallow waters can significantly reduce the cost of shipping such high volume materials, as well as to facilitate sand replenishment on recreational beaches.

Future Marine Applications

Additional marine applications that are achievable, following such development activity, can be summarized as follows:

- Detailed Three-Dimensional Mapping of Seafloor Mineral Resources

The output of the Acoustic Core System can be interfaced with AutoCad hardware, or other computerized plotting systems, to produce full color, three-dimensional maps of both shallow water and deep-ocean mineral deposits. Definition of the unique seafloor structures associated with massive polymetalic sulfide deposits, or high-value placer minerals is a relatively near-term application of great interest.

- Seafloor Pollution and Environmental Surveys

Using an ensemble of techniques, contaminated and disturbed sediments can be analyzed and detected. This application is very near realization. Such surveys can provide vital data for restoration of near-shore living resource habitats and harbor clean-up of such contaminated sediments.

- Deep Seismic Definition of Subbottom Materials

With adaptation to down-hole acoustic source and receiver equipment, cross-hole topographic studies can be conducted for resource exploration. The approach is appli-cable to both subsea and to onshore resource development, and has been proven by actual tests in the field.

The Acoustic Core Technology is by no means limited to marine applications, although the system hardware for onshore utilization is only in the development stage. A few of such promising applications can be listed as follows:

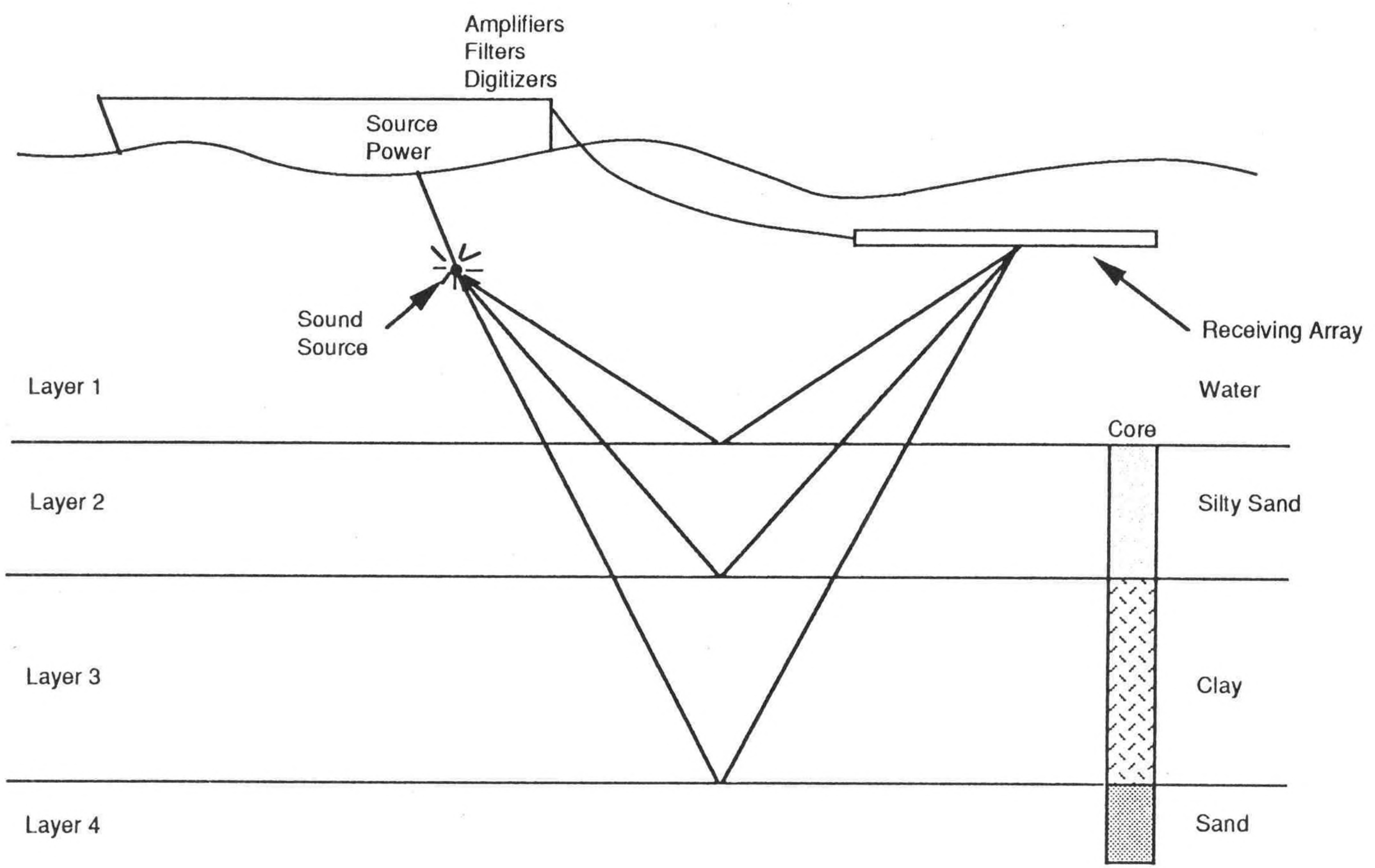
- Detection and Mapping of Underground Water Tables

Definition of both shallow and deep fresh water tables can provide important sources of emergency fresh water supplies, in areas of low fresh water availability, and at significantly lower costs than drilling of test wells.

- Detection of Faults and Fracture Zones

In areas of geological instability, due to seafloor spreading or other volcanic phe-nomena, the detection and mapping of existing fault and fracture zones can be of significant priority to present and future economic development.

Figure 1
Shallow Seismic Reflection System



CAULFIELD ENGINEERING

TITLE			
JOB			SCALE
DWN			REV.
ENG			
DWG. NO.			

Figure 2

Acoustic Core Technology Summary

- Estimates Sediment Density vs. Depth.
  - Mathematical Model
  - Statistical Processing of Shallow Depth, Standard Seismic Digital Data.

- For Each Subbottom Layer, Model Estimates -
  - Reflectivity
  - Absorption
  - Acoustic Impedance Relative to Sea Water.

- Model Compensates for Absorption Losses as a Function of Frequency.

- Computes Equivalent Reflection Coefficients of Layer Sediments, as if a Surface Layer.

- Estimates Density from Empirical Tables.

- Empirical Tables are Calibrated from Local Geophysical Core Data.

- Sediment Materials Identified vs. Depth.

- 2-Dimensional or 3-Dimensional Displays

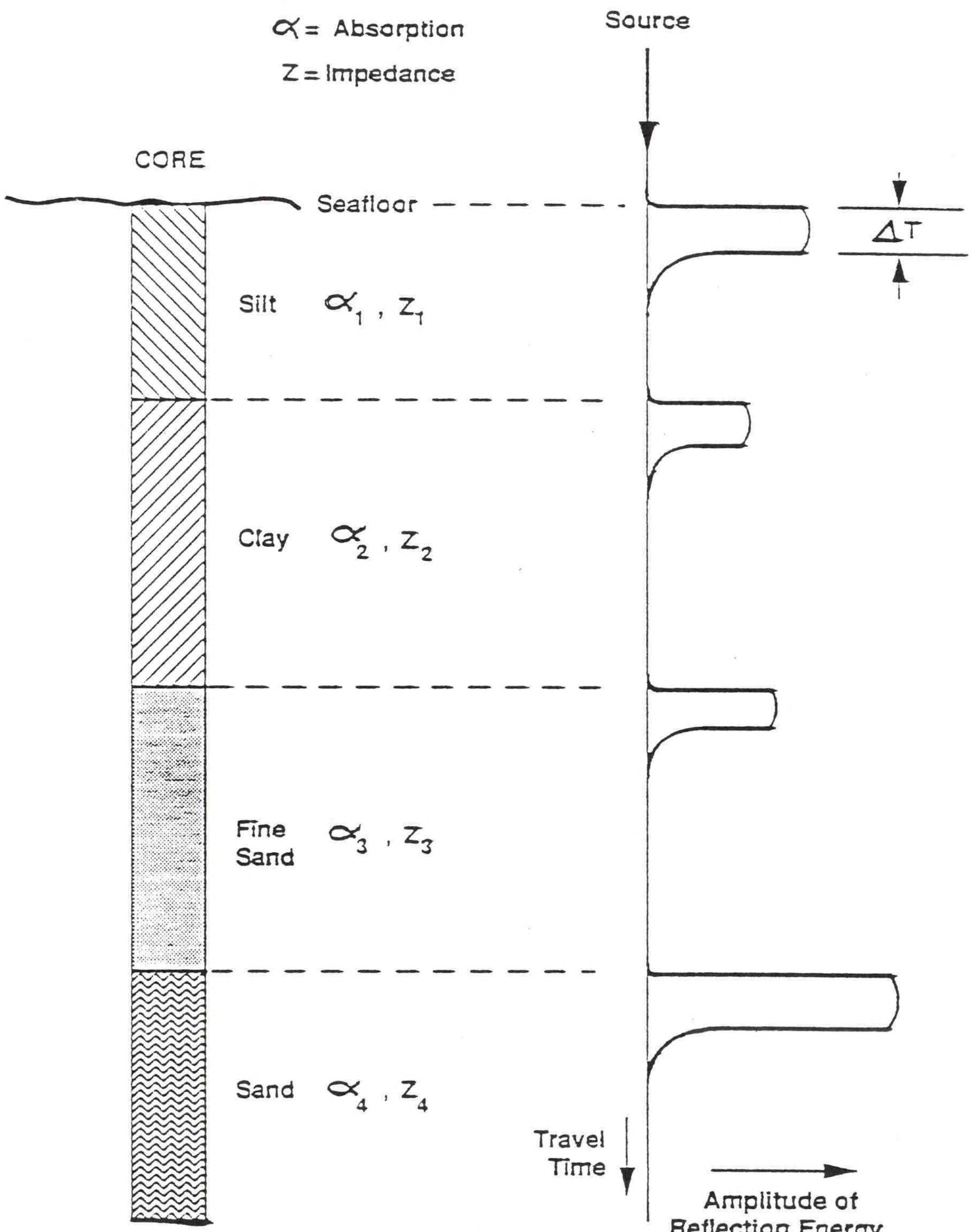


Figure 3

Simulated Reflection Energy Envelopes

Figure 4

Basic Caulfield Engineering Acoustic Core System

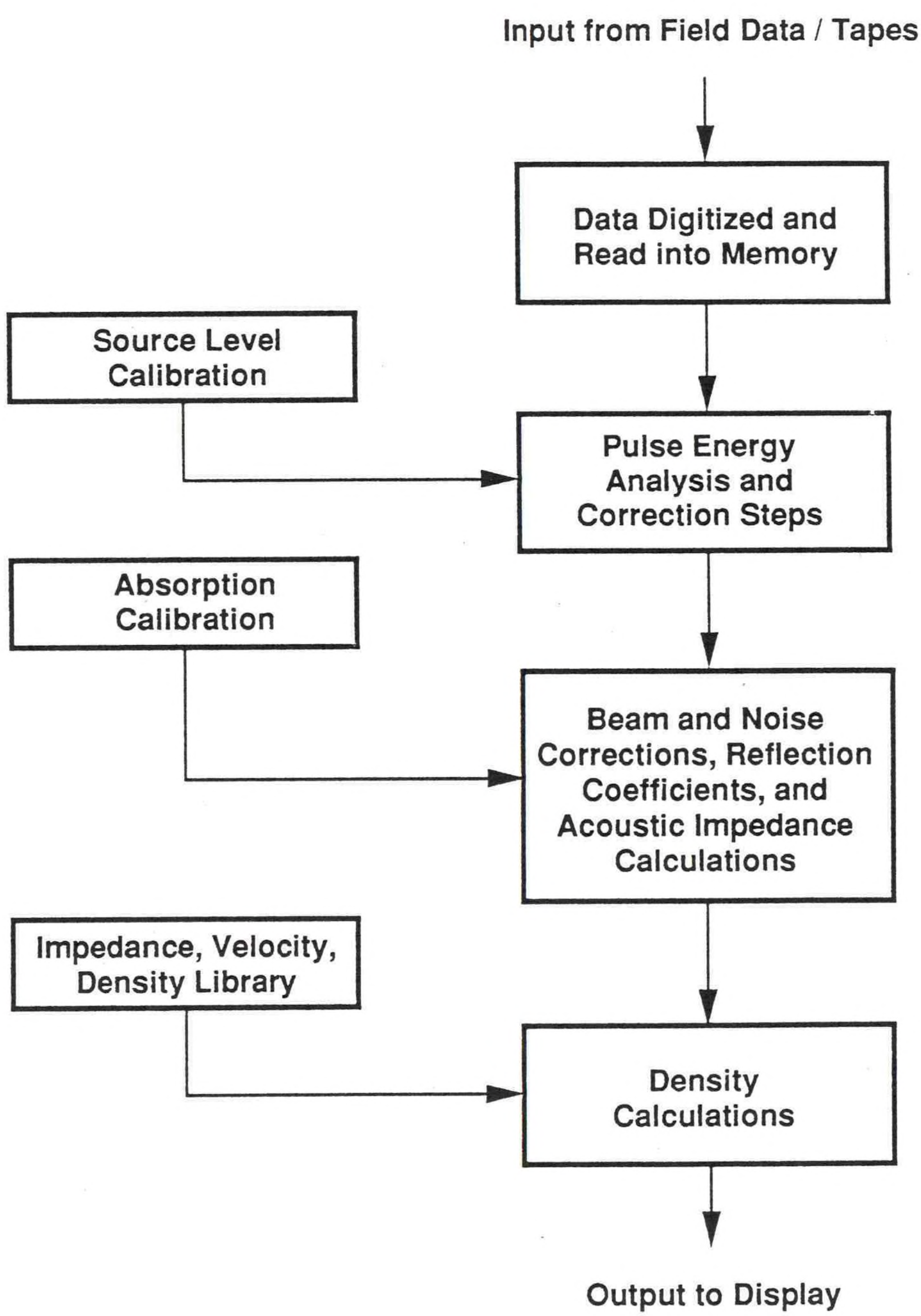


Figure 5

Acoustic Core System General Characteristics

- Mandatory Initial System Calibration / Quality Control

  - Amplifier Gain Levels -- Are the data clipped?
    Are the Gain Levels Set for Optimum Signal to Noise?
    System will not operate unless data are linear.
  - Optimum Frequency -- Are the filter settings correct?
  - Computer Calibration -- Timing, Tape speeds, Sampling rates.
  - Processing Parameters -- Input Data Correct?
    Step by Step Input Menus.

- Proven Mathematical Model

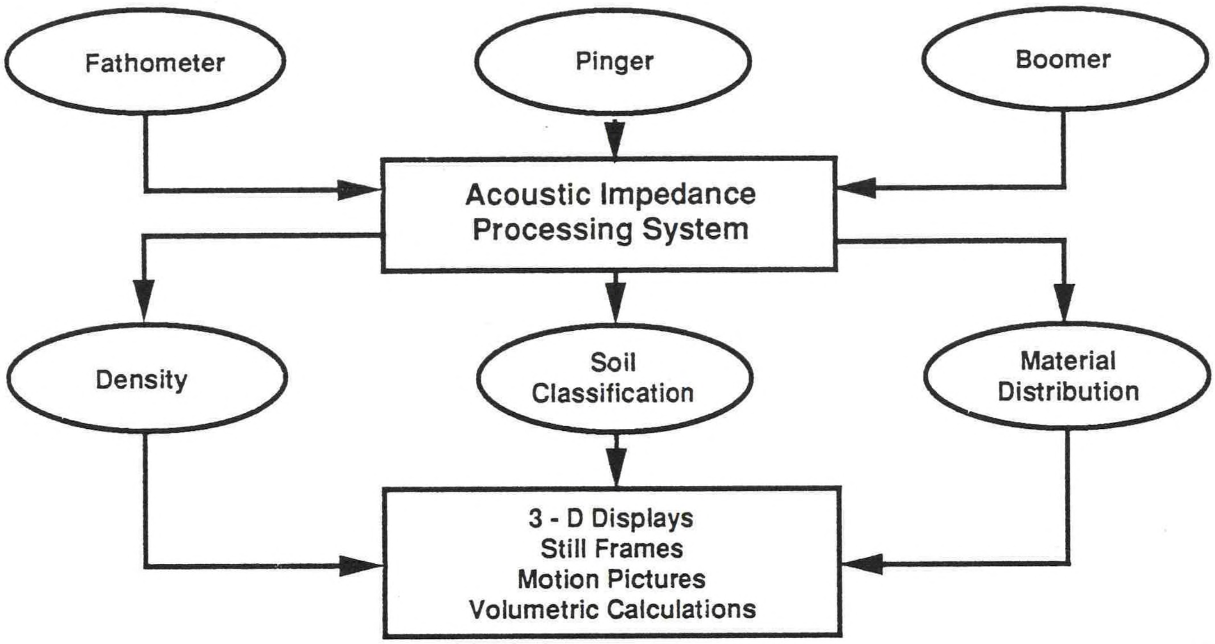
  - Estimates Sediment Density & Impedance vs. Depth
  - Computes Equivalent Reflection Coefficients of Layer Sediments, as if a Surface Layer.
  - Compensates for Absorption Losses as a Function of Frequency.
  - Sediment Materials Identified vs. Depth
  - Menu Driven for each Process Phase.
  - Color Video & Color Hard Copy Playback Options for Analysis at Each Step of the Process.
  - Acquisition Quality Controls Supplied -- Digital Field Acquisition System (DFAS).

- Extensive Geophysical Data Base

  - Estimates Density from Empirical Tables.
  - Permits Calibration of Tables with Local Core Data to Improve Accuracy of Density / Impedance Estimates.
  - Can Accommodate "Non-Standard" Marine Sediments.

Figure 6

Current USACE Survey System



1991 Technical Specifications
Hydrographic Acoustic Impedance Survey System

Make	Model	Item
Multi-Frequency Fathometer System		
SEA-TEX	HE-730	3 kw Precision Multi-Frequency w/Color Monitor
High-Resolution Pinger System		
EPC ORE ORE	3200 140 3.5 to 7.0 KhZ	Graphic Recorder 10 kw Transceiver Transducer Array
High-Resolution Boomer System		
EPC OSE EG&G EG&G OSE OSE	3200 245 231-A 232-A 241 240	Graphic Recorder Amplifier/Filter Trigger/Capacitor Power Supply Hydrophone Streamer Sound Source
Acoustic Impedance Processing System		
IBM-Compatible PC Hewlett-Packard Caulfield Engineering Caulfield Engineering Syquest	286/386 Paintjet CE-1B-100 AC45/DF12 SY555	Computer Color Plotter Interface Board Processing Software 44 MB Disk Drive

Figure 7

Acoustic Core Technology Applications

- Marine Applications - Current Technology
  - Harbor Dredging
  - Bathymetric Survey and Mapping
  - Shallow Seismic Definition of Subbottom Materials
  - Location of Shallow Gas Deposits
  - Exploration for Construction Mineral Deposits
  - Detection and Mapping of Buried Mines

- Marine Applications - With Development
  - Seafloor Pollution and Environmental Surveys
  - Detailed 3-Dimensional Mapping of Seafloor Minerals
  - Deep Seismic Definition of Subbottom Materials

- Non-Marine Applications - With Development
  - Underground Mine Detection
  - Detection & Mapping of Underground Water Tables
  - Detection of Faults & Fracture Zones
  - Illicit Materials Identification & Classification

LNG FPSO Unit applying Self-supporting Prismatic Tanks

Eiichi Isobe
(Ishikawajima-Harima Heavy Industries Co.,Ltd.)

1. Preface

A floating production, storage and off-loading unit (FPSO) utilizing a LNG tank of Self-supporting Prismatic-shape Type B (hereinafter, refer to as SPB) which satisfies Type B specified in the IMO code, was developed and designed. So, its explanation is given.

Self-supporting prismatic type tanks have been used for a long time, however, this type B system was developed relatively recently, and it was adopted in consideration of that its specific feature does well match FPSO of LNG.
Up to the present, various proposals have been made for using FPSO of LNG, because FPSO offers excellent economy for use in offshore natural gas fields, but it has yet to be applied in practice. Many crude oil FPSOs are operating in offshore oil fields and the superiority of this FPSO system has been confirmed, on the other hand, demand for LNG has been increasing recently as a low pollution fuel; FPSO is considered to be applicable in gas fields in the near future.

The FPSO described in this paper was planned to liquefy gas into LNG at sea areas of Southeast Asia, where offshore natural gas is obtained, and to load the LNG directly onto LNG carriers to send it to Japan, however, the system can be applied to other sea regions by changing the conditions.

2. Application of SPB Tank to FPSO

Outline description of FPSO and SPB tank:

2.1 FPSO in general(for crude oil or natural gas)

The FPSO unit is a base for gathering crude oil or natural gas taken out from excavated wells, processing it and stowing the products in a floating structure, and loading it onto a ship at the site.
Normally, a FPSO has production facility, storehouse and loading facility to process the crude oil or natural gas taken out from

wells in the condition required for deliver. In the conventional method without using FPSO, a long pipe-line is installed from the offshore oil or gas field to a land production facility constructed on near-by land, then the oil or gas product is transported to an off-loading berth, for loading on a tanker or LNG carrier. Therefore, FPSO has economical advantages in the case where the oil or gas field is far from land, or the quantity of the oil or gas in the field is small.

Total systems including FPSO consists of well group, a gathering unit, riser, mooring unit, FPSO and shuttle LNG carriers. (Refer to Fig. 1) In the case of FPSO for natural gas, a liquefaction plant and a cryogenic storage are necessary.

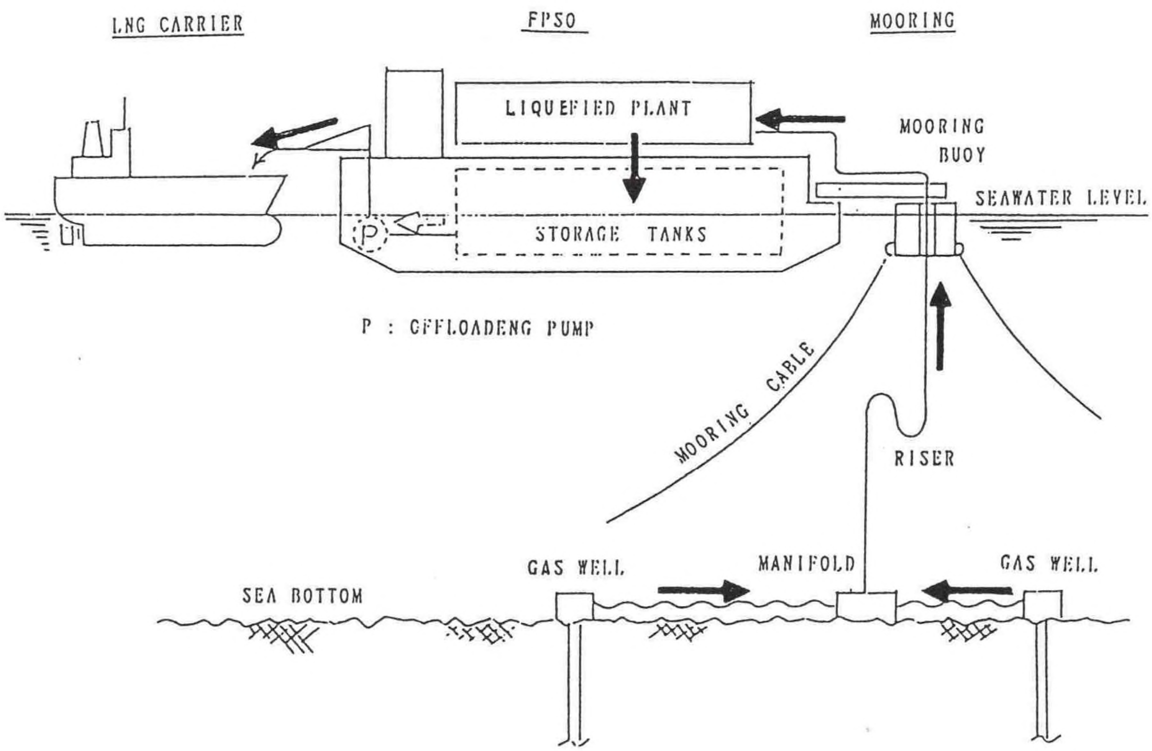


Fig.1 Outline of FPSO System

2.2 SPB Tank

LNG has a cryogenic temperature of -162. C, therefore, tanks to accommodate LNG shall be taken special countermeasure such as way for cold insulation, thermal contraction, supporting of tank weight, secondary barrier and the like. Various types of tank have been devised.

LNG tanks have been classified as tanks for LNG carriers or tanks for land use, however, application of land-use tanks for LNG FPSO is difficult at present due to technical reasons and applicable regulations. Therefore, in the following, a description is given about a tank to be used on a LNG carrier.

The following types are available for tanks of LNG carriers:

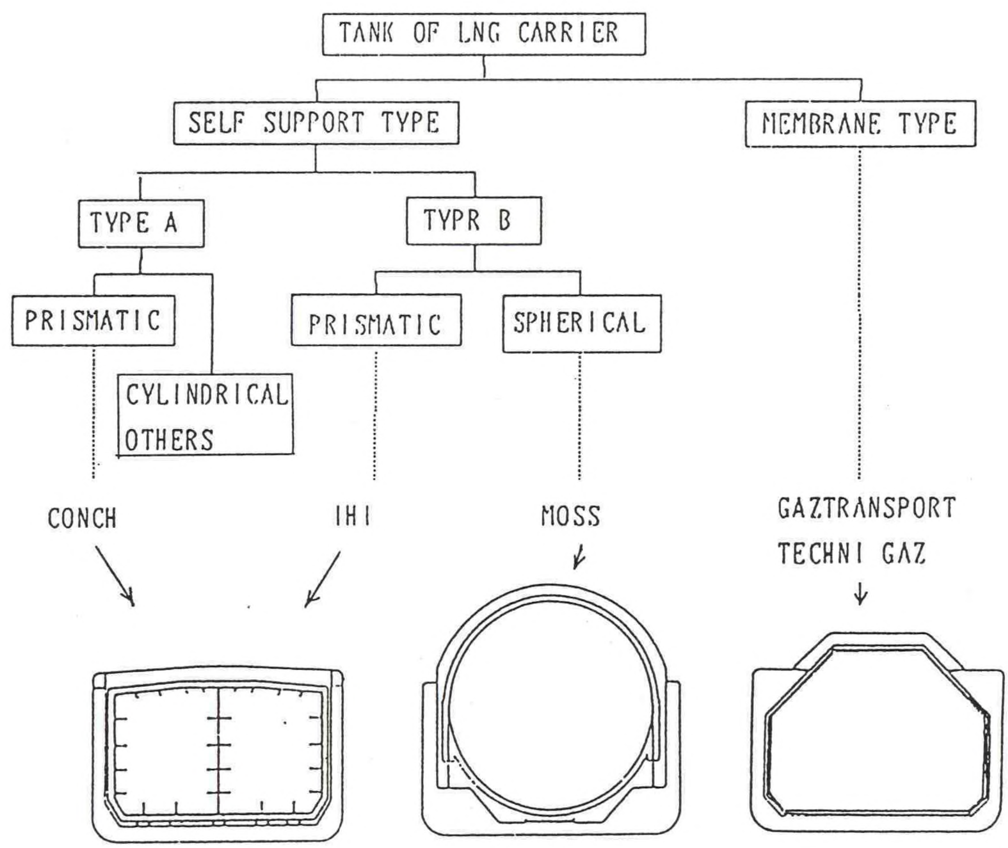


Fig. 2 Types of LNG Tank

Tanks may be roughly classified into membrane type and self-supporting type. The membrane type is only a thin layer made of corrugated thin plate or material having a very small heat contraction, and has no strength to maintain a form by itself, and the form is to be sustained with the strength of the hull structures through cold insulating materials.

On the other hand, the self-supporting type is sufficiently strong to maintain the form of the tank by itself, and is classified

by regulations into two types: A and B. Type B is subjected to a fatigue strength assessment to satisfy the IMO code, and it is confirmed that: (1) fatigue cracks does not initiate, (2) even if a crack occurs by some reasons, it would not grow larger to the point of penetration, (3) even if there be a leakage of LNG, it can be detected immediately before it reaches crucial failure. Such an analysis had been technically difficult, however, it is now possible due to advances in analytical technology using computers, and a complicate structure can be handled without any problems.
This analysis is not performed for type A, therefore, safety measures on the premise that LNG might leak are required.

Configurations of the tank are classified as spherical and prismatic. The spherical form receives internal load with the tension of the surface, therefore, it is simply structured with an outer skin only, however, the prismatic type receives a bending load at the corner part, and then stiffeners and webs for supporting the stress are necessary. Thus, the prismatic type requires many materials for the tank itself when compared with the spherical type. On the other hand, prismatic type has the advantage of allowing it to be formed in an arbitrary configuration, the tank support method is easier and cheaper, the tank itself is strong and can be formed easily as an anti-sloshing structure and so on, and evaluation may depend on what point priority is placed.

The structure of the SPB tank is shown in Fig. 3.

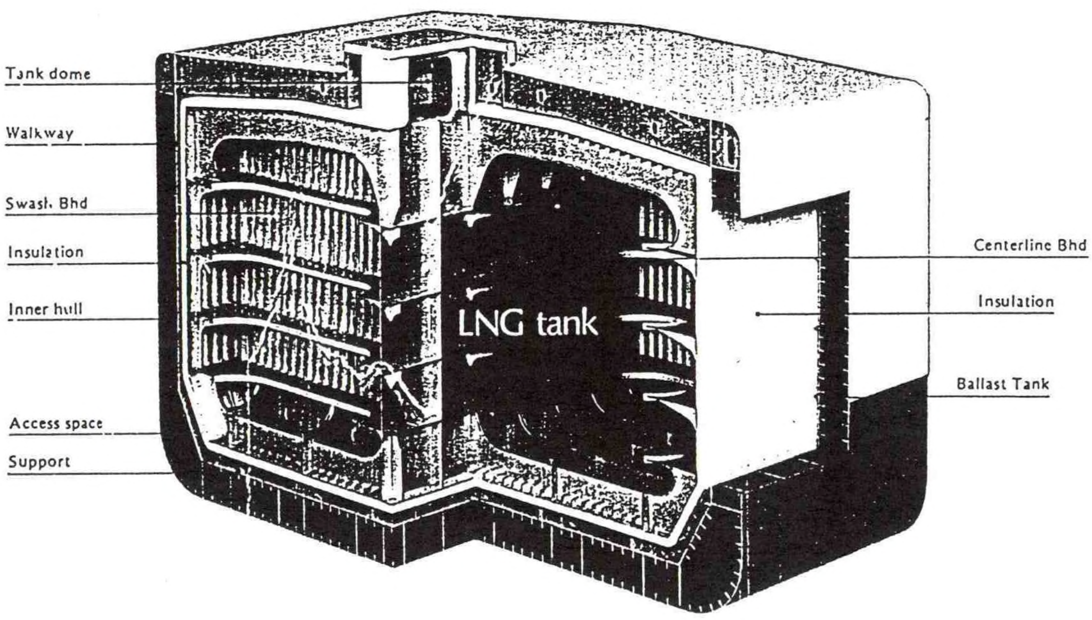


Fig.3 Structure of SPB Tank

2.3 Advantage of application of SPB to FPSO

To plan FPSO for LNG, it was found that there are many advantages as a total FPSO system when SPB is applied, depending on the specific features of SPB. This is summarized in Fig. 4. According to this, application of FPSO has advantages in terms of economy and safety. Unlike the case of a ship, the FPSO has following specific features for a SPB tank: (1) LNG is always being produced and loaded, therefore the liquid level of the tank is kept at the half-loaded status, and is subject to sloshing, (2) a place to locate a large plant facility is necessary, (3) a mooring system is part of the system, and it is possible to reduce the mooring force by miniaturizing the size of FPSO.

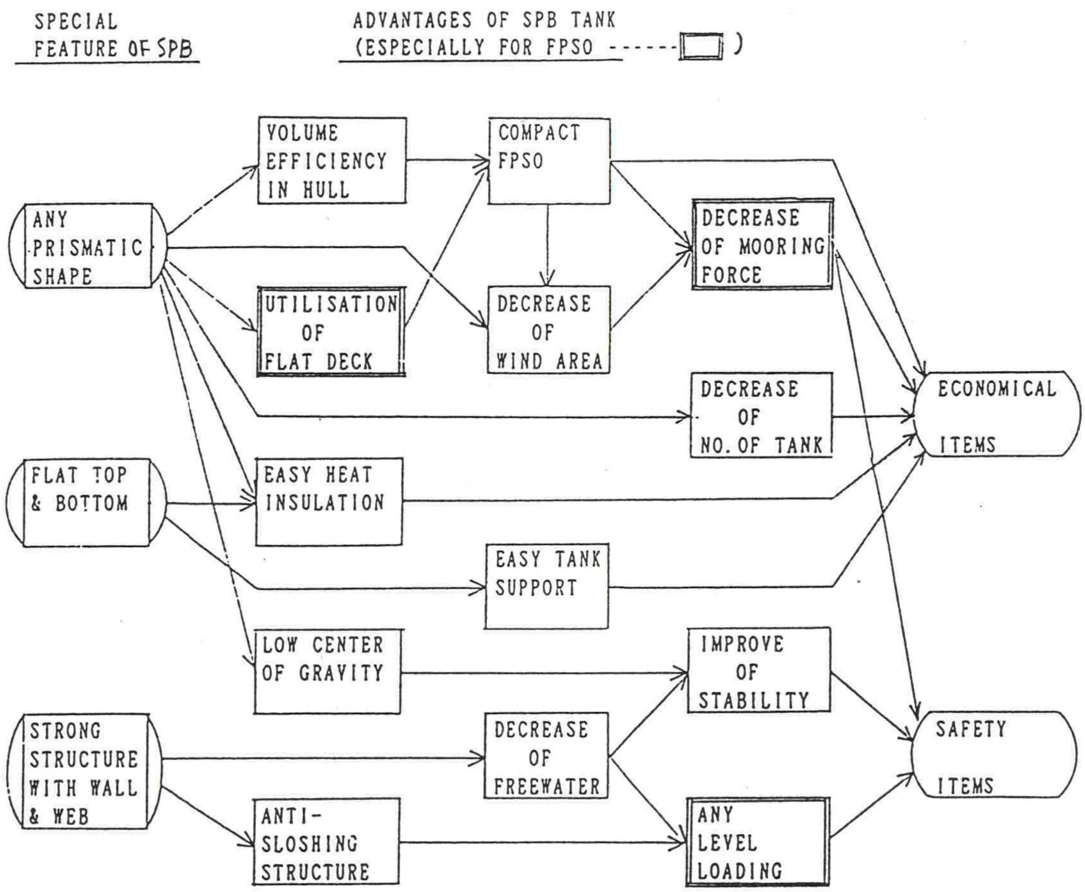


Fig.4 SPB Tank for FPSO System

Special attention has been paid to safety when installing plants on the upper part of the tank, and plants are not installed directly on the deck, but are located with sufficient space for security. This system has already been reviewed for safety by the Classification Societies, and has basically been approved.

3. Outline of Concrete Design

3.1 Design Condition

Following conditions are design basis of this FPSO unit and mooring facilities.

Capacity of products	1,700,000 tons/year	
Off-loading ship	125,000 cub.m type LNG carrier	
Sae conditions	Normal cond.	Extreme cond.
Wind speed	33.5 m/s	74.2 m/s
Wave height	11.6 m	20.1 m
Current	1.7 m/s	2.5 m/s
tide	0.5 m	1.2 m
Earthquake Horiz./Vert.	0.2 g /0.1 g	
Water depth	50 m	

3.2 Outline Particulars of FPSO

A rough sketch of the FPSO is shown in Fig. 5.

Type	Single point mooring with yoke, Barge type vessel containing liquefaction plant, storage tanks and off-loading facilities
Classification	Nippon Kaiji Kyokai

Principal Dimentions of FPSO

Length	300.0 m
Breadth	50.0 m
Depth	28.0 m
Draft	10.0 m

Tank Capacities

LNG	Type	Self-supporting prismatic type B
	Material	Al uminium alloy
	Volume	160,000 cub.m
Naphtha	Volume	8,000 cub.m
Fuel oil	Volume	5,000 cub.m

Liquefaction Plant	
Liquefaction system	Propane & mixed refrigerant cycle combination 1 train
Liquefaction capacity	5,500 tons/day
Prime mover	Steam turbine
Unloading system	
Location	Aftpart of FPSO
Type and number	Flexible unloading arm and hose 2 set

4. Conclusion

A LNG project involves large costs for developing the gas field as well as the receiving (Consuming) side, therefore, development has been limited up until now. As stated at the beginning, however, demand for natural gas has increased and development of gas fields has also increased. It is expected that the FPSO of this type will be constructed. IHI has been performing research on the SPB tank for a long period, and has developed LNG carriers, performing various experiments with LPG carriers, in addition to the structural analysis. The company has received orders for two LNG carriers with SPB tanks, and is now constructing the ships installed with this type of tanks. The actual results will be obtained before long. We are sure that a FPSO with the special features of a SPB will be developed and applied in the near future.

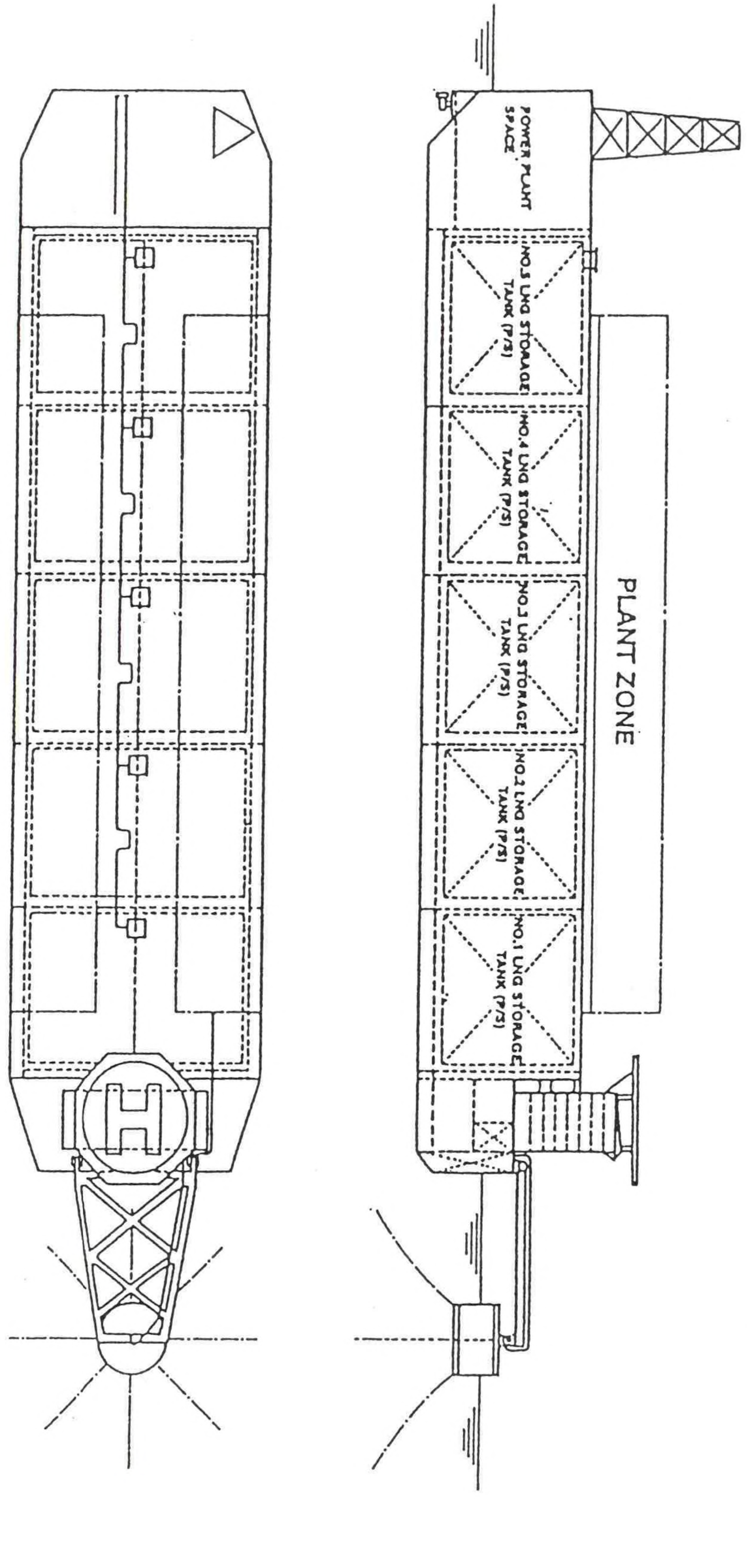


Fig. 5 Rough General Arrangement of LNG FPSO

SHIRASHIMA FLOATING OIL STOCKPILING TERMINAL

Hitachi Zosen Corp. Eifu Kataoka

I. OCEAN DEVELOPMENT IN JAPAN

1. Trends in ocean development

In Japan, coastal waters have so far been developed mainly through reclamation.

If the coastal reclamation is taken as the first generation mode of ocean development, the construction of artificial islands in the coastal waters may be said to be the second generation.

In recent years, we are entering a new era opening up the third generation of ocean development, in which the trend is toward developing a new functional space far off the coastline.

The main areas for which ocean development has been performed nowadays include:

- development of structures and facilities to support advanced use of littoral areas, regional development, and redevelopment of urban areas;
- development of spoil ground for disposal of dredgings and domestic refuse;
- construction of facilities for which inland sites are unavailable; and
- development of fishery facilities and recreational facilities; etc.

Because offshore development is projected to predominate in the future to replace coastal reclamation, and also because developers will have use more and more consideration for the environmental protection, the demand for floating structures for ocean development will increase.

2. Trends in the development of floating offshore structures

In recent years, marked technological progress has been made in the field of development and engineering of floating offshore structures, and large-scale event halls, aquariums and other structures with verified seaworthiness, moorability and corrosion resistance are beginning to be constructed one after another.

Functionally, the floating offshore structures may be classified as follows:

- Mooring facilities: Jetties, breakwaters, mooring buoys
- Fishery facilities: Underwater vegetation systems, nursery barges
- Stockpiling facilities: Oil storage vessels, LPG barges
- Industrial facilities: Power plant barges, pulp plants, water-making plants, offshore cement silos, polyethylene plants
- Infrastructural facilities for urban life: Wastewater treatment plants, domestic waste transshipping terminals, hotel barges, floating houses
- Leisure and sports facilities: Marine museum, floating houses, restaurants, hotels

It is expected that the floating offshore structures will find increased applications in the future, particularly for pisciculture in line with the mounting needs to change the fishing style from the hitherto "preying on dwindling fish resources" to "cultivation", for the construction of domestic infrastructural facilities for which inland siting is getting increasingly difficult in recent years, and for leisure and sports facilities for the young.

3. Barriers that stand in the way of ocean development

(1) Compensation for commonage of the fishers

It is said that Japan's fisheries law dates back to the age of warlords when feudal lords enfeoffed their vassal fishers with coastal waters as the common of piscary.

It was in 1933 when the common of piscary was incorporated into a modern statutory law.

Now the entire coastal waters are reduced to the vested rights of local fishers.

Any attempt to use a coastal space faces difficult negotiations with the interest groups of fishers.

Because the interested fishers form a large body and also because the compensations are rising year after year, long, traumatic negotiations usually are experienced before the settlement of economic conflicts between the fishers and project promoters.

[A case with Kansai International Airport]

The Kansai International Airport Project cost ¥49,000 million paid to 9,400 fishers of 70 fishery cooperatives in the form of direct compensation, funds for livelihood security measures and fishing promotion, subsidies, etc.

This means that the project spent $310,000 to acquire an acre of airport space.

It is reported that the compensation cost per unit area of the common of piscary usually amounts the land price of the same unit area of shore land.

Over and above, the Kansai International Airport Project required vast sums of money for reclamation only to send up the land cost exorbitantly.

(2) The land myth

In Japan, effective land space available for residential, farming, business and industrial purposes is quite limited, and there is a heavy demand-supply imbalance in lopsided favor of land owners, creating a myth that land acquisitions are overriding principle for success.

Reflecting this land myth, Japan's national land has been appreciated prohibitively, so that so long as the current land prices stand, it happens to lead to an absurd anomaly that the price of Japan's national land is worth twice or more as much as the U.S.A.'s.

While people have deeply embedded attachment to land that survives forever, the floating structures can only serve for about 50 years, and are far less in property value as compared with land.

All these speak volume about why the floating offshore structures are not received well as investments.

(3) Regulations

Offshore structures are bound hand and foot by various shore and offshore laws and regulations associated with ships, ports and harbors, construction, fishery, fire prevention and control, etc.

These regulations are often found imposing heavy burden on the development of floating offshore structures.

In many cases, floating offshore structures are registerable by law neither as ship nor building, and are completely deprived of a yardstick with which to evaluate their property value.

Marine insurance premiums required for the floating offshore structures are by far expensive as compared with shore structures.

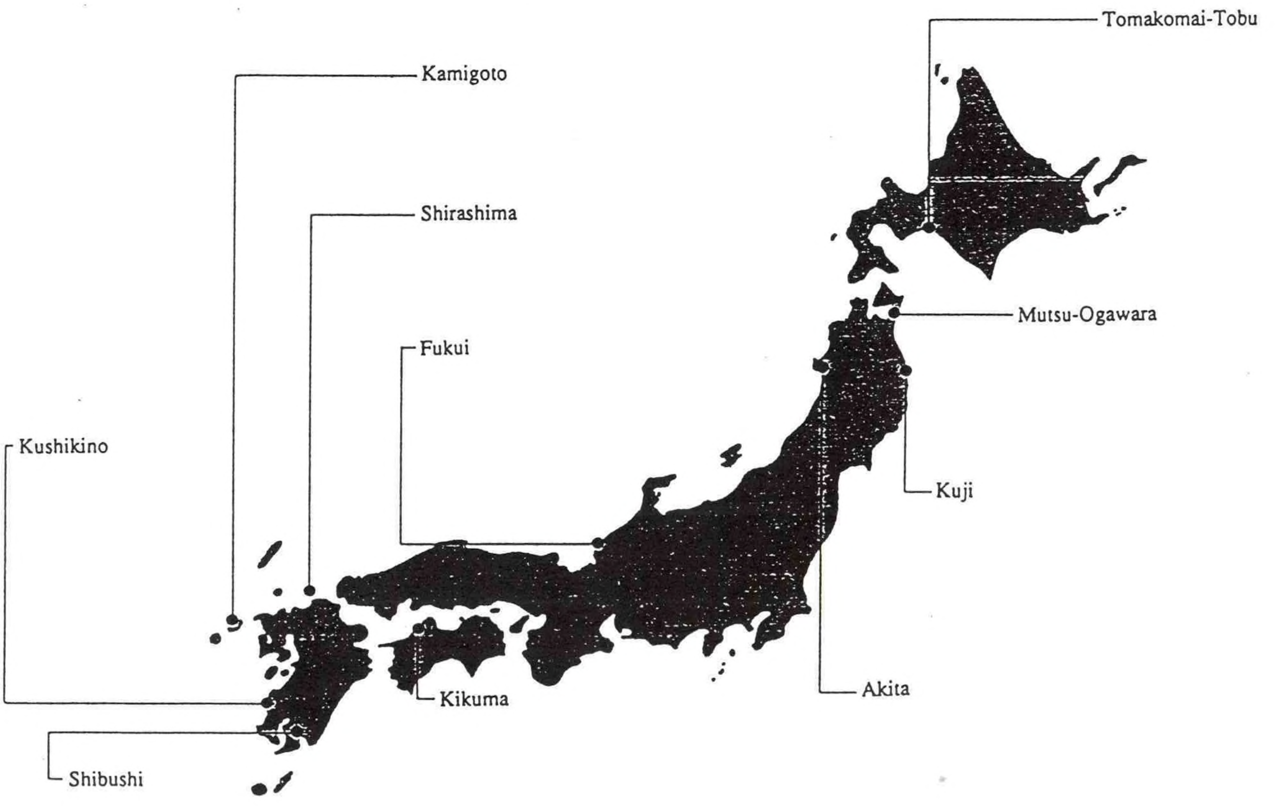


FIG.1 LOCATION OF NATIONAL OIL STOCKPILING

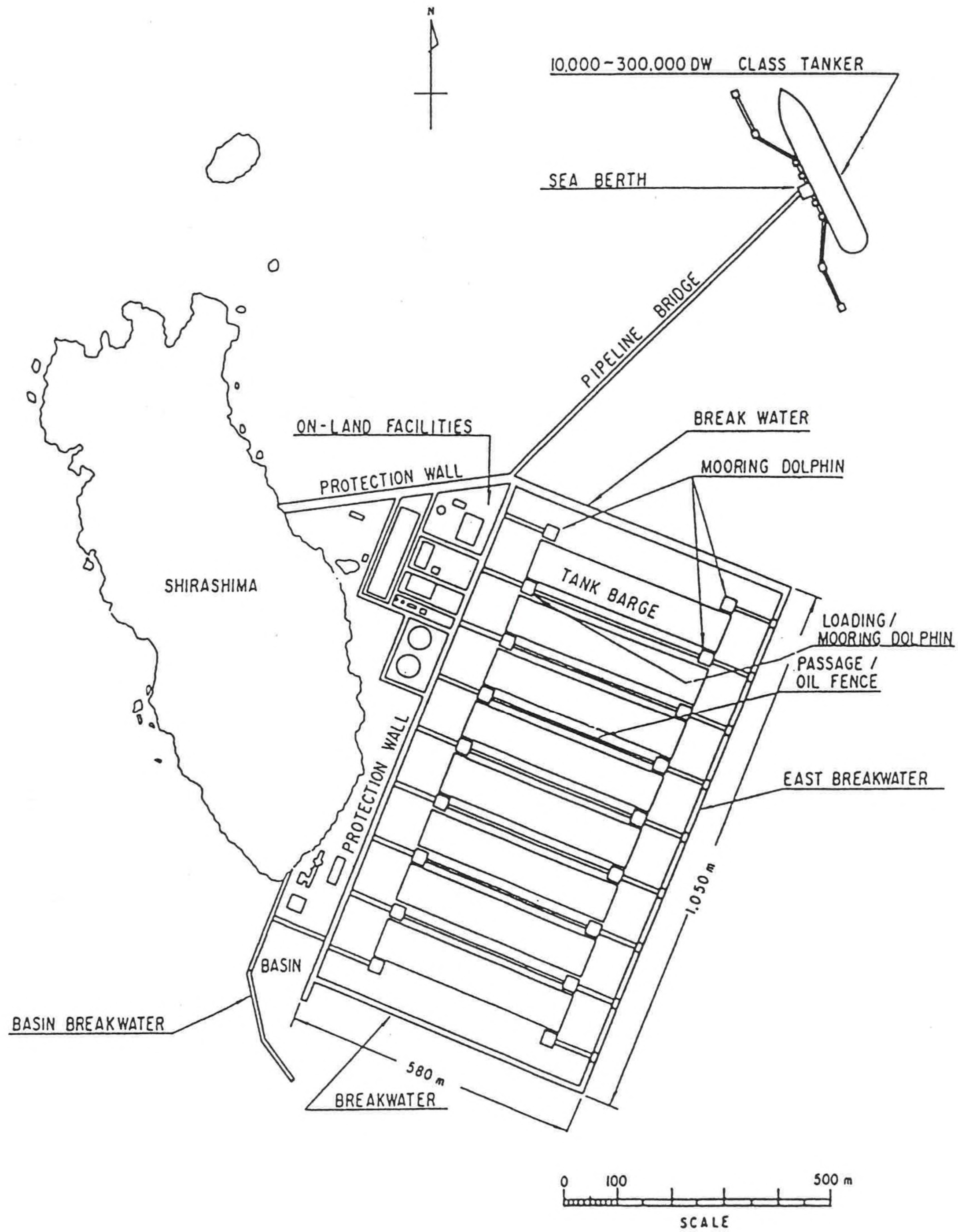


FIG. 2 PLAN VIEW OF SHIRASHIMA TERMINAL

II. SHIRASHIMA FLOATING OIL STOCKPILING TERMINAL

1. Purposes and objectives

Alarmed by the 1973 Oil Crisis, the Japanese Government decided to provide oil stockpiling measures in more or less the same way as practiced in Europe and the U.S.A. In 1972, the Oil Stockpiling Law was established to enforce private oil distributors to keep a specified level oil in reserve.In 1978, Japan National Oil Corp. (JNOC) was chartered to reserve oil on a national level.

Since then, Japan increased the oil reserve at an annual rate of 2.50 to 3.50 million kilo-liters.Toward the end of FY 1988, the reserve reached an original target level of 30 million kilo-liters.Now efforts are being made to stockpile 50 million kilo-liters by the mid-1990s.

At present, Japan has ten oil stockpiling terminal construction projects, including four already completed.

The four projects completed are Mutsu-Ogawara Terminal (May, 1985), Fukui Terminal (June, 1986), Kami-Goto Terminal (September, 1988), and Tomakomai Terminal (November, 1990).

Of the ten projects, Kami-Goto Terminal and Shirashima Terminal are offshore projects.

2. Shirashima oil stockpiling Co.

Capital: ¥10,000 million

Shareholders: Japan National Oil Stockpiling Corp., private oil companies, shipping companies, Kita-Kyushu Municipal Government, Fukuoka Municipal Government, financial institutions, etc.

Line of business:-

(a) Leasing of oil stockpiling facilities
(b) Storage, loading and unloading services
(c) Investment and loan to businesses closely associated with oil stockpiling
(d) Others

3. A brief description of terminal facilities

(1) Floating storage facilities:-
approx. 700,000 kl
x 8 vessels (397 m x 82 m x 25.4 m)

Pump facilities:-
Cargo oil pump: 2,500 kl/h x 2 units/vessel
Seawater pump: 1,500 kl/h x 2 units/vessel

(2) Port & harbor facilities: -
Main breakwater:
570 m + 1,050 m + 570 m + 160 m
Aggregate length of revetment:
436 m + 890 m + 36 m
Stockpiling vessel mooring facilities:
Dolphin x 14 sets
Primary oil dike floating type: 11 lines
Cargo loading and unloading facilities: -
Fixed berth loading arm, 400A x 3 sets
Pipeline bridge: 800 m
Utilities:-
Emergency power plant: 1,400 kW x 5 units
Smothering gas feed station: 6,250 Nm3/h x 1 set
Water-making plant: 60 m3/d x 1 set
Environmental control facilities:-
Wastewater treatment plant:30 m3/h x 2 trains
Slop tank: 9,900 kl x 2 units
Blowoff gas treatment plant: Grand flare system

(3) Construction schedule

Originally, the project was scheduled for completion in March 1990.

But in February 1987, phenomenal sea attacked Kita-Kyushu, running havoc with the breakwater under construction to cause a substantial delay in completion.

At present, dredging, reclamation and the construction of breakwater have been nearly completed, and mooring dolphins, primary oil dike, sea berth and pipeline bridge are under construction.

No. 1 stockpiling vessel which is under construction at Hitachi Zosen's Ariake Shipyard. All facilities are scheduled for completion in 1996.

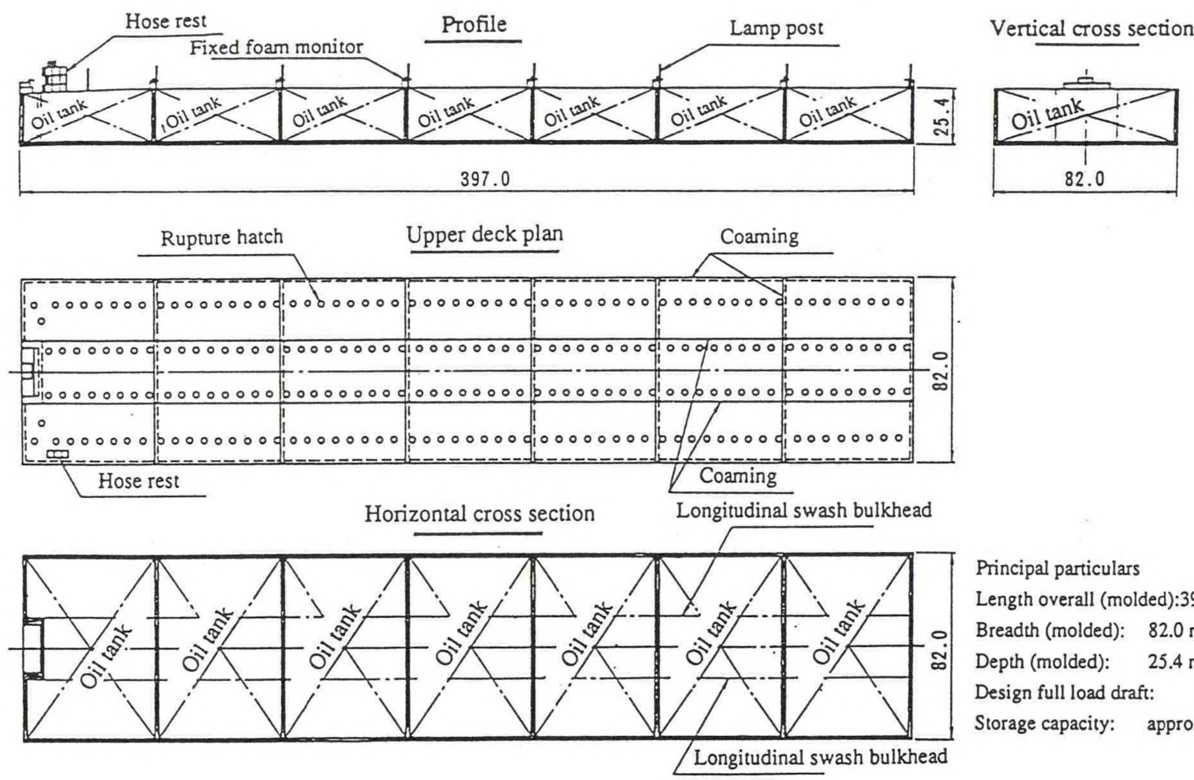
(4) Structural design of the stockpiling vessel, and the mooring system

The stockpiling vessel has a double-hull structure with two longitudinal bulkheads.

The oil hold is divided into seven.

(5) Breakwater construction

See Fig. 6.



Principal particulars
Length overall (molded):397.0 m
Breadth (molded): 82.0 m
Depth (molded): 25.4 m
Design full load draft: 22.7 m
Storage capacity: approx. 700,000 m3

FIG.3 GENERAL ARRANGEMENT OF STOCKPILING VESSEL

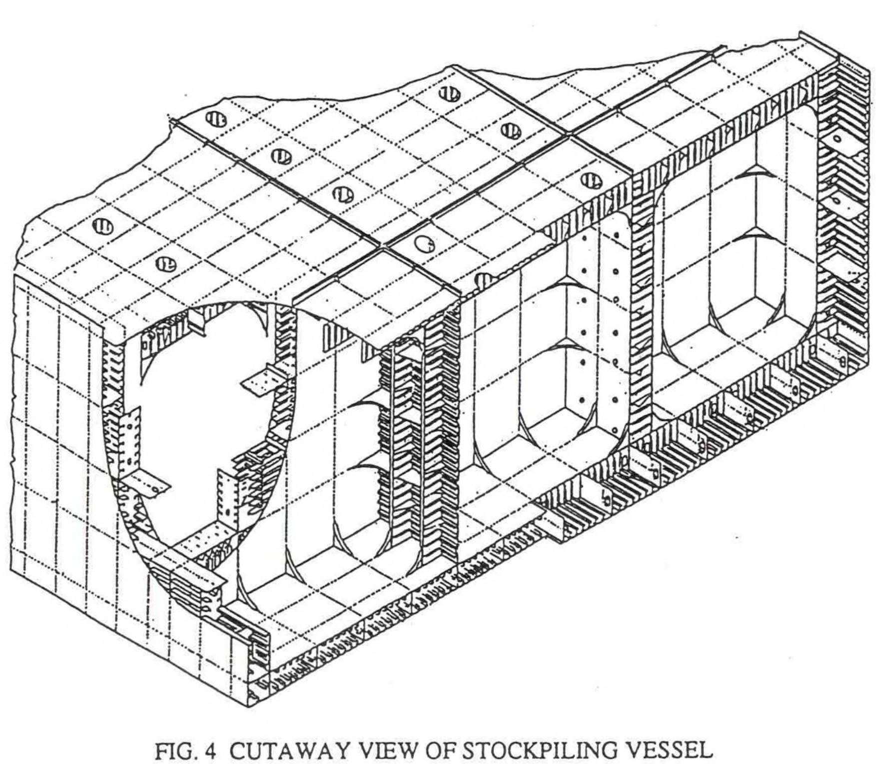


FIG. 4 CUTAWAY VIEW OF STOCKPILING VESSEL

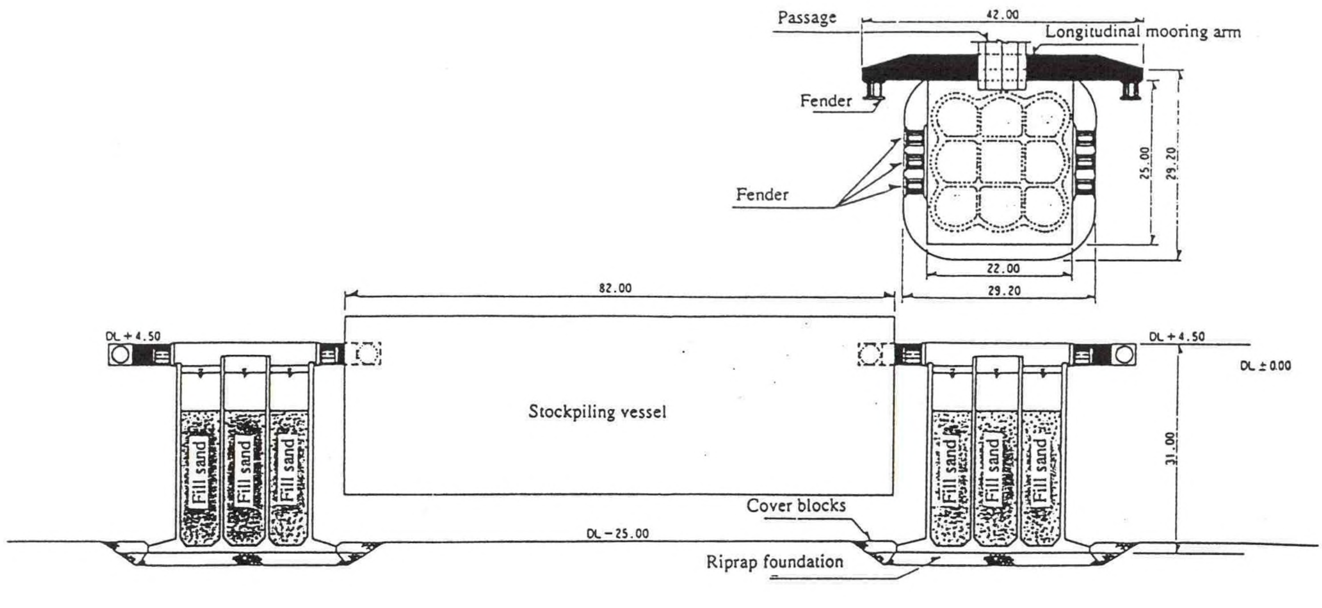


FIG. 5 MOORING DOLPHIN

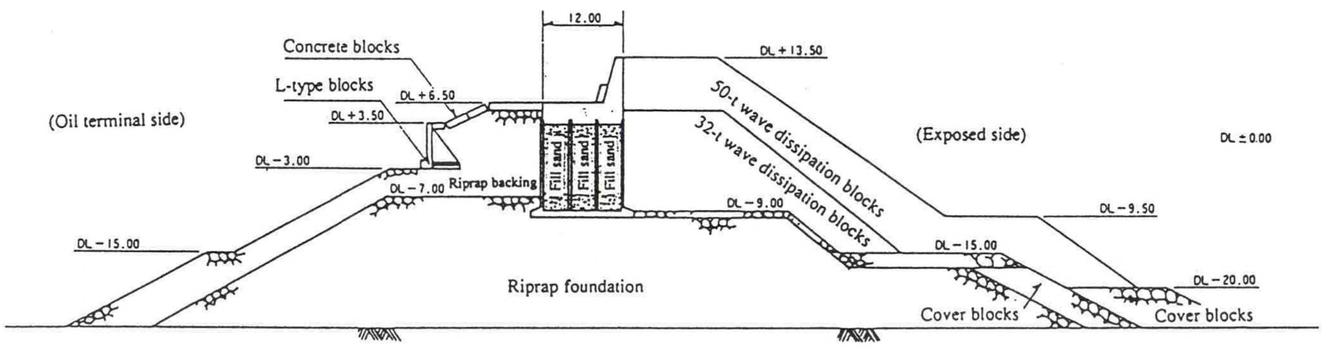


FIG. 6 PROFILE OF NORTH BREAKWATER

4. Safety and environmental measures

(1) Environmental assessment

The Kita-Kyushu Port Authority studied the impact of the port and harbor development and land use for the project on the surrounding environment.

The following is a summary of the findings.

(a) There is no major source of emissions that may pollute the environmental air, and the project will not pose any serious air pollution problem.

(b) Changes to the tidal current are limited to a small area around the project site, and their effects will be minimal.

(c) Turbidity loadings resulting from the construction activities are slight, and their impact on the environmental waters and aquatic life will be minimal.

(d) Emissions of air pollutants are small, and the fundament of the island is kept intact by prohibiting any act ashore.

Thus the impact of the project on the terrestrial life will be minimal.

While there are rare marine species in the nearby waters, the effects of the reclamation, changes to tidal current and water quality will be minimized to protect marine life including such species.

(e) Fishers will be affected by the loss of fishing grounds, restrictions on fishing operations in the nearby waters, and damage to the ecosystem for the marine life.

But such affected area of waters is quite limited.

Evil influence of the project on the most vulnerable fishers will be reduced to a minimum by promoting the development of new fishing grounds and by careful implementation of the project in a manner to minimize its effect on the marine environment.

In sum, the project is judged unlikely to cause any problem for the environmental protection.

(2) Measures against high tides

The billowing waves that battered at the Kita-Kyushu coastal line in February 1987 were the most serious in the local history of oceanological observation, registering the wave heights far exceeding the most notorious one ever experienced.

Roaring waves which were estimated to have a significant crest height of 5.5 to 6.5 m stayed for long hours to damage the breakwater (design crest height: 6.1 m) under construction.

From this lesson, the north breakwater was redesigned to withstand a crest height of 6.9 to 7.1 m.

To put in more detail, the following reinforcements were provided for the north breakwater:

(a) rubble mound measuring 13 to 17 m in width;

(b) reinforcement of the existing 32-t wave dissipation
revetment with 50-t wave dissipation blocks, and moderation of revetment slope;

(c) protection of the eastern end with 64-t wave dissipation blocks; and

(d) improvement of some of fills for the caissons.

(3) Oil spill measures

The stockpiling vessels are of the double-hull design. The space between the inner and outer shells is filled with seawater, and the crude oil tanks are held in a negative pressure.

Should oil spill occur, its dispersion can be prevented by the primary oil dike (floating type) installed around each tank.

In addition, the berth is impounded by the sturdy gravity caisson type breakwater serving not only as a protection against waves but also as a secondary oil dike with oil-tight structure.

(4) Monitoring and control facilities

There are provided oil handling operations monitoring and control system, fire prevention and control system, oil leakage detection system, telecommunication and warning system, and meteorological and oceanological observation system.

The tanks are always filled up with inert gas to provide against fire and explosion hazards.

PROGRESS IN DEEP OCEAN OIL TECHNOLOGY

Richard J. Seymour and John E. Flipse
Offshore Technology Research Center

Introduction

The Offshore Technology Research Center (jointly operated by Texas A&M Univ. and the Univ. of Texas at Austin) is devoted to basic engineering studies in support of economical oil and gas production in water depths from 2-3km. It has recently become recognized that conventional technology - even that which has been successfully applied to depths as great as 1000m - will not be economical at the depths of interest here. Now beginning its fifth year, OTRC has made significant strides in several major areas in advancing the required technology. This paper will present a summary of representative research achievements.

Hydrodynamics

A basic research study to investigate nonlinear random reversing flow behavior in order to eventually understand flow-induced forces on slender member offshore structures is being pursued. Central to this study is a unique computer controlled water tunnel equipped with a 3-D laser Doppler anemometer system and a variety of other probes and sensors. In the study the various test cylinders are mounted horizontally in the water tunnel and the end walls of the water tunnel are computer controlled. By utilizing the velocity measurements in the near field and far fields, force and displacement measurements of the cylinder, together with advanced signal processing techniques, the investigator is gaining new fundamental insights into the various fluid-structure interaction and near wake phenomena associated with random reversing flows.

Other projects utilizing these data include the development of an unsteady flow simulation model using an adaptive finite element model of the Navier Stokes equations. The focus of this project is to numerically model the flow around the cylinders used in the experimental studies and to utilize the experimental data to verify the accuracy of the predictions. Recently it was demonstrated that their computer models could simulate the flow around a cylinder at a Reynolds number of 1000. It is possible to simulate the entire process of vortex formation, vortex shedding as well as vortex/vortex interactions. These flow simulations were carried out to times representing about 30 periods, where one period corresponds to the convection time over a distance of one cylinder radius. The second project which also utilizes these experimental data involves advanced time series analysis methods utilizing higher order statistical signal processing and nonlinear systems modeling to analyze both small or large scale experimental data. These systems include linear, quadratic and cubic Voltera kernel models and have already been applied to important offshore problems.

Structural Integrity

Studies have been made on the dynamic characteristics of offshore structures using realistic system models with several degrees of freedom incorporating the dominant nonlinearities associated with the dynamic loads and structural behavior. In contrast with sophisticated finite element models which are intended to provide detailed information regarding the response of tension leg platforms, the models considered in this project are aimed at providing qualitative understanding of the overall behavior of the platforms. Specifically, the study of a model of a tension leg platform with the tethers idealized as nonlinear springs has been completed. The second-order superharmonic responses, arising from the nonlinear coupling of surge and heave motions of the platform, were detected near the natural frequency of the surge motion and one half of the frequency of the heave motion.

Dynamic analysis of tension leg platforms is being explored through the use of a hybrid frequency-time-domain procedure. Convergence of the iterative scheme requires splitting the duration of the excitation into small time intervals. An improved computation of the Fast Fourier Transform in each interval has been developed. Significant progress has been made in the investigation of the use of quadratic or cubic transfer functions to perform the nonlinear dynamic analysis in the frequency domain.

A study of the interactive response of tendon/riser pairs in waves involves experimental and theoretical investigations of the response of long, flexible cylinders to regular and random wave excitations. Experiments on a single cylinder as well as on pairs of cylinders have already been completed in the Center wave basin. Measurements have been taken of the curvature along the cylinders, the tension and inline and transverse wave forces at the top and bottom of the cylinders. A comparison of experimental data with results of analytical simulations shows that numerical models predict no contact between risers while experiments show that they hit in certain random wave experiments.

Computational tools for the analysis of stiffened tubular structures, e.g., pipelines, tethers, tubular members of compliant towers are under development. The use of stiffeners is expected to become increasingly significant in deepwater applications. In this study, a robust and efficient computational procedure for the analysis of buckle arrestors has been devised. This work is akin to studies of neck propagation in polymeric specimens.

Additional work on the integrity of deepwater tubular structures involves a combination of experimental and analytical work on buckle propagation in the presence of tension (in pipelines and tethers). Experiments have been conducted in a combined pressure-tension test facility. They have been complemented with simplified as well as detailed analyses. Tension was found to lower the propagation pressure (minimum pressure required for buckle propagation) significantly.

Materials

Investigations were made on the effects of seawater absorption on the fatigue behavior of a graphite/epoxy composite to establish microstructure and performance mechanistic relationships that include evolution relations for damage development and property reduction. Since the onset and growth of delamination have been identified as the most critical steps in the fatigue failure of a composite structure, the complex moisture effect on delamination was monitored.

Edge delamination fatigue tests were performed with dry and presoaked samples to gage the effect of absorbed seawater on the fatigue delamination growth. An environmental cell was constructed so that the sample could be tested in tension-tension fatigue under the exposure to seawater.

Since the cracking is of fiber/matrix interfacial failure in either dry or wet condition and the number of cracks did not increase for presoaked samples, seawater absorption did not appear to degrade the interfacial strength of the system used in this study. The modulus was monitored as a function of the number of fatigue cycles for a dry and three wet fatigue tests. Little difference in the trend of modulus reduction between dry fatigue with dry sample and wet fatigue with 0.35% moisture sample can be observed.

effect of dispersed particles upon the mechanical properties of polymer films. The properties of the interface between the dispersed particles and the polymeric binder are critical to understanding coating behavior, but we have no knowledge or control over interfacial properties in commercial composite coatings

In studies of the effects of biofouling activity on corrosion of marine materials, a consortium of marine bacteria has been assembled that includes slime-producing, acid-producing and sulfate-reducing bacteria that can be used to evaluate the impact of marine bacteria on the electrochemical properties of metals, and the disbonding and blistering of polymeric composites. Sulfur isotope fractionation during sulfate reduction by this consortium has been documented. Three stainless steels have been exposed to the natural marine environment at the Naval Civil Engineering Laboratory, Port Hueneme, California. Electrochemical parameters, including corrosion potential, polarization resistance and capacitance have been measured over a four-month period. Biofilms on the surfaces have been documented using ESEM. The biofilms were patchy, containing isolated colonies of bacteria and numerous diatoms. The corrosion potential does not indicate an ennoblement of these materials that would lead to crevice corrosion. Homopolar and conventional welds in carbon steel have been exposed to a fresh water source known to contain iron-deposing bacteria. Conventional welds in ferrous materials exposed to this source have suffered premature failures because of the activities of the iron-depositing species. Eight composite materials have been exposed for six months to natural seawater in Galveston Bay, Texas. Weight gain has been measured and biofilm composition documented. Calcareous film thickness measurements were made of the wet layers using ESEM.

Mathematical models have been developed that can be used to design Cathodic Protection (CP) systems for deep ocean structures. The mathematical models for calcareous film formation that were previously available do not include sufficient detail to account for the effect of the changes in the sea water chemistry on the growth of the film. A model, developed by OTRC, based on experimental data, does include many of the needed details. In addition to the calcareous film model, a two-dimensional model boundary element was developed for predicting potential and current distributions for cathodic protection systems for either sacrificial anodes or impressed current systems. The model uses a polarization curve for low carbon steel generated in artificial seawater as the boundary condition on the surface of the steel.

Seafloor Engineering

Significant progress has been made in the areas of understanding and detecting gas hydrates (frozen gas, existing under conditions of great depths and low temperatures) in deep marine sediments. For purposes of developing an in situ hydrate-detection probe, the properties considered included shear strength, electrical resistivity, thermal conductivity, in situ temperature profile, and sediment density. An apparatus has been developed to produce hydrates in the laboratory to allow measurement of these properties as hydrates are formed. Mixtures of pure hydrates, as well as hydrate-sediment mixtures, have been made and tested Tests revealed that electrical resistivity measurements have good potential as a means of detecting hydrates. The electrical resistivity is frequency dependent within the range of 100-1000 Hz, and it appears that resistivity is not a function of temperature. Thermal conductivities of hydrates are of the same order as for water saturated sediments, consequently thermal conductivity measurements may not be conclusive in detecting hydrates. However, this is an important property in studying hydrate phase change and heat transfer.

The design of the hydrate-detection probe has been investigated using a computer program for simulation purposes. Using this approach, the probe and electrode spacing have been optimized and the hydrate-detection probe has been fabricated.

Two types of remote sensing methods (acoustic waves and seismic interface waves) have shown significant capabilities for hydrate detection and classification. Geoacoustic parameter values for gassy and hydrated seafloor layers have been incorporated into simulations of the response of a hull-mounted 3.5 kHz vertical incidence subbottom profiling system. Initial simulations used only the available, limited empirical results. Subsequent, ongoing simulations are using the results of a theoretical study which is also a part of this project. Results of these simulations indicate that under many circumstances, the presence of the hydrate within a seafloor layer should produce discernible returns on a profiler record. Such a prediction does not (yet) suggest the possibility of unambiguous, independent identification of gas hydrate within the seafloor with standard profilers, but they do indicate the possibility of extrapolation of hydrates identified by other means.

A study with seismic surface waves (also called interface waves because they propagate along the water-soil interface) has been employed in analytical studies that showed, for wavelengths shorter than about 0.5 times the water depth, interface wave velocity is independent of wavelength and only depends on the stiffness of the half-space and of the water over the half-space. Experimental studies in a small-scale facility showed good agreement with the analytical results when wavelengths were less than about 0.5 times the water depth. When the shear wave velocity of the seafloor is greater than the compression wave velocity of water, then additional acoustic waves are generated that have significant amplitudes at the soil-water interface. These additional acoustic waves can influence the interpretation and use of surface wave measurements offshore. These acoustic waves are dispersive and independent of water depth and a nearly infinite number of waves may exist with velocities ranging from the compression wave velocity of water to the shear wave velocity of the stiff seafloor. For a given wavelength-to-water-depth ratio, the acoustic wave with the minimum energy has a velocity very close to the velocity of the classical Rayleigh wave which propagates along the surface of a stiff material overlaid by air.

The collaborative study on the behavior of piles in sand has completed the initial stages of collecting case histories and the results been very enlightening. The axial capacity of steel pipe piles used in offshore structures is predicted using simple friction theory with the needed parameter coming from the API-RP2A design guidelines. Use of these guidelines for terrestrial pipe piles in sand leads to differences between measured and computed pile capacities of up to about five times with a tendency to under predict the capacity of piles penetrating less than fifty feet and possibly over predict the capacity of piles penetrating more than about 80 feet (no load test data available for large penetrations). One reason for these differences is that current design methods do not account for installation effects, in particular, the effect of the soil core inside the pile on the lateral stresses between the soil and the pile wall, i.e., on pile capacity. Under static conditions, sand cores arch across the pile diameter and form a plug.

Other efforts concerning deepwater foundations, and in particular piles, have been the study of the impact of hydrate melting and the improvement in predicting pile capacity using a driven cone penetrometer. The idea of a driven penetrometer arose from earlier work on hydrate detection using the static cone penetrometer. The hydrate melting problem has involved performing thermodynamic numerical analyses to evaluate the steady-state distribut3ion of temperatures around hot-oil conductor pipes and the extent to which the temperature regime influences adjacent piles. The results show that a hydrate content of 0.5% is likely to be manageable while a hydrate content of 10% will create significant problems for typical situations.

Study on Protection of Oil Spill from Crude Oil Tankers

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Introduction

In March 1989, the EXXON VALDEZ ran aground in Alaska, spilled about 36,000 tons of crude oil and caused disastrous pollution of marine environment. After the accident, protection of oil spills from tankers became one of the great concerns of the world. The new regulations on oil tankers were established by International Maritime Organization (IMO) and Congress of USA to prevent marine pollution.

In Japan, Association for Structural Improvement of the Shipbuilding Industry (ASIS) started a 7 year research and development program on 'Protection of Oil Spill from Oil Tankers' in 1991 with support from the Japanese Ministry of Transport.

The objective of this program is to establish methodology to predict the extent of structural damage and to predict expected value of oil outflow due to collision and grounding and finally to develop new structural design method to prevent oil spill from tankers by collision and grounding.

An outline of the project ~~is~~ as follows, although the program will be detailed year by year to more concrete one.

1.Prediction of structural failures due to collision and grounding(1991-1994)

The subject of this section is to develop or improve the method for prediction of structural damage of tankers sustained in collision and grounding. To prevent oil spills from tankers the following failure modes are important, because those structural failures inevitably cause oil outflow.

(a)Rupture of inner side shell due to collision
(b)Rupture of inner bottom shell due to grounding
(c)Bottom raking due to grounding

(1)Structural failures of oil tankers at collision or grounding(experimental)

In this item failure behavior of specific structures of tankers is to be studied. Model tests and full scale tests are being performed to investigate the sequence of structural failures caused by collision and grounding. Similar tests have been executed by some institutes or academies. But the data do not necessarily obey the law of similarity, because the tests mostly depend on small scale models. To avoid errors caused by scale effect in experiments , large scale models or actual ships are to be used. It is believed that these tests will substantially contribute to improve our knowledge about structural failures, and succeeding theoretical study will enable us to make accurate prediction of damages due to collision or grounding.

1991

(a)Full scale ship collision tests

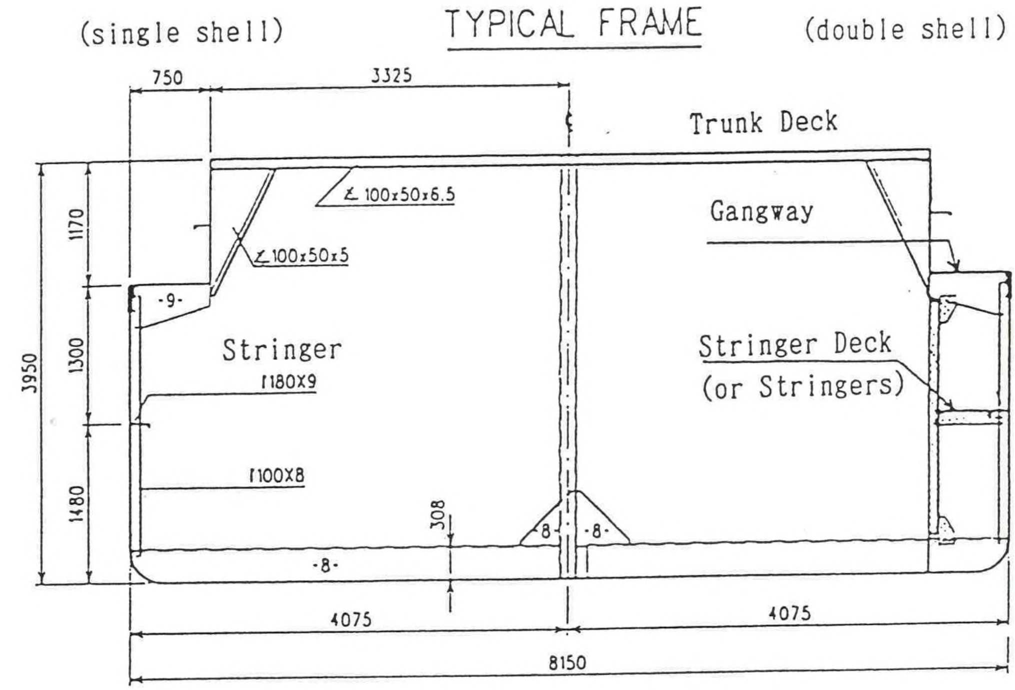
Four full scale collision tests were executed by the Netherlands Foundation for the Coordination of Maritime Research(CMO) and ASIS. The tests were carried out in a harbor basin nearby the village of Moerdijk in Netherlands. Two inland water way tankers were used for the tests. Table 1 shows the general particulars of the striking ship and struck ship. At each collision the bow of the striking ship hit the side of the struck ship at right angle(90 degrees). The structure of the struck ship and strike location are shown in Fig.1. In the first two tests single side structures were examined. The third test aimed at studying a double shell structure with stringers. During the fourth test, also with a double shell, the stringers were replaced by a stringer deck between the inner shell and the outer shell. Table 2 shows the conditions of the tests. Collision force , penetration depth, strain and motion of ship were measured during the collision as function of time. Initial cracking of the shell occurred at a welding line in all tests and there was no crack of the inner shell in the tests of double shell structures.

	Striking ship	Struck ship
Name of ship	RANCO	BORIS
Length O.A.	80 m	80 m
Breadth	8.2 m	8.2 m
Depth	2.8 m	2.8 m
Displacement	1000 Tonnes	1260 Tonnes
Building year	1958	1958

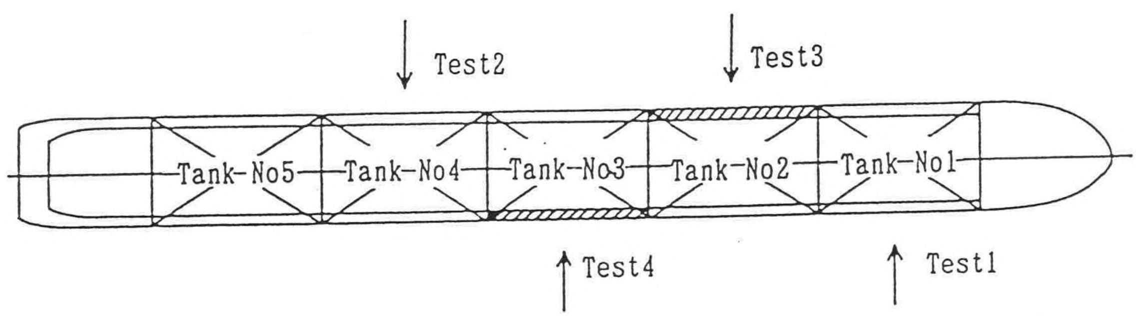
Table 1 General Particulars of the Striking Ship and Struck Ship

	Test 1	Test 2	Test 3	Test 4
Side structure of struck ship	single shell with a stringer	single shell with a stringer	double shell with stringers	double shell with stringer deck
Strike location	tank No.1(SB)	tank No.4(PS)	tank No.2(PS)	tank No.3(SB)
Displacement	1284 Tonnes	1242 Tonnes	1263 Tonnes	1266 Tonnes
Drought	2.22 m	2.15 m	2.19 m	2.19 m
Collision speed	5.3 km/h	14.8 km/h	15.2 km/h	15.6 km/h

Table 2 Conditions of Tests



(a) Structure of Struck Ship



(b) Strike Location

Fig.1 Structure of the Struck Ship and Strike Location

(b)Model experiments of structural failure due to grounding

To simulate bottom raking damage during grounding, two cases of experiments were done with 1/3 scale structural models of VLCC(ex. 2.0x4.5x1.0m,t=7mm). One is single bottom and the other is double. A wedge shaped rigid rock model, fixed to a press machine, was pushed against the model along the direction of ship length quasi-statically. Fig.2 shows a sketch of the experiment. Raking force F, penetration length, displacement and strain at several points were measured.

The raking force vs. penetration length of single bottom model are shown in Fig.3 in which structural behavior during the experiments are described together.

To predict the raking force F, the following equation is often used.

$$F = a * SUM (s_y * A)$$

The formula is a kind of Minorsky method with empirical constant a, yield stress s_y and area A. A is a sectional area of longitudinal members, measured in the plane perpendicular to the direction of ship length. SUM means sum of the members. As the empirical constant, a=0.8 was determined from the experiments for general cargo ships.

For the present experiments, the approximate raking force, obtained from the equation using a=0.8, are about 60-70% of the measured maximum forces as shown in Table 3. One reason of the discrepancies may be the structural characteristics of VLCC, which has wider space between stiffeners and between transverse rings. The other reason is that the rock model is extremely sharp. Each of those two factors has the effect by which the stiffeners are easily bent before compressed. This means that the stiffeners can not bear enough force expected in equation.

	Single bottom	Double bottom
Experiments	240 ton	410 ton
Equation	402 ton	601 ton

Table 3 Maximum Raking Force
- Comparison Between Experiments and Equation

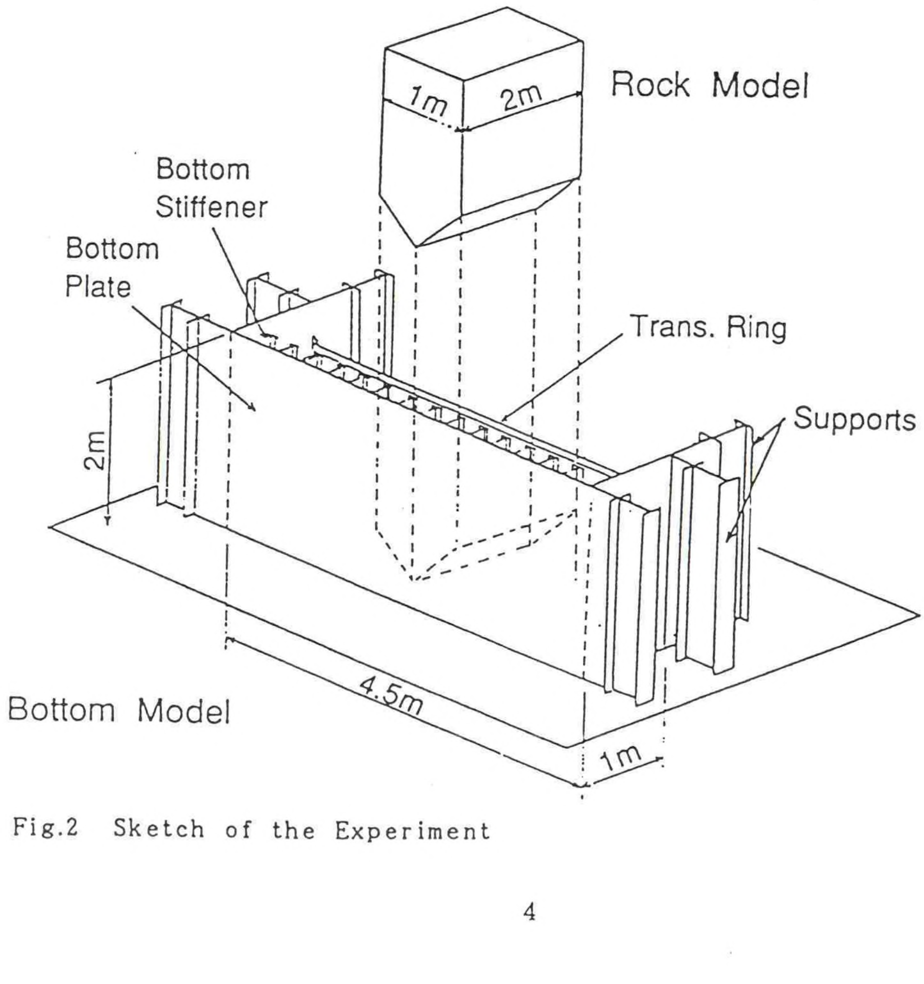


Fig.2 Sketch of the Experiment

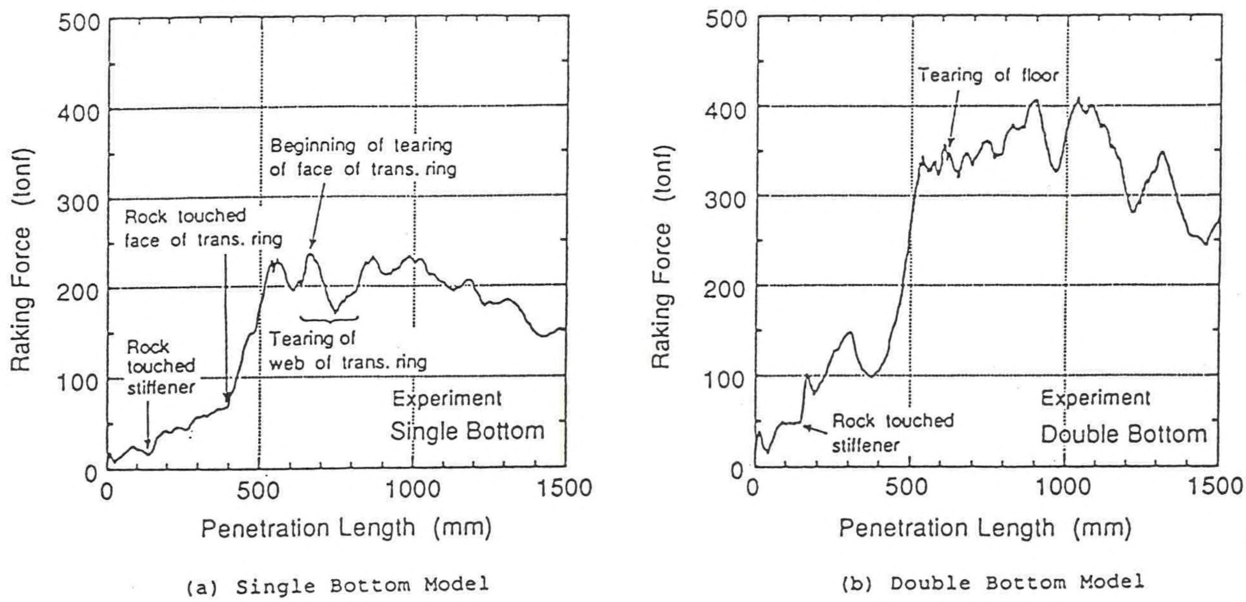


Fig.3 Raking Force vs. Penetration Length by the Experiments

1992

Failure experiments of structure members by dynamic loading are to be performed for study of dynamic effect. The structure members with 1/2 scale are parts of typical side structure of VLCC.

(2)Numerical simulations of ship collision or grounding(analytical)

In order to make a proper judgment of tanker structure crash worthiness, it is of importance to have analytical tools for prediction of damages due to collision or grounding. We are hopeful to use a method of numerical simulation by computer as such a tool. Several numerical codes are available for prediction of damages caused by high energy impact of collisions, and they have been successfully applied to many areas such as crash of cars. But for ship structure, availability of the methods has not yet been verified. The information from model experiments and full scale ship collision tests will promote the research for developing numerical simulation models for prediction of damage to ship structure at collision and grounding.

1991

(a)Numerical simulations of full scale collision tests

Each of the tests has been simulated using the numerical methodology in which the structure-structure interaction is computed with MSC/DYNA, an explicit finite-element program which enables the full simulation of the dynamic of the collision events. Fluid-structure interaction is taken into account by means of a system of springs and dampers, of which the characteristics are determined using the MSC/PISCES program. The computations were successful in simulating the main features of the collision process and the resulting damage, like hole size and penetration depth. An example of simulation model is given in Fig.4. Table 4 shows the comparison between test results and numerical ones. The maximum computed collision forces are 30-70% higher than the measured maximum collision forces. A better match with the experiment can be obtained when crack initiations in welding lines are taken into account in the modeling. Prediction method of the ship motions after the collision should further be improved.

	Penetration		Maximum contact force		Displacement of center of gravity in transvers direction of struck ship	
	actual test	numerical simulation	actual test	numerical simulation	actual test	numerical simulation
Test1	0.3 m	0.3 m	1300 kN	2200 KN	0.2 m	0.1 m
Test2	1.0 m	1.1 m	3700 kN	5300 kN	1 m	0.4 m
Test3	0.8 m	0.9 m	3900 kN	6500 kN	1 m	0.3 m
Test4	0.9 m	1.1 m	5400 kN	6800 kN	1 m	0.3 m

Table 4 Comparison between Test Results and Numerical Results

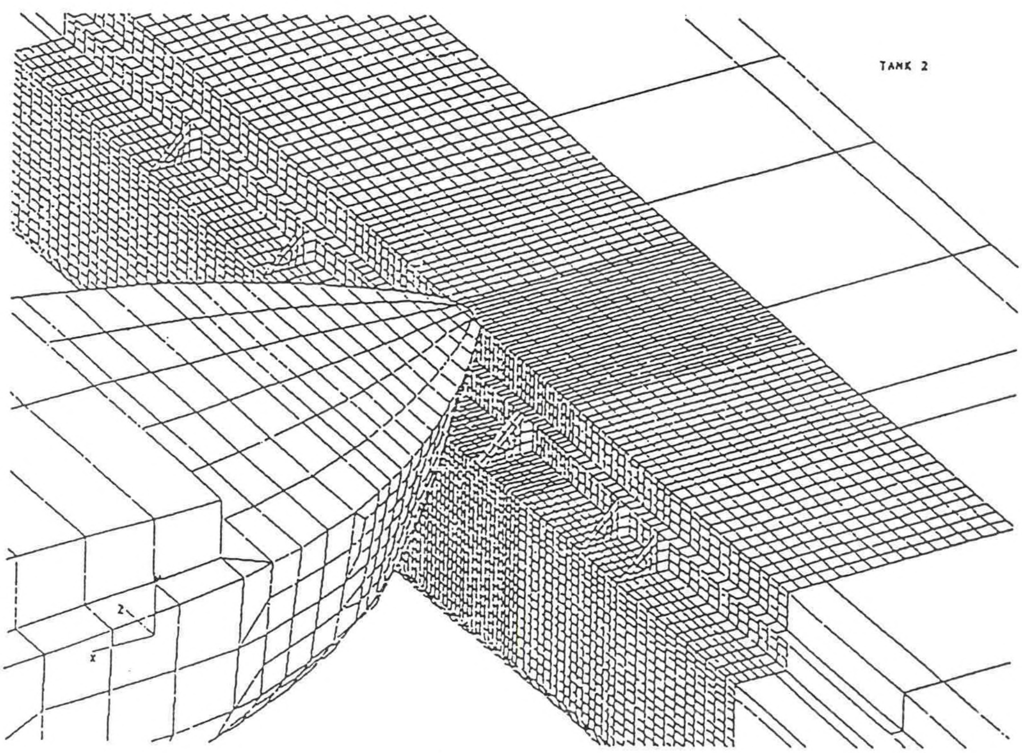


Fig.4 An Example of Simulation Model of the Ship Collision

(b)Numerical simulation of model experiments of grounding

The bottom structures were modeled for the simulations by finite elements. Taking account of their symmetry, 1/2 of the single bottom structure and 1/4 of the double bottom structure were modeled. The supports for the structures in the experiments were rigid enough, so the fixed boundary conditions at the supports were given for the simulations. The rupture condition for the simulations were given only at the center line of the bottom structure, the line along which the right angle edge of the rock model passes. Contact between the bottom model and the rock model and contact between each part of the bottom structures were considered. Friction associated with the contacts were taken into account. Though the rock model moved quasi-statically in the experiment, the moving speed of the rock model in the simulation was given to 6 m/s to reduce the computational time.

Deformations of bottom structure obtained by the simulation are shown in Fig.5. The deformations are in good agreement with the experimental ones. In Fig.6, the numerical results are compared with the experimental results. The raking force by the simulation have some sharp peaks, which are considered to be numerical spikes. Maximum raking force, excluding the sharp numerical peaks, were about 30% higher than experimental results. One of the reasons of the difference is that failures of the fillet welding were not considered in the numerical simulations. In the experiments, some failures of the fillet welding between stiffeners and bottom plates and between webs and faces of stiffeners were observed. Appropriate modeling of fillet welding of members is one of the subjects to be improved.

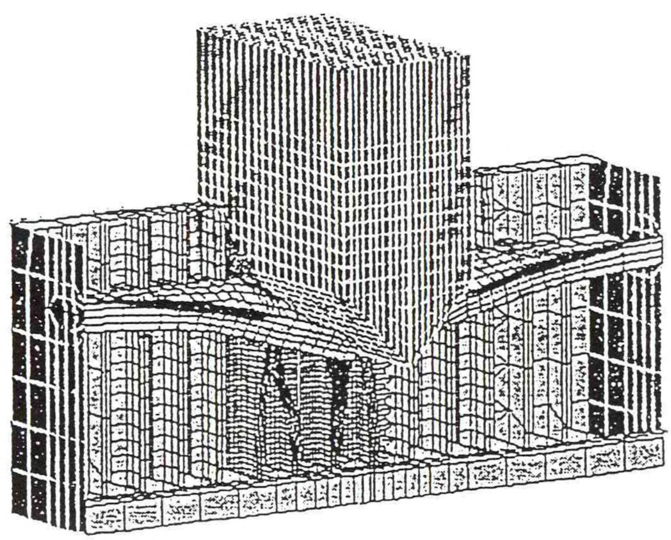
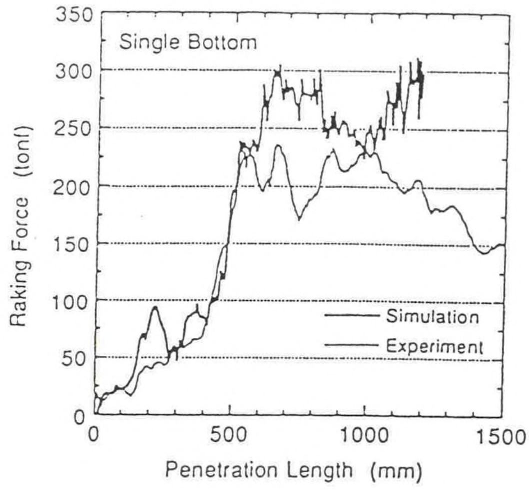
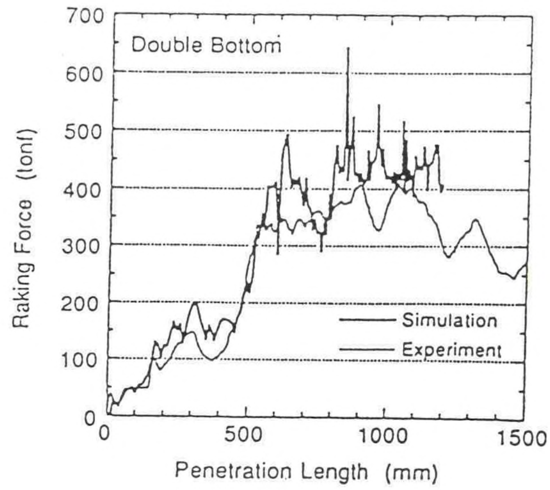


Fig.5 Simulation of Deformation of Bottom Structure(Single Bottom)



(a) Single Bottom



(b) Double Bottom

Fig.6 Raking Force vs. Penetration Length
- Comparison between Experiments and Simulations

1992

(a)Calculations are under plan to simulate dynamic failures of the structure members in the experiments.

(b)Dynamic effect on buckling, strain rate effects are to be studied.

(c)Initiation of rupture and welding are to be appropriately modeled in calculation.

(d)Analysis on the ship movements is to be studied by simulating the Dutch-Japanese full scale collision tests.

2.Prediction of oil outflow from damaged tankers(1992-1995)

In this section the mechanism of oil outflow behavior from the rupture is to be clarified, and the methodology of prediction of oil outflow from tankers is to be studied.

(1)Oil outflow behavior

For a given broken hole, a rough estimation of oil outflow volume could be given by the hydrobalance method, but actual conditions are more complicated, and the estimation requires to be corrected by appropriate measures. Prior to the study about such corrective measures some model tests are needed to evaluate the effects of motion of ships, current, swell and tide. Model tests were already conducted by Tsukuba Institute of Ship and Ocean Foundation for the IMO Oil Tanker Design Comparative Study. The results of the test are very impressive. Similar tests should be extended to different conditions to clarify the oil outflow behavior from the rupture of tankers. Analysis on accident reports of oil spill from tankers are also of use to clarification of oil outflow behavior.

1992

Experiments by IMO and other institutes or academies are to be analyzed.

(2)Prediction of oil outflow

Behavior of oil outflow being studied, some simulation models by computer are to be set up. In the light of the outcome of the model experiments, methods by simulation models to predict the volume of oil outflow are to be improved.

1992

Existing simulation models of oil outflow are to be studied.

3.Probability analysis of collisions and groundings(1992-1995)

Probability analysis of collisions and groundings could give us possible damage area, crash energy and other valuable information which should be taken account of for tanker structural design.

1992

To establish the database on collision and grounding accidents , existing databases and damage reports are to be assessed. And the standardized form of database are to be studied.

4.Expected value of oil outflow(1994-1997)

Expected value of oil outflow is supposed to be used as a tool to objectively evaluate pollution risks of different tanker designs. If we could agree on a particular expected value as a minimum standard, we could treat the minimum value as a performance standard. Then designers can have a room to display their ability. They could elaborate a balanced set of pollution reduction measures without being troubled by the illogical requirements of the letter of the regulation.

5.Trial design of oil tankers and total examination(1996-1997)

By combining the method to predict of structural failures and the method of prediction of oil outflow, predicting methodology will be established. Estimations will be performed for various types of oil tankers to develop new technology to design tougher oil tankers which minimize outflow of oil from them. Following items are to be taken into account for designing tougher tankers;
(a)Increase of collision and grounding resistance
(b)Defensive allocation of tanks and void spaces

The outcome of this program will be integrated into trial design of several oil tankers, and building cost or operation cost of these tankers as well as the validity for pollution prevention will be examined. We are convinced that the outcome of the project will be a tool of world-wide ship designers and ship builders to cope with marine pollution.

Systems Study on Sending CO_2 into Deep Ocean for CO_2 Recovery and Ocean Storage

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1. INTRODUCTION

The increasing awareness of global warming due to the greenhouse effect caused by carbon dioxide (CO_2) emissions from fossil fuel burning, is accelerating the study of countermeasures including the suppression of the increase in atmospheric CO_2.

To reduce the amount of CO_2 released into the atmosphere, various approaches have been suggested, which include the promotion of energy-saving measures, the shift of energy sources to ones which generate no/few CO_2, the recovery and fixation of CO_2 from flue gas, etc. At any rate, the volume of CO_2 at issue here is enormous and the situation of this problem is demanding urgent attention. Therefore, every possible solution should be studied and be evaluated quantitatively in terms of its effectiveness as well as its impact on the social economic situation.

For CO_2 recovery from flue gas, industrial research and development is in progress and pilot plant tests for some type of recovery methods have started at electric power stations in Japan[9]. Consequently, it is necessary to explore the possibilities of CO_2 fixation for their post-process.

Based on such background, ocean storage of CO_2, one of the fixation methods is treated in this paper, especially focusing how to transfer CO_2 from plant on land into deep ocean.

2. OCEAN STORAGE OF CO_2

As a method of suppression of the rise in the concentration of CO_2 in the atmosphere, the idea of recovering CO_2 from flue gas without releasing it into the atmosphere, and sending it into the ocean, is not so unusual. Its general concept has been mentioned in reports or articles that survey possible solutions to the problem of global warming. It is only recently, however, the studies have begun to be made on the effectiveness of this idea or the technological issues involved[1)-6)].

CO_2 which is released into the atmosphere used to be moved or be "transferred" into the ocean with the passage of time. However, the interchange of surface seawater with deep seawater is extremely slow, so that now there is a delay in CO_2 transfer which cannot keep pace with the increase in CO_2 volume in the air. If CO_2 is recovered and sent directly down into deep seawater, it should be possible to reduce the transfer backlog. From the aspect of volume to be treated, moreover, ocean has a great potential for storage space. But there are many problems to be studied to make clear how suitable this is as a long-term solution, and what will be its effects on the environment of deep ocean.

The whole process of ocean storage of CO_2 is divided into three phases in the context (see Fig.1). First phase is the process on land where CO_2 is recovered from flue gas and transformed into adequate form for transportation by some method or other at a land facility, and stored temporarily. Second phase is the system for CO_2 transfer from land to deep ocean which consisits of loading, transportation, sending, etc. And the last phase is concerned with the environmental assessment in the deep ocean; predicting and monitoring of CO_2 behaviour after sending into deep ocean is significantly important for the feasibility of this method.

3. CO_2 TRANSFER SYSTEM

The way of sending CO_2 from land into seawater is pigeonholed as follows;

1) Destination
   - offshore of plant on land
   - into seawater under thermocline
   - into seawater deeper than 3000m and more
   - on the seabed of deepwater
   - in trench
2) Form of CO_2
   - gas
   - liquid
   - solid
   - hydrate
3) Delivery
   - transport by ship
   - pipe line
4) Means of sending
   - gather to a specified domain
   - scatter

· leave to take its own course · dilute before release

The outline of CO_2 transfer system will be given by selecting items mentioned above and combining so as to be suitable from the viewpoint of environmental influence, cost, technological reliability and so on.

Needless to say, proper evaluation of environmental influence is most important. At the present time, however, adequate knowledge of and information (physical, chemical, and biological) about the condition of the ocean depths to which CO_2 would be sent is not available, and because there is no established criteria for making such evaluations, there is no choice but to defer addressing this subject to a later date.

Neverthless, the environmental influence and the way of sending CO_2 are interdependent. Therefore, supposing some tentative system that seems good and submitting it as a basis for discussion may be valuable at present stage. In the next section, one example of the CO_2 transfer systems tentatively examined by authors et al.[7),8)] is described.

4. CONCEPTUAL STUDY ON TRANSFER SYSTEM OF LIQUEFIED CO_2

For an example of CO_2 transfer system, the system depicted in Fig.2 is treated here; liquefied CO_2 is delivered by ship, and sent into ocean depths more than 3000m with use of suspended pipe under floating platform.

The system consists of CO_2 carriers, an ocean platform at the sea base, and suspended pipe for sending CO_2.

The CO_2 carrier comes alongside the pier or wharf in the port and takes on liquefied CO_2. Then the ship sails to the ocean platform, connects its tanks with the storage tanks of the platform through loading/unloading manifolds, and delivers CO_2 to the platform. The condition of this CO_2 would be something like -54° C, 6 bars (cf. phase diagram in Fig.3). Therefore, the function of the ship is fundamentally not different from that of pressure vessel type of LPG or LNG carrier which transport liquefied gas from one port to another. The conceptual drawing for the CO_2 carrier becomes like that depicted in Fig.4. In developing a liquefied CO_2 carrier, the technology already implemented in liquefied gas carriers can be utilized, considering the differences in physical properties.

The role of the ocean platform is to stand by at site, receive CO_2 from ship, store it temporarily, and send it into the ocean depths via suspended pipe. A semisubmersible platform (like that depicted in Fig.5) will be appropriate for the floating platform in the open sea in order to minimize dynamic motion in waves. However, should it be necessary to provide the ocean platform with large storage capacity of CO_2, a conventional ship type platform seems better, provided that it can readily seek refuge from hazard weather (see Fig. 6).

Besides the suspended pipe and storage tanks, the ocean platform would also be equipped with required facilities for piping, handling of pipe for raising and lowering, maintenance, mooring ship, etc. It should also have some kind of dynamic positioning system so that it will not be drifted from the planned sea area by winds or current.

Suspended pipe under the platform is used to send the liquefied CO_2 continuously down to the ocean depths more than 3000m. This depth of 3000m is based on the temperature and pressure conditions under which the density of liquefied CO_2 becomes greater than the density of seawater because of the difference of compressibility between liquefied CO_2 and seawater (cf. Fig. 7). The behaviour of CO_2 in deep ocean is something that must be studied later. However, in terms of the fundamental objectives, it is necessary that the CO_2 will not float up to the surface in the short term and be released into the atmosphere.

The system described above should be implementable using either existing technology or its extending applications. Undeniably, however, various elemental technologies would have to be developed; especially reliable technology of sending CO_2 with use of a long suspended pipe.

5. BASIC EXPERIMENTS ON LIQUEFIED CO_2 BEHAVIOUR IN DEEP OCEAN

In order to investigate the properties of CO_2-seawater system under the deep water conditions, a deep-sea simulating test apparatus is manufactured that could withstand 500 bars corresponding pressure of 5000m water depth[10]. Inside capacity of apparatus is about 2 liters; inner diameter of 50mm and height of 1000mm. Schematic view of the apparatus is given in Fig. 8. The test apparatus is situated in the cold room where it is possible to set the temperature under control.

Basic tests are conducted in which liquefied CO_2 is injected through a nozzle slowly into the apparatus filled with seawater/pure water under high pressure, and the CO_2 behaviour is observed.

The condition of descending CO_2 liquid drops is shown in Fig. 9. The upper photograph in Fig. 9 shows the condition seen from the window that is installed in the vicinity of the injection nozzle. Slowly injected liquefied CO_2 hangs down from the nozzle end due to its interfacial tension, and becomes larger gradually until its weight in water excess the interfacial tension. After separation, the liquid drops of CO_2 forms nearly perfect sphere (for example 16mm in diameter under the test condition of the displayed pressure of 368 kg/cm², the temperature of 2 ° C and the nozzle diameter of 2mm), and descends in the seawater at a speed of 12 cm/sec. The lower photograph shows the condition seen from the window installed near the bottom of the vessel, 98cm below the nozzle end. The drops continue to maintain independent spherical shapes after reaching the bottom.

On the other hand, at pressure below 300 kg/cm², the injected CO_2 forms relatively small drops (2-10mm) and ascends.

Thus it is demonstrated that liquefied CO_2 sinks in seawater under pressures corresponding to ocean depths of approximately 3000m or more. In other words, the most basic principle underlying the idea of sending liquefied CO_2 into the deep ocean is verified experimentally. Hereafter, this test apparatus will be used to obtain more data on the properties of CO_2-seawater system under the deep water conditions.

6. CONCLUSION

In this study, the ocean storage of CO_2 for recovery and fixation approach is discussed, especially focusing how to transfer CO_2 into deep ocean. The industrial process of ocean storage consists of three phases, that is the process on land, the transfer system, and assessment phase. First of all, proper evaluation of environmental influence is important, so that the transfer system and even the process on land should be determined under consideration of it. At the present time, however, there is no established assessment criteria or technique for making such evaluations. The environmental influence and the way of sending CO_2 are interdependent. Therefore, supposing some tentative transfer system and submitting it as a basis for discussion would be valuable to step forward the feasibility study of this procedure.

One example of CO_2 transfer system is described in this paper; liquefied CO_2 is delivered by ship, and sent into ocean depths more than 3000m with use of suspended pipe under floating platform. Furthermore, basic experiments are conducted on the behaviour of liquefied CO_2 in deep ocean using a high pressure vessel in the cold room.

The feasibility of the ocean storage of CO_2 for recovery and fixation approach should be evaluated comprehensively, looking at the whole process. Thus, there is still much evaluation work to do, including comprehensive economic evaluations, long-range effectiveness evaluations, and investigations into the influence on the deep ocean environment.

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process on land		CO_2 transfer system		assessment phase
*Recovery *Volume reduction (solidification/ liquefaction, etc) *Temporary storage	⇨	*Transfer (loading/ transportation/ sending, etc)	⇨	*CO_2 behaviour in deep ocean (prediction/ monitoring)

Fig. 1 Process of ocean storage of CO_2

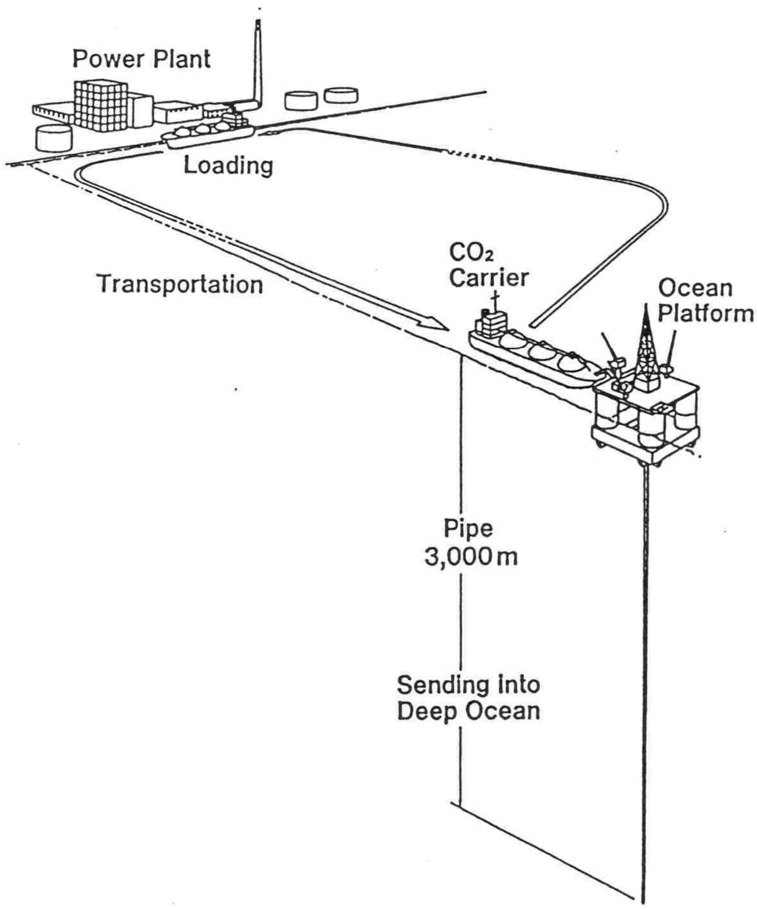

Fig. 2 Conceptual general view of transfer system of liquefied CO_2 into deep ocean

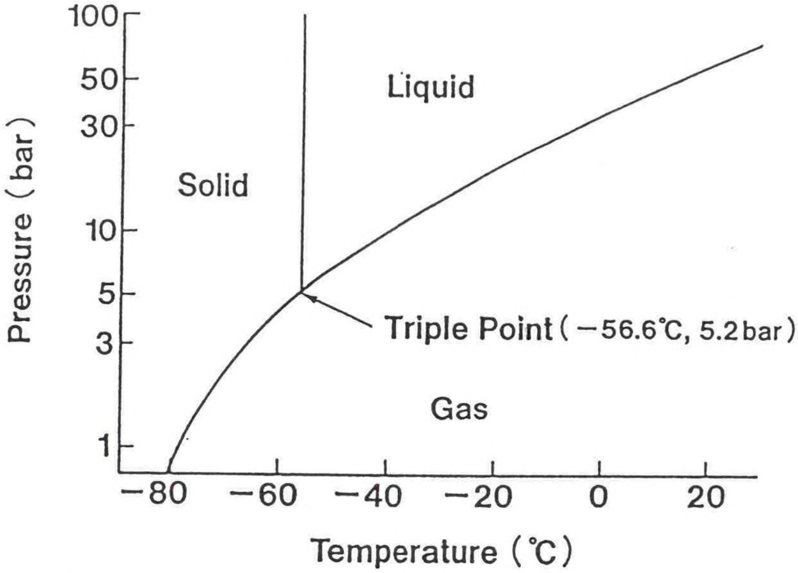

Fig. 3 CO_2 phase diagram

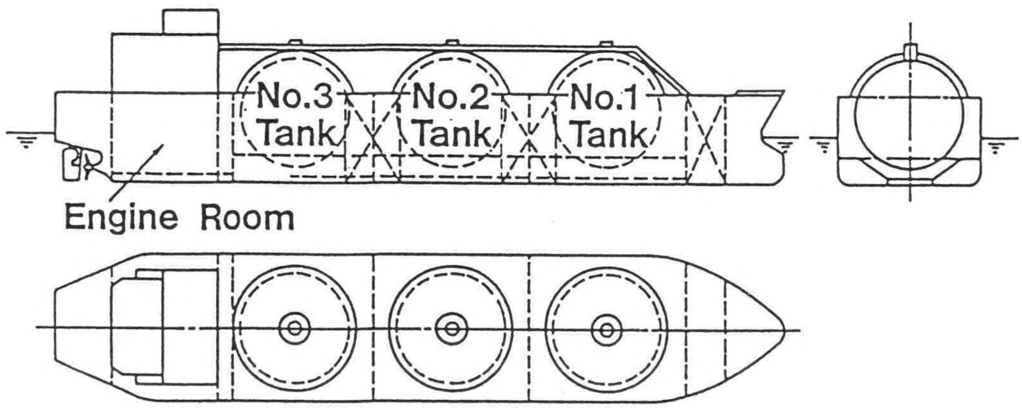

Fig. 4 Rough arrangement of CO_2 carrier

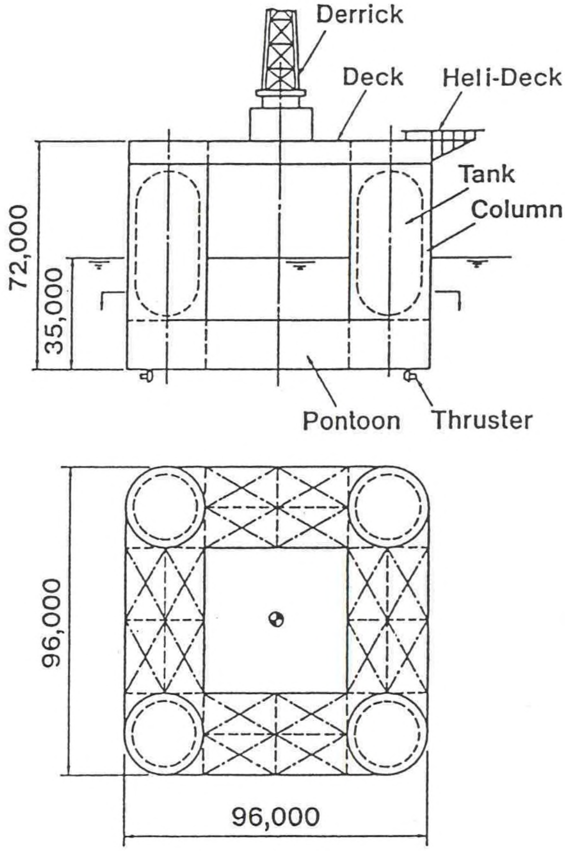

Fig.5 Rough arrangement of ocean platform of semisubmersible type

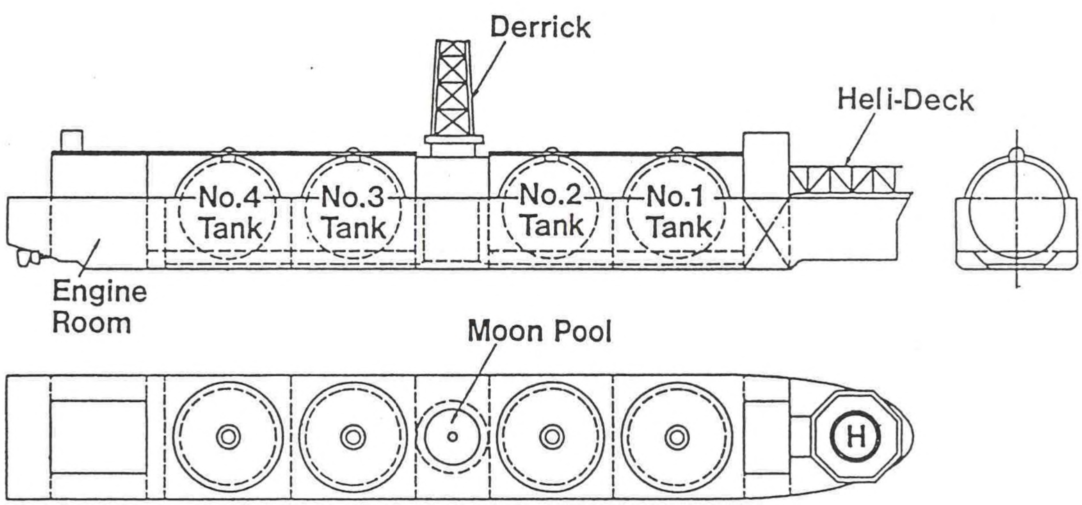

Fig.6 Rough arrangement of ocean platform of ship type

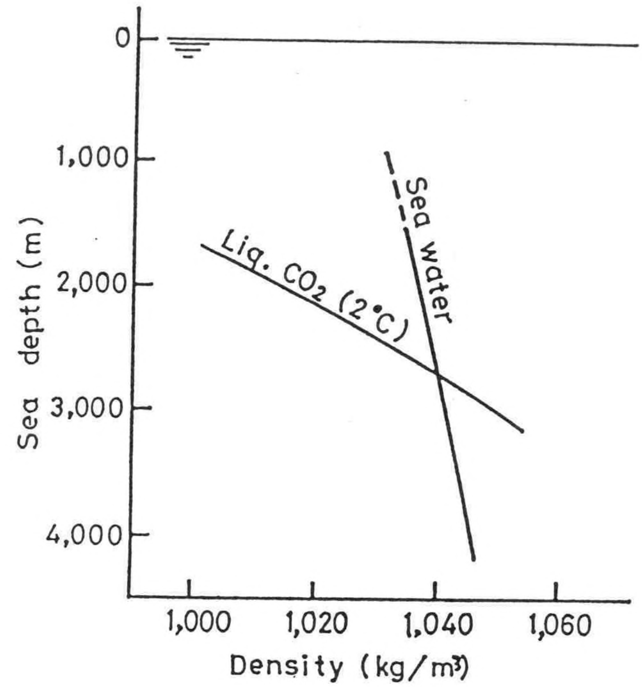

Fig.7 Comparison of density between liquiefied CO_2 and seawater

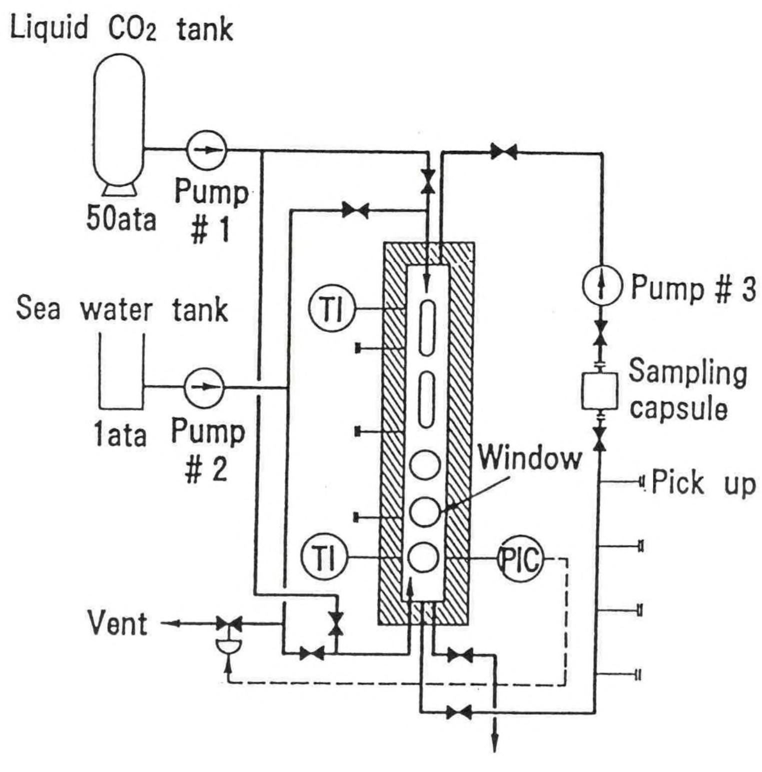

Fig.8 Schematic view of test apparatus

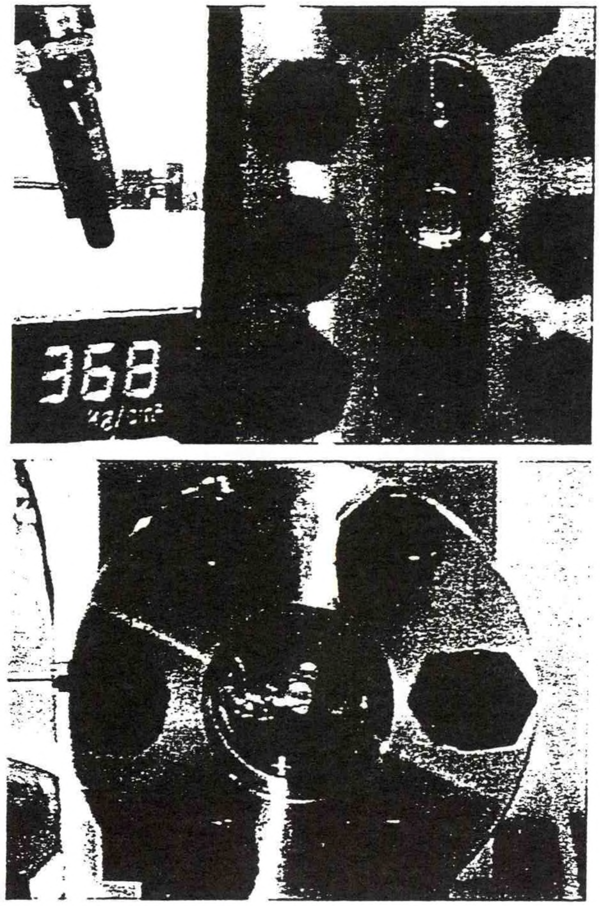

Fig.9 Appearance of CO_2 injection test;
Sinking liquid drops of CO_2 in seawater

Research in the US and Japan on Pendular Wave Energy Converters: Multi-Product Applications

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Introduction

This paper describes two independent wave energy development projects, one in Japan and one in the United States, and how the results of each can be combined to yield a durable, low-cost module for perimeter construction of large open-ocean platforms. This module could provide several products:

- Platform protection from damaging wave forces
- Seawater pumping for aquaculture recirculation and for space or process cooling
- Fresh water from desalination by direct reverse osmosis
- Electric power

The first section of the paper describes the wave energy development work that has been carried out at Muroran Institute of Technology in Japan, supported in part by the Hitachi Zosen Corporation. This project is directed towards utility-scale wave energy breakwaters on the order of a few megawatts capacity and has involved construction of the world's longest operating wave power plant, a 20 kWe caisson-based unit located on the west coast of Hokkaido, which was reported nine years ago at the 11th Meeting of the UJNR Marine Facilities Panel [1] *.

The second section describes a much more recent project, initiated by SEASUN Power Systems in the United States. With support from the U.S. National Science Foundation and Virginia's Center for Innovative Technology, laboratory wave tank testing has been conducted on a totally submerged wave-powered pump. This project is directed towards the small-scale needs of island communities and rural coastal areas, where the provision of a few thousand liters of fresh water per day or a few kilowatts of power would improve basic living conditions and facilitate economic growth.

Although these two projects are very different in scale and commercial application, the fundamental geometry of the wave energy absorber is that of a simple pendulum, where absorber restoring moment is provided by weight or buoyancy, depending on whether the absorber is suspended from above the sea surface or attached to the seafloor. Based on this geometric similarity, the third section of the paper describes a wave energy module that combines the best features of these two projects. The last two sections of this paper describe potential applications of such a module in coastal breakwaters and offshore utilization of ocean space.

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* Numbers in brackets are reference citations, listed at the end of the text.

Muroran Institute of Technology

For over a decade, the Muroran Institute of Technology has developed a caisson-based pivoting flap device, which it calls the Pendulor System [2]. The Pendulor itself is a stiffened steel plate that hangs down into a recessed capture chamber. Unlike oscillating water column devices, where the capture chamber extends below the sea surface, the Pendulor System caisson is entirely open to the sea (Figure 1). Incident waves interact with waves reflected off the back of the chamber to create a standing wave. The Pendulor is positioned at the node of this standing wave, where horizontal forces are at a maximum. As the Pendulor swings in response to these surge forces, it drives a double-acting hydraulic cylinder.

The fluid output of the cylinder is rectified such that one hydraulic motor is driven on the cylinder's compression stroke, and a second motor is driven on the cylinder's extension stroke. The speed of the generator drive shaft thus remains relatively constant throughout the wave cycle.

In April 1983, a 5 kW (hydraulic motor rating) prototype was installed at Muroran Port, on the south coast of Hokkaido. The prototype caisson is sited in front of an existing seawall, in a water depth that ranges from 2.5 m at low tide to 4 m at high tide. Two capture chambers have been built into the caisson, but only one has been fitted with a Pendulor (Figure 2).

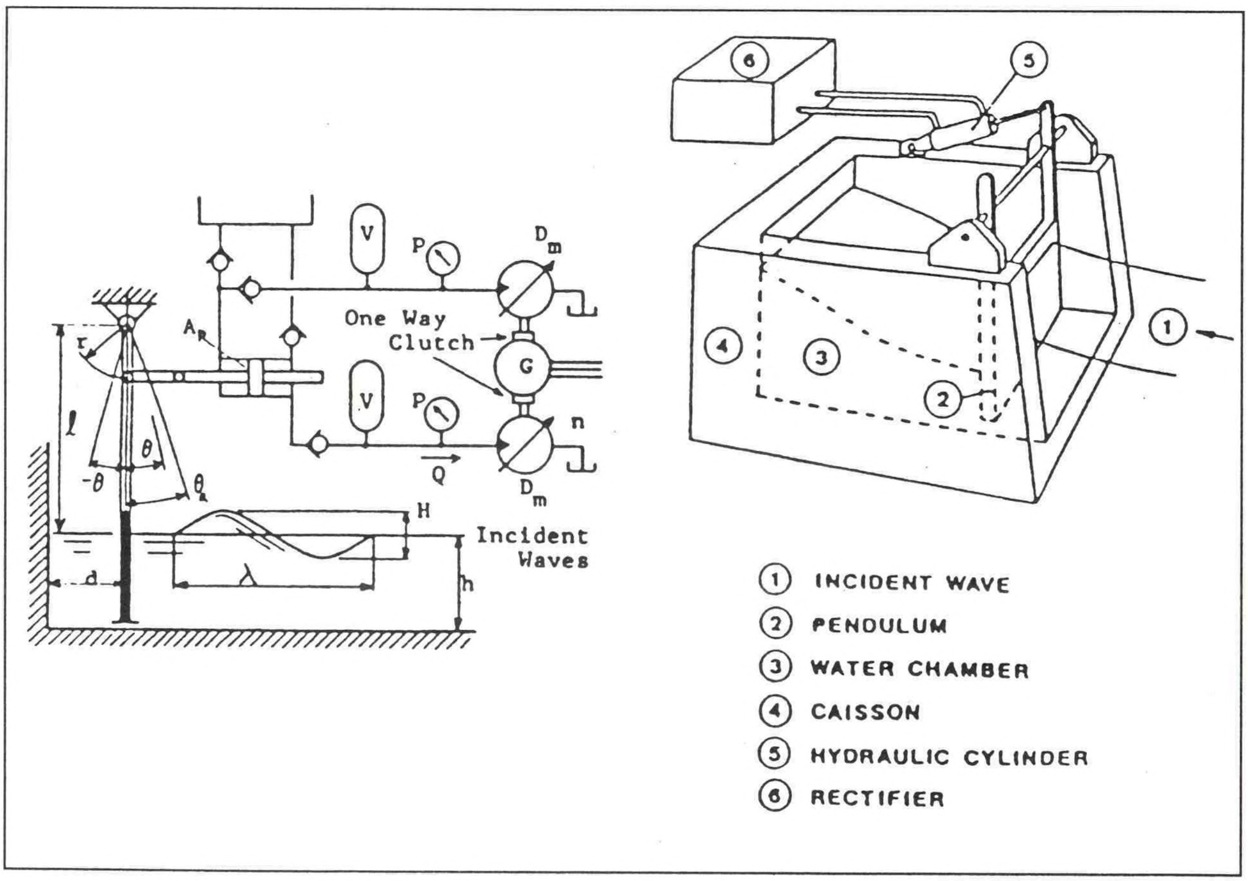

FIGURE 1. Pendulor System - concept and schematic diagram of rectifier.

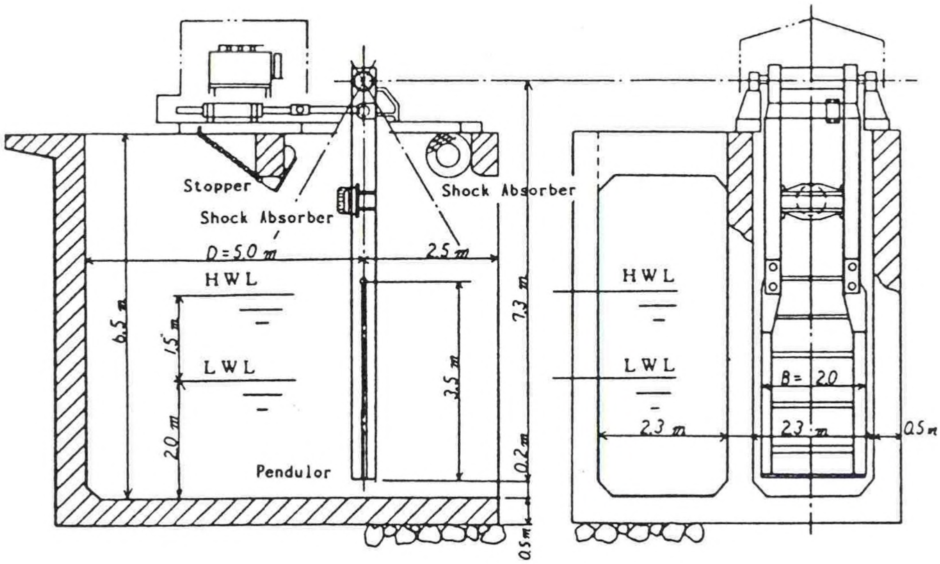

FIGURE 2. Pendulor System - 5 kW (hydraulic) prototype at Muroran Port.

Twenty months after its installation, the Pendulor was bent during a severe storm, and the shock absorbers for the end-stops, which prevent over-stroking of the hydraulic cylinder, had to be redesigned. A new Pendulor was installed in November 1985, and the prototype has survived several severe storms since then, without damage.

A small Pendulor System that generates electric power was deployed in 1981. Rated at 20 kWe, this unit is used to heat the public bath of a fishing cooperative at Mashike Harbor, on Hokkaido's west coast [1]. Unfortunately, its Pendulor was also damaged by a storm, just three months after installation. It was replaced by a shorter Pendulor in 1983, which left a considerable gap at the bottom of the capture chamber. While this has prevented further damage, it also lowered the system's conversion efficiency [3]. Nevertheless, the plant continues to operate.

SEASUN Power Systems

This project is directed towards establishing the feasibility of using a wave-powered pump to provide high-pressure seawater at remote coastal and island locations. Its potential commercial value revolves around the many possible uses of high-pressure seawater: it can be circulated in onshore aquaculture ponds, passed through a reverse osmosis membrane to produce fresh water, or passed through an impulse turbine to generate electric power.

This is a small-scale device, assembled from modular components that can be handled by a crew of two to four people and deployed by SCUBA divers working out of an open boat. Offshore components would be deployed in relatively shallow water, close to shore, and would be entirely submerged beneath the sea surface.

In shallow water, wave orbital motions flatten into ellipses, and most of the wave's sub-surface energy is directed horizontally. During a series of wave tank tests conducted during the summer of 1991, the submerged shape designed to absorb this surge energy evolved from a buoyant horizontal cylinder into a rectangular box [4].

An absorber model was built with four tall rectangular compartments arranged side by side across its width. The central two compartments were open on the front (seaward) face of the absorber, while the outer two compartments were enclosed and could be flooded with water to any level, thereby changing the model's buoyant restoring moment.

Two versions of the box-shaped model were tested (Figure 3). In Model 1, the outer two compartments were almost completely filled with air, such that buoyancy provided the restoring moment when the absorber was deflected by waves. In Model 2, the outer two compartments were completely flooded, such that the absorber's net buoyancy was slightly negative, and restoring moment was provided solely by a clamped leaf spring.

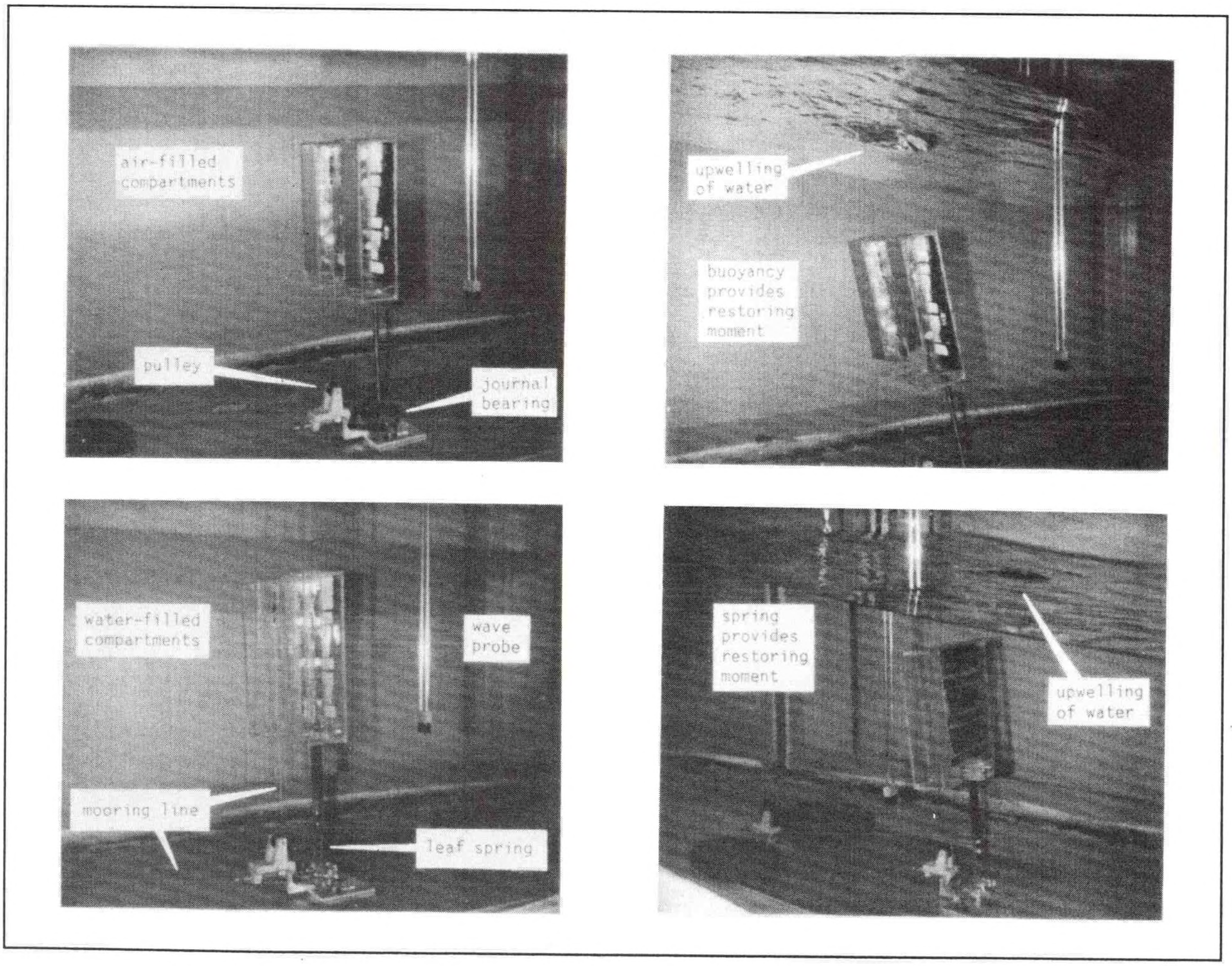

FIGURE 3. SEASUN Power Systems' wave energy absorber model in still water (left photos) and deflected seaward under a regular wave (right photos). Top photos are of Model 1, bottom photos of Model 2.

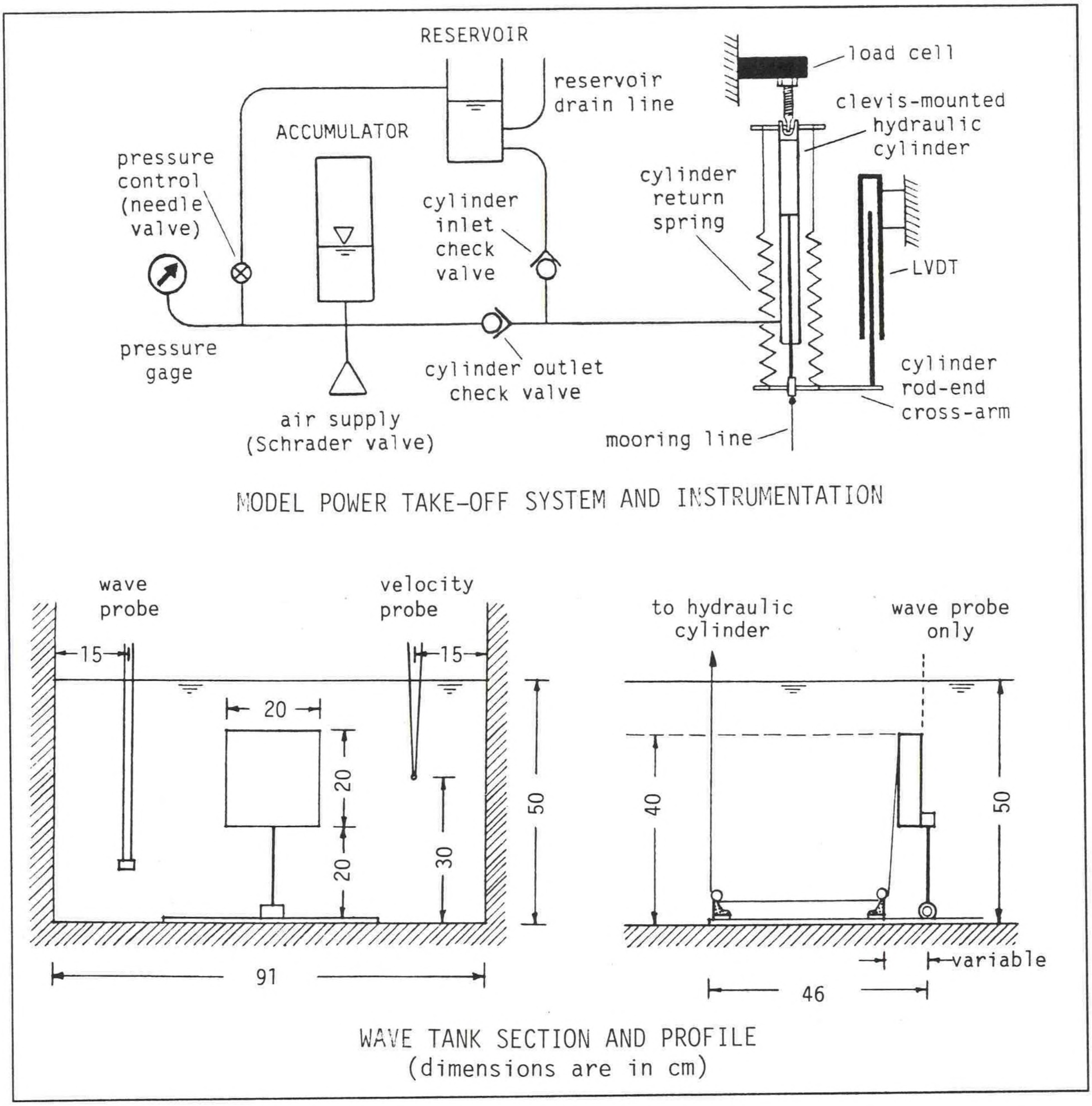

FIGURE 4. SEASUN Power Systems' model power take-off system and absorber test arrangements.

The power take-off system of a full-scale device would be a single-acting pump mounted in line with a taut mooring between the top of the absorber and a seafloor anchor located seaward of the absorber's pivot point. For the wave tank tests, it was more practical to run the mooring line through a pair of pulleys to a hydraulic cylinder mounted on an overhead carriage, for ease of access and instrumentation (Figure 4). Apart from the frictional resistance of the pulleys, however, this model arrangement has the same mechanical damping characteristics as if the pump were submerged and placed in line with the mooring as described for the full-scale unit.

A single-acting power take-off system has several practical advantages in that structural components of the pump/mooring need be designed only to resist tensile loads. At first glance, it seems to be inherently less efficient than a double-acting system, since energy is recovered only during the pump's power stroke. Upon considering the balance of forces acting on the absorber throughout the wave cycle, however, it can be seen that a single-acting system actually recovers energy absorbed during the pump's refill stroke as well.

When the absorber is deflected seaward during the refill stroke, restoring moment is accumulated either by increasing buoyant moment arm (Model 1) or bending of the leaf spring (Model 2). This accumulated moment represents stored potential energy, which is released when the absorber is deflected shoreward later in the wave cycle. Thus during the power stroke, the pump is driven by potential energy stored during the refill stroke, as well as the wave's kinetic energy acting directly on the absorber.

Last summer's wave tank tests also confirmed that a leaf spring can be used instead of net buoyancy to provide restoring moment without sacrificing hydrodynamic performance. This means that the seafloor anchoring system for the absorber base need be designed to resist overturning only, rather than overturning *and uplift*. The use of a leaf spring also eliminates the need for a journal bearing, with its potential for binding due to eccentric wave loading and/or sediment buildup between bearing surfaces.

Combining Both Projects

In the double-acting Pendulor System, the pump is stroked during both seaward and shoreward deflections of the Pendulor, and its swing is mechanically dampened in both directions. If this were converted to a single-acting system, however, the seaward swing of the pendulum would be much greater, and it would store up that much more energy for recovery during its shoreward swing later in the wave cycle.

If the single-acting pump was provided with sufficient return spring, then it would operate constantly in tension, with no compressive stresses or potential buckling problems due to eccentric loading of the cylinder rod end.

Another advantage of this modification is that single-acting pumps are available that have been expressly developed for seawater service in wave energy applications. An open-circuit seawater system has many practical benefits:

- No risk of chemical pollution
- No requirement for a heat exchanger to dissipate excess absorbed energy in extreme wave conditions
- The possibility of fresh water production by direct reverse osmosis, without an electric high-pressure pump

With an open-circuit seawater system, a variety of co-products could be produced by a single wave energy breakwater. Some of the pumped seawater could be diverted to onshore aquaculture ponds, while the rest would enter a reverse osmosis (RO) module. At a seawater pressure of 800 psi (5.5 MPa), only 20% of this flow would pass through the RO membrane as fresh water; the remainder could be discharged through a Pelton turbine to generate electricity.

Two very different seawater pump designs have been developed that could be used in such a modified Pendulor System.

One of these is the composite hydraulic cylinder design developed by Hicks, Pleass, and Mitcheson at the Universities of Delaware and Puerto Rico for their heaving buoy wave energy device [4]. Another is the elastomeric hose pump developed by Gotaverken Energy in Sweden for their heaving buoy system [5]. Both of these pump designs have been proven in full-scale sea trials.

Application to Wave Energy Breakwaters

Since caissons reflect all wave energy that they don't absorb, there is the possibility of a distinct low-energy "shadow" developing behind the plant, depending on how closely the individual caissons are spaced. This maximizes their potential environmental impact on longshore sediment transport. It is this reflective feature of caissons, however, that make them ideal candidates for combining wave energy generation with breakwater protection at coastal harbors. In such cases their visual appearance would probably not be considered intrusive, since local scenery has already been altered by the existing harbor development.

Even in remote coastal areas, an occasional wave energy breakwater might be acceptable for creating a harbor of refuge for small craft in the event of sudden storms, medical emergencies, fuel depletion, or engine problems. The co-production of fresh water and electricity would have obvious advantages in such an application.

It should be noted, however, that the potential market for wave energy breakwaters is relatively small. For example, Pacific Gas and Electric Company (PG&E) has an open ocean coast approximately 1,000 km in length. Yet a recent survey identified only two existing harbors that needed additional breakwater protection, and five coves that could be developed into harbors of refuge. The potential wave generating capacity at these seven locations was estimated to be only 12.5 MWe [6], which is insignificant in terms of PG&E's grid-wide demand. Nevertheless, if even the smallest of these (700 kWe) was developed, it would more than double the world's present wave generating capacity. Therefore, breakwaters are an important stepping stone in the commercialization of wave power.

Application to Ocean Space Utilization

Very large floating structures (VLFS) have been proposed for a variety of offshore applications, including airports, space launch facilities, naval bases, living and recreation complexes, and production of energy-intensive materials and fuels. Barge-like VLFS modules are less costly than semisubmersibles, but require protection from wave action [7]. Fabricating the perimeter of such a VLFS in the form of recessed capture chambers to accommodate pivoting flaps should not add significantly to its total construction cost.

The large inertia of the VLFS provides the necessary reaction point for these absorbers, which in turn act to remove energy from the wave before it passes under the platform. It should be noted that much of this energy is ultimately absorbed by the VLFS via structural foundations for power conversion equipment, but these may be less costly than designing the platform to withstand large sagging and hogging loads associated with undampened waves.

Fabrication of the concrete caissons accounts for 75% of the direct capital cost of the Pendulor System [2]. If the fabrication cost of the VLFS is supported by revenue derived from its main function, then wave energy costs for power conversion equipment and other balance-of-plant are projected to be less than 10 ¢/kWh in the relatively low-energy wave climate of Muroran Port [9]. It could well be less than half this amount for a modified Pendulor System incorporating a single-acting, high-pressure seawater pump, exposed to the more energetic waves of the open ocean.

The development of VLFS-based offshore wave power plants could lead to the large-scale production of hydrogen for mainland electric power generation and as a heating or transportation fuel. If so, wave energy has the ultimate potential to supply a large portion of global energy demand, as explained below.

A steady wind blowing over water imparts its energy to waves, which grow in size until they become unstable and break. Shorter-period waves reach limiting steepness first, while longer-period waves continue to grow. Longer-period waves also have a higher group velocity (the speed at which wave energy propagates across the ocean surface), and for a given wind speed, waves longer than a certain period travel faster than the wind. Once waves of this period have reached limiting steepness, the sea can absorb no more wind energy and is said to be fully developed. At this point, energy input from the wind is offset by energy losses due to wave breaking.

If energy is absorbed from a fully developed sea by a wave power plant, however, the waves can absorb more energy from the wind than otherwise. Given sufficient fetch downwind of the plant, the waves will again become fully developed, regaining the energy that was absorbed.

To use an agricultural analogy, waves re-grow as they are "grazed", and the overall productivity of the sea surface (in terms of rate of energy yield, or power) increases. If such cropping can be achieved economically on a worldwide scale, then the global wave energy resource exceeds that of ocean thermal energy conversion [10].

The persistent trade winds of the tropics provide a wave climate in which such cropping is a realistic proposition. Mathematical modeling indicates that at a wind speed of 10 m/sec, wave regrowth between power plants spaced 50 km apart along a 600 km fetch increases wave energy yield by 40% [11].

The ultimate prospect of large-scale production of wave-generated hydrogen suggests certain criteria for wave energy conversion devices that might be targeted for accelerated research and development during the next five years. One criterion is an absorber configuration that can be easily integrated into VLFS perimeter construction. Another is the use of high-pressure seawater as a working fluid. Efficient electrolyzers require fresh water, and with a sufficiently large ratio of absorber area to pump cross-section, seawater can be desalinated directly via reverse osmosis, without an electrical intermediary step.

It is hoped that this paper will lead to a cooperative program between Japan and the United States that would combine the best features of the two projects described herein to produce a wave energy module meeting the above criteria. Such a program might commence with wave tank testing and lead to the deployment of a kilowatt-scale caisson-based unit for ocean testing of performance and durability.

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Antifouling System for Ship Hull by Electro-Conductive Coating

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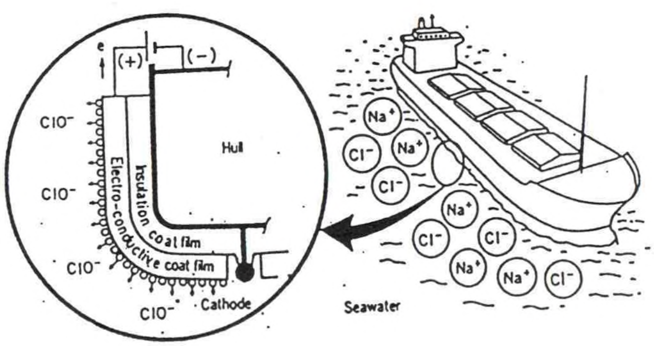
When marine growth adheres to the surface of ship's hull, fuel consumption increases, and conventionally antifouling paints consisting of organic tin compounds have been used for preventing adhering. However, organic tin compounds dissolving from these are known to contaminate the environment and tributyl tin compounds were designated as toxic substances in September, 1990; a substitute antifouling system is required.

Mitsubishi Heavy Industries (MHI) and Ship & Ocean Foundation (SOF) have developed a new antifouling technique using electrolysis technology, that prevents marine growth from fouling the surface of ship's hull.

1. Basic principle of the technology

The water contact surface of the hull shell plating is coated with an electro-conductive paint film through an insulated coat film, a small current is passed through this paint film to form the anode, while the electrode surface layer of the electro-conductive film is coated with hypochlorous ions by electrolyzed reactions as shown in Fig. 1. In this way adhesion of marine growth such as microorganisms, algae, and seashells may be prevented. The hypochlorous ions formed on the electro-conductive film surface are only slight, and disappear as they depart from the hull surface on reacting with other components in seawater, and will not contaminate the ocean.



Anodic reaction

$2Cl \rightarrow Cl_2 + 2e$ (1)

$4OH \rightarrow O_2 + 2H_2O + 4e$ (2)

$Cl + 2OH \rightarrow ClO + H_2O + 2e$ (3)

In a weak alkaline aqueous solution,

$Cl_2 + 2NaOH \rightarrow NaClO + NaCl + H_2O$ (4)

Cathodic reaction

$2H_2O + 2e \rightarrow 2OH + H_2$ (5)

Fig. 1 Principle of marine growth prevention system by electro-conductive coating

2. Features

This technology features the following points:

(1) By making use of the electrolytic action of seawater, an environment that tends to prevent adhesion of marine growth is directly formed on the surface of the object, and the coat film does not contain pollutant such as organic tin or heavy metals (cuprous oxide, etc.), so that harmful substances are not eluted to the seawater, and ocean pollution is prevented.

(2) The electro-conductive paint used in this technology does not contain components eluting into the seawater, differing in this way from the conventional antifouling paint, and stable antifouling performance is maintained for a long period. In addition, having no eluting components, the coat film surface remains as smooth and fresh as it was immediately after coating, thus contributing to saving fuel.

(3) This technology also involves the function of impressed current cathodic protection, thereby if the coat film is damaged and the outer plank exposed, the part is protected electrically. In other words, the anodic reaction area is increased in the impressed current cathodic protection being used for existing vessels, and all the underwater portions are covered.

3. Present situation of the study

3.1 Development of electrolysis-resistant and high electro-conductive film[1]

In the case of this technology, since the film is used as the electrode in the seawater, in addition to excellent electro-conductivity, high electrolysis resistance is required.

As results of experiment of various resin paints and electro-conductive pigments, a two-layer structure was designed, with the electro-conductive material in the lower layer and the electrolysis-resistant material in the upper layer, to develop an electro-conductive film possessing both high electro-conductivity and excellent electrolysis resistance.

3.2 Confirmation of antifouling performance

Fig. 2 shows the results of the immersion test using raft outside Nagasaki Port.

Two test pieces coated with electro-conductive film, one energized and the other not, were suspended in the sea and immersed for about a year. To the non-energized piece, marine growth was wholly adhering, but no deposit was detected on the energized piece, and the antifouling efficacy of this technology was confirmed.

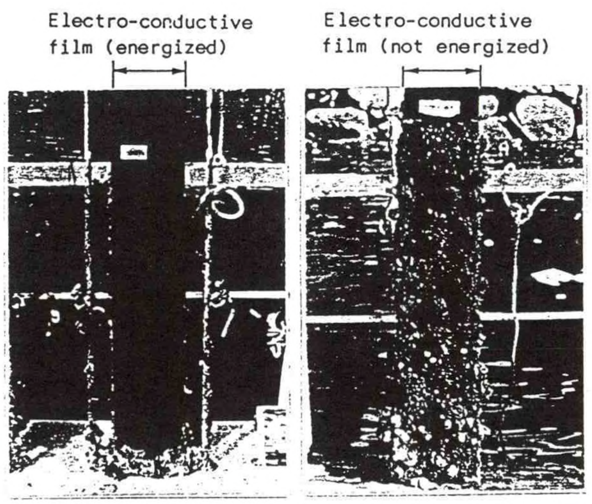


Fig. 2 Immersion test
(test pieces after about one year's immersion at Nagasaki Port)

3.3 Development of current supply method

This technique is intended to exhibit the antifouling effect by using the electro-conductive paint film as the anode, supplying current to the anode, and electrolyzing the seawater; a counter electrode is necessary in principle, but separate installation of the counter electrode may not always be desirable in practice. As a countermeasure, the fundamental test taking into account the ecological cycle of the marine creatures was performed. As a result, it was confirmed that fouling may be prevented by supplying electric currents at regular intervals, instead of supplying continuously. Therefore the coat film itself is used alternately as anode and cathode so that no counter electrode was necessary. This current supply method was applied to the 40GT ferry boat and the 200GT tag boat, and favorable results were obtained.

3.4 Full scale test using a small ship

Fig. 3 shows the result of the navigation test in the three summer months when the activity of the marine creatures is at its peak. In the test, the electro-conductive paint was applied in August, 1988 to the bottoms of the 40GT ferry boat "Tsubame" used at Nagasaki Shipyard & Machinery Works. This test was continued for about two years, and antifouling performance comparable to that of the organic tin paint applied for reference was confirmed in the sea cruising state.

Furthermore, in August, 1990, as shown in Fig. 4, the entire shell plating surface of the "Tsubame" was coated (about $100m^2$), and the antifouling durability test was started. The appearance of the shell plating seven months later is shown in Fig. 5; no adhesion of growth was found.

In April, 1991, as shown in Fig. 6, 200GT tag boat "Shohomaru" was coated and the antifouling durability test was started.

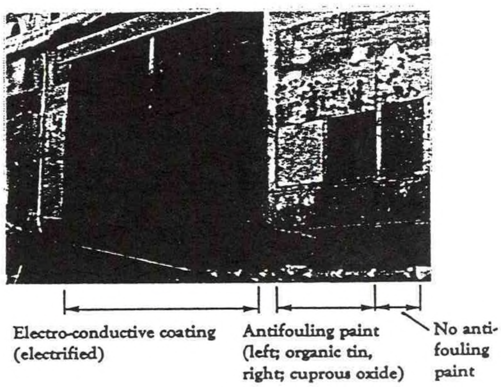


Fig. 3 Full scale test using a small ship (after about three months in summer)

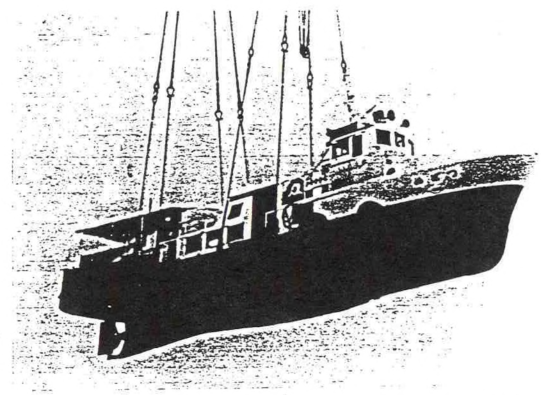


Fig. 4 Full scale test: using small ship "Tsubame", just applied electro-conductive coating

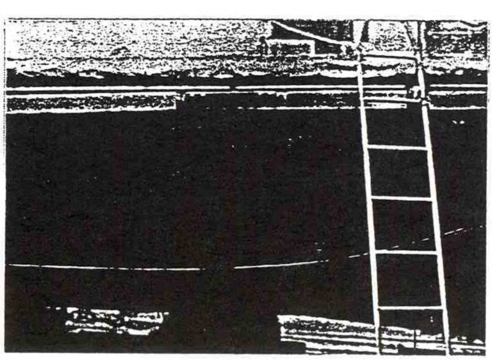


Fig. 5 Full scale test: "Tsubame" after seven months

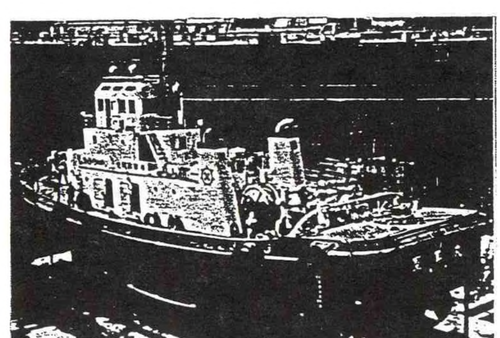


Fig. 6 Full scale test: 200GT tag boat "Shohomaru"

4. Hull antifouling system based on this technology

This system is composed of two parts, namely:

(1) Electro-conductive paint film applied on the hull shell plating through insulated coat film.

(2) DC power supply unit to control the current supply to the electro-conductive paint film.

On the electro-conductive paint film of (1), electric current is supplied while the polarity of the electro-conductive paint film is controlled by the power supply unit of (2) to prevent fouling of the hull shell plating.

The current supply used at this time is very small, roughly equivalent to the current used in the existing impressed current cathodic protection of hull, and its effect on the human body, peripheral devices in the ship or the cargo is nil. The power consumption is correspondingly low, equivalent to some scores of watts per $100m^2$.

In this system, through installation of short circuit properly controlled with the hull shell plating as shown in Fig. 7, if the coat film is damaged and the hull shell plating exposed, it is protected cathodically.

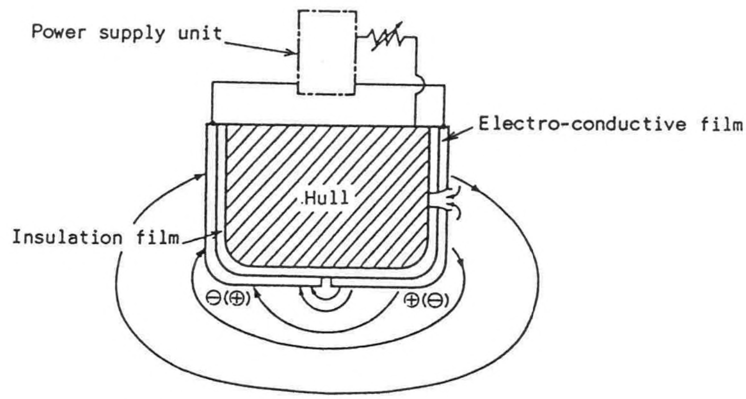


Fig. 7 Antifouling and anticorrosion system for ship's hull by electro-conductive coating

5. Future problems

By means of the fundamental tests conducted so far, feasibility in small ships was verified, as shown above. For application to large vessels, the following problems are the main subject of studies for commercialization at present.

(1) Improvement in performance of electro-conductive coat film (electrolysis durability, electro-conductivity)

(2) Seizing the relation between seawater properties and optimum current supply condition.

(3) Establishment of effective application method to ships, and optimum system designing method

(4) Verification of long-term antifouling performance and durability.

(5) Confirmation of practically and reliability in actual ships.

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STUDY ON THE WAVE POWERT DEVICE "MIGHTY WHALE"

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ABSTRACT

The Mighty Whale wave energy converter is a floating device to extract the energy from sea waves and convert it to electricity or compressed air energy. The model test has achived a improvement in efficiency and dissipate the waves behind the device which calm water can use for another aquaculture and marine leisure activities.

1. INTRODUCTION

Ocean waves are generated entirely due to wind blowing ocean surface. If wave energy could be completely absorbed by wave energy devices, waves surrounding the device would disappear completely, resulting in a calm sea. Accordingly, if it is possible to combine the use of wave energy and utilization of offshore area, the economic of wave power would be greatly increased. New configuration of the device called Mighty Whale has been developed. It can absorb about 60% of wave power at the maximum, dissipate about 80% of incident waves under the condition of normal sea state and the mooring force is very small. The Mighty Whale was designed to be applied a lot of experiments which were obtained by several tests of "Kaimei", shore based "Sanze" and floating terminator.

2. OUTLINE OF THE MIGHTY WHALE

The Mighty Whale has several air chambers which can absorb the incident wave energy and convert to the air energy resources. Every air chamber has an air turbine generation on it. A floating chamber behind air chambers has the ability to keep the buoyancy. Behind the floating chamber, a sloped plate is attached as the stabilizer and it creates an artificial beach which faces to natural beach for a marine leisure on it. A scheme of the Mighty Whale is shown in Fig.1. Usually, the Mighty Whale is moored by some chain lines, and its longitudinal axis coincides to the significant direction of wave crests at offshore like a the floating breakwater.

Most characteristic behaviors of the Mighty Whale are;

(1) High efficiency of energy conversion from wave power to air power,

(2) High efficiency of dissipation of incident wave height,

(3) Small mooring force (Minus mooring force in some cases of wave frequency and wave height)

3. PERFORMANCES OF THE MIGHTY WHALE

Fig.2 shows the efficiency of conversion wave power into air power (wave power absorption) versus wave length(λ) divided by length(L) of the device. The data in this figure are obtained by the two dimensional scale model test of 1/100 in regular waves. The maximum efficiency of wave power absorption is about 60% and the band width of high efficiency is wider than our former type of the floating wave power device. These results show the Mighty Whale has excellent performance of wave power absorption.

Fig.3 shows the performance of dissipation of incident wave, that is the ratio of transmitted wave height divided by the incident wave height versus λ / L . Since the scale of this model is 1/100, it was made clear that the Mighty Whale can reduce the incident waves more than 80% within the range of normal sea state along the coasts of Japan.

The above results leads the performance of the Mighty Whale on the wave power absorption and dissipation of incident waves are excellent. The reason for such outstanding performance are that the pitching motion respons to waves is very small due to the stabilizer slope and coupling motion of the air chamber and oscillating water column.

By the way, the steady drifting force in the waves is very small also, and the minus values were measured sometimes as shown in Fig.4. In this figure, the vertical axis is the nondimensional steady drifting force. Fd is measured steady drifting force, ρ is density of water, g is gravitational acceleration, B is the breadth of device and Hw is wave height. The Mighty Whale will be able to go ahead against incident waves, so that the mooring force is generaly very small. Consequently, it was made clear that it will not be difficult to moor the Mighty Whale in the waves. We theorize this propulsion effect is one of the way to utilize the wave energy generated by Wave activity.

4. NEW CONCEPT OF WAVE POWER DEVICE

Up to this time, the wave power device was evaluated by the cost for the generation of electrical power, and it was compared with some fuel and nuclear power plants. In addition, the wave power plant has a possibility to be of use for other purposes such as floating breakwaters and rafts for fishing and swimming. In Japan, there is a great demand to develop many calm sea areas in the bay and many beaches for marine leisure activities.

If the mighty whale can be installed offshore as shown in Fig.4, an another benefit may occur. This figure shows the transportation system of clean sea water from offshore to inside of the bay in order to recirculate refresh the sea water for fish farming and marine leisure projects. The wave power device would contribute by suppling the power to service this system. We suppose that the power to service such a system is a pollution measure that should be suppled by some natural energy sources, because it will not occur any pollution. Therefor the wave power device will be suitable for such would systems.

5. CONCLUSION

Following conclusion were obtained.

(1) The Mighty Whale has an excellent performance of wave power absorption. The maximum efficiency of it is about 60% under the condition of two dimensional scale model test.

(2) The performance on the dissipation of wave by the Mighty Whale is also very good than our former type of the floating device,and it is almost same as usual floating breakwater.

(3) As the Mighty Whale has such behavior, it will be very convenient for the supplyment of energy, create the calm sea behind the device for aquaculture and marine leisure activities.

(4) The energy absorbed and converted by the Mighty Whale will be utilized to the system for the refreshment of sea water in a bay and another system some measure for pollution of sea.

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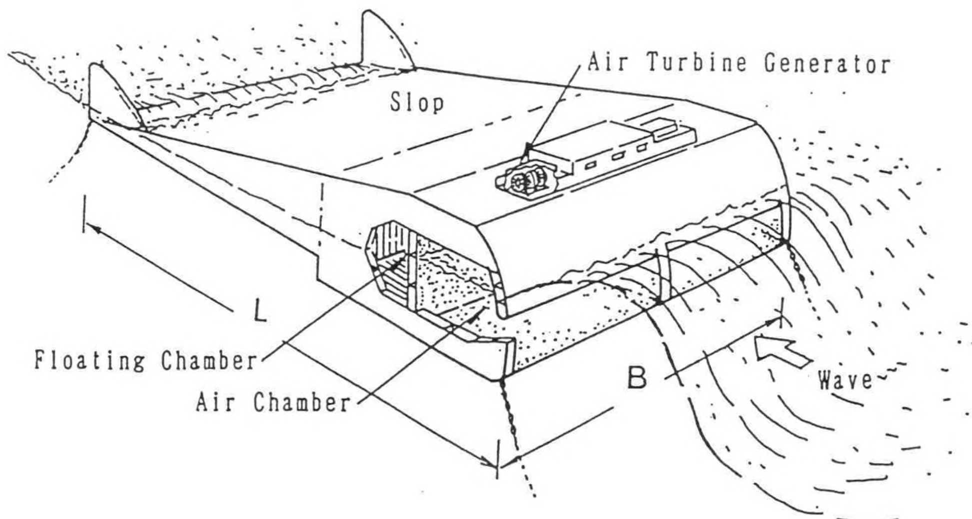

Fig.1 A Scheme of the Mighty Whale

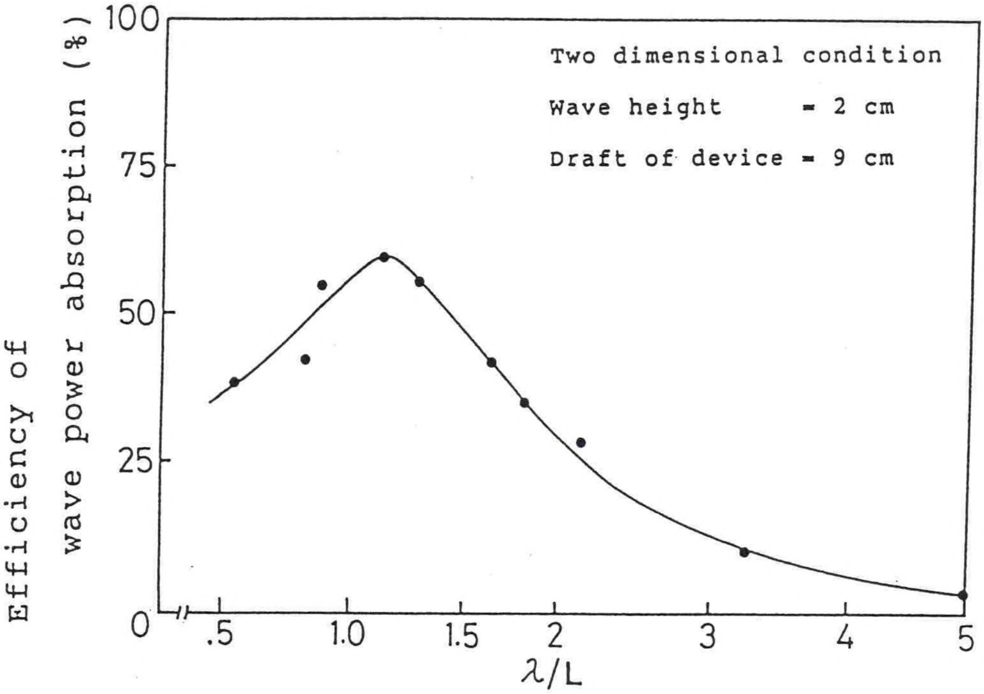

Fig.2 Performance of Wave Power Absorption

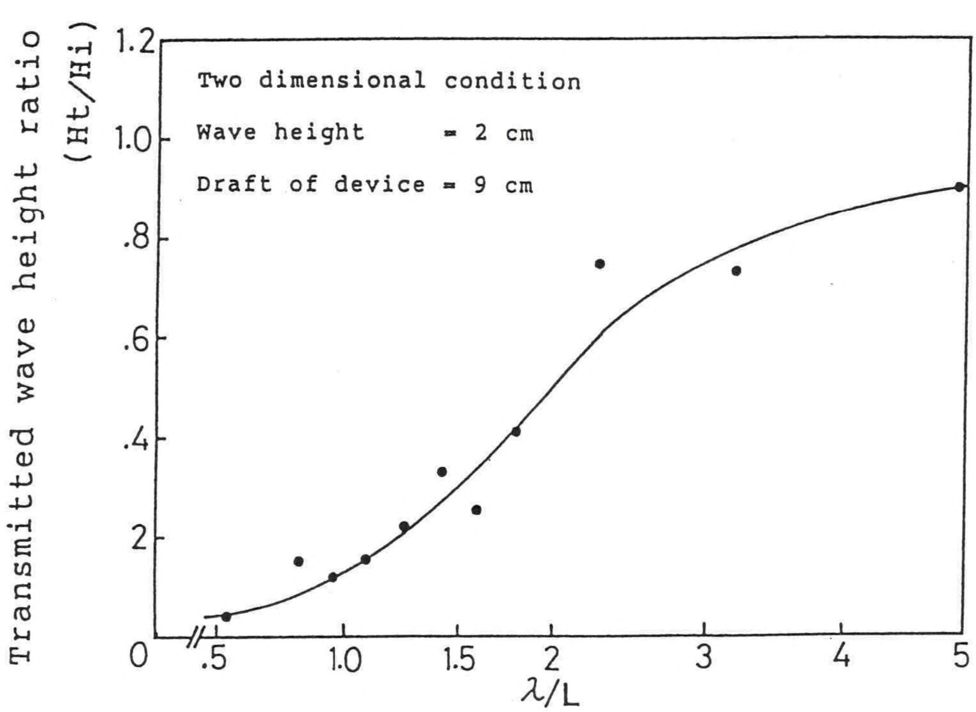

Fig.3 Performance of Dissipation of Incident Wave

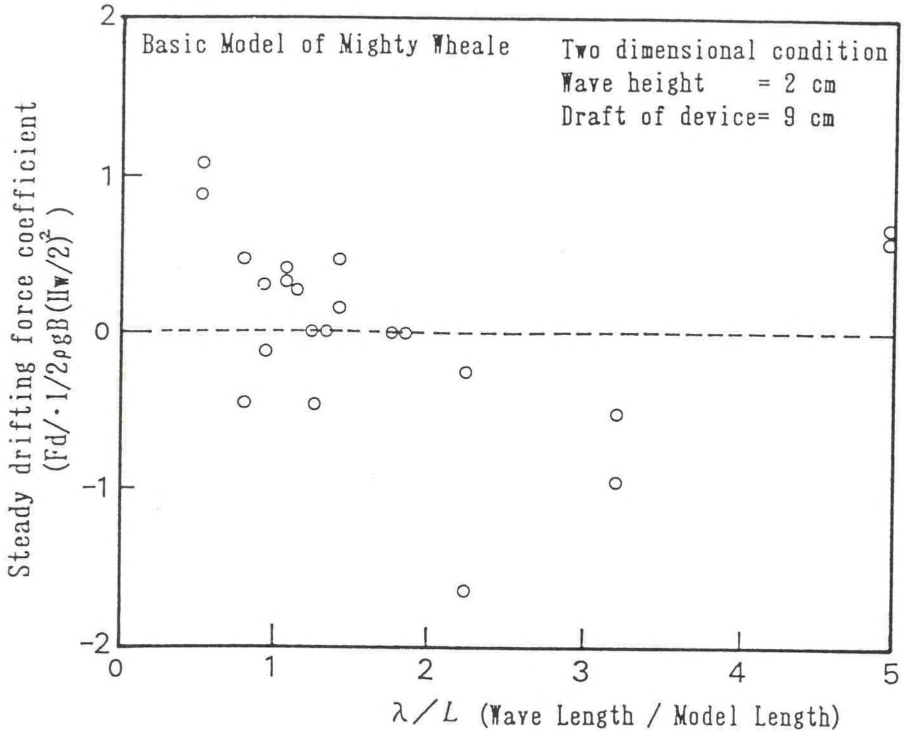

Fig.4 Experimental Results of Drifting Force

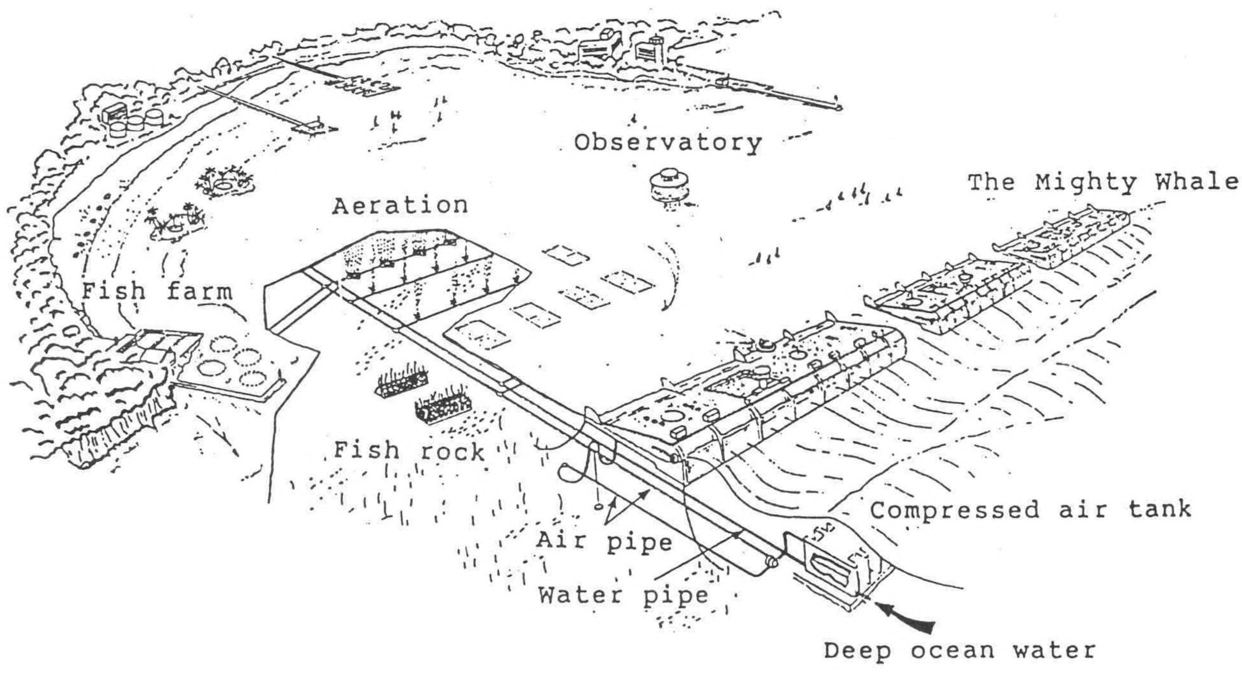

Fig.5 A Future Plan of the Mighty Whale for the Offshore Utilization

JAPAN MINING COLLECTOR
FOR MANGANESE NODULES

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INTRODUCTION

The national R $ D project on manganese nodules mining system has started in 1981 and will continue till 1996. The total project expenditure is about 154 million dollars. This work is performed under the management of the Technology Research Association of Manganese Nodules Mining System as a part of the Large-Scale Project sponsored by NEDO.

The mining system in this project is a submerged dredging method in which manganese nodules are collected by a towed collector on the deep sea floor and lifted to a test vessel by a hydraulic system using electric pump and / or air lift pump through a long pipe of several thousands meters.

Fig. 1 shows general arrangement of the mining system.

The mining system consists of following five sub-systems.

1) Total system

This system is aimed for coordinating whole systems, designing the test vessel, planning the mining test schedule and the research of the commercial mining system.

2) Collector system

This system is to develop a mining collector capable of collecting manganese nodules from the deep ocean floor efficiently and supplying nodules constantly to lifting system.

In order to develop a much efficient mining collector, the performance tests for essential equipment are carried out such as nodule collecting, separating, crashing and constant feeding. In addition to the above, the simulation analysis of collecting capability and collector motions has been made.

3) Material lifting system

This system consists of pump lift type slurry pumps, air lift type slurry pump and pipe strings. Pipe strings consist of main steel pipes, flexible lifting hoses and vibration reducing equipment.

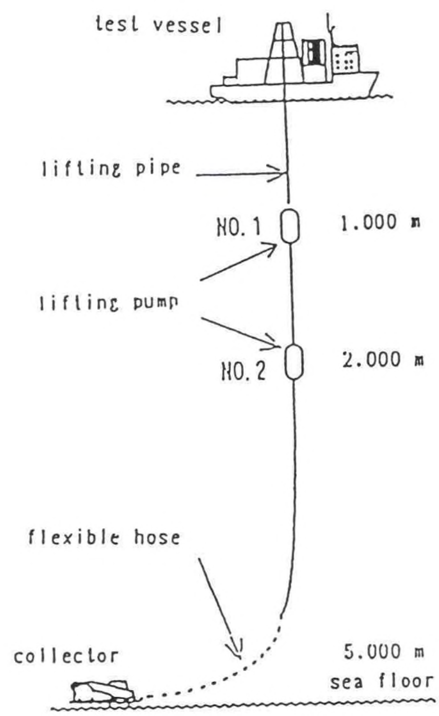

Fig. 1 GENERAL ARRANGEMENT OF THE MINING SYSTEM

4) Machinery handling system

This system is to develop safe, reliable and speedy handling equipment treating the underwater machineries such as collector, pipe strings, slurry pumps etc.

5) Measurement and control system

This system is to develop electric power supply equipment for underwater machineries; data transfer by using optical / electrical umbilical cables and ajusting and controlling the measurement equipment.

DESCRIPTION OF THE COLLECTOR

The mining collector consists of nodule collecting equipment, separating and feeding equipment, riding equipment, frame. electoric power equipment, hydraulic oil equipment, and measurement and contorol equipment.

The nodule collecting equipment collects the manganese nodules using the water jet, and sends the nodules to the separating device through collecting ducts after pre-separating of the sediments.

The separating device discharges almost all of sediments and the feeding device crashes the nodules and controls the feeding capacity to the pipe strings.

The riding equipment consists of sleds, stabilizing fin and bouyancy material. This equipment take care of keeping proper posture and reducing contact pressure of the collector.

The frame is the main structural body of the collector and supports minining machineries and fittings.

The electric power equipment consists of motors, transformer and distribution boxes in the collector and swicthboard etc. on the test vessel.

The hydraulic oil equipment includes the power source and actuators.

The measurement and control equipment consists of sensors in the collector and control panel on the test vessel.

Fig. 2 shows bird's eye view of the mining collector.

Table 1 shows main particulars of the collector.

CONSTRUCTION OF THE COLLECTOR

Photo.1 shows the mining collector at this stage. Construction of the collector is started in 1987 and now main construction work has been finished. Remaining jobs are manufacturing the buoyancy material. pump for water jet and electric motor for crasher and installation of fittings such as hydraulic oil pipes, measurement equipment electric cables, etc.

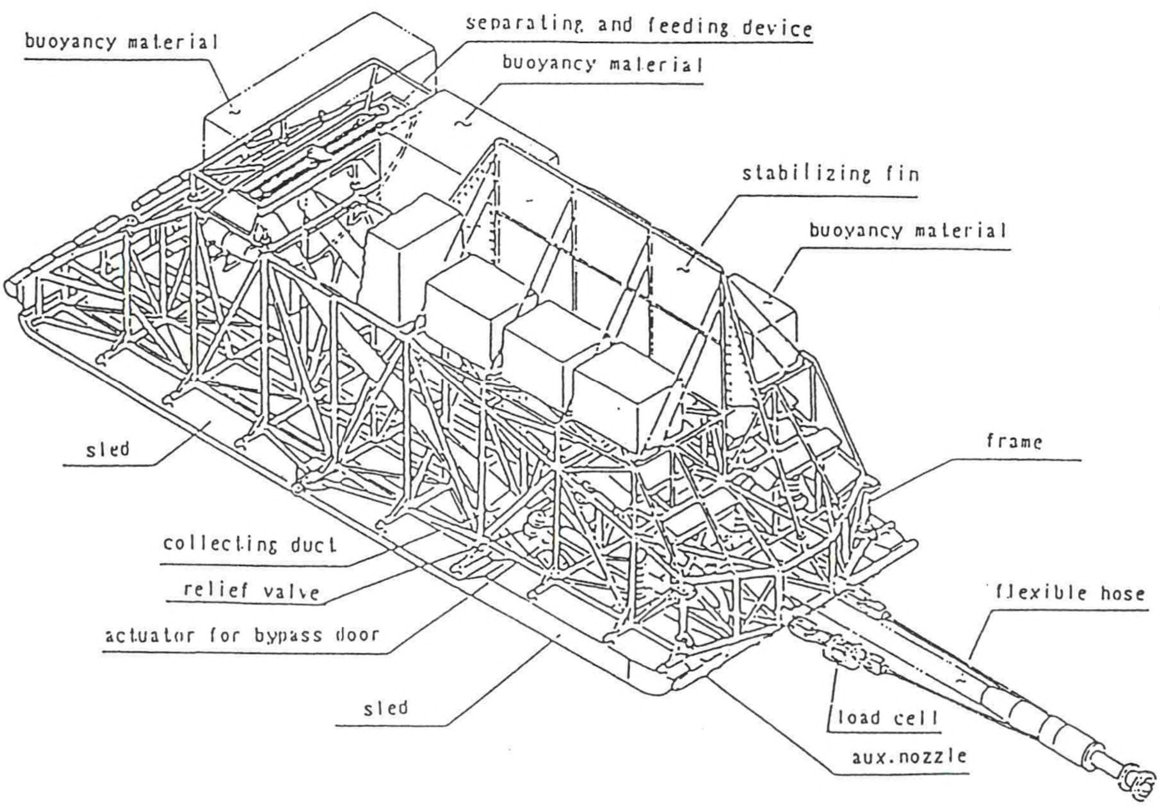

Fig. 2 BIRD'S EYE VIEW OF THE MINING COLLECTOR

CONCLUSION

The development of the mining collector is now under the final construction stage, in consequence with concept design, initial planning, tests of element technology, tests of functional performance, simulation analysis and basic design stage.

From now on, we will try to the best for completion of the mining collector and for detail planning of the pilot mining test.

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Table 1 MAIN PARTICULARS OF THE COLLECTOR

Item	Particular
Length	12.9 m
Breadth	4.6 m
Height	5.0 m
Weight in air	32.4 ton
Weight in water	10.7 ton
Collecting capacity	Max. 74 ton/hour
Towing speed	Max. 1.2 knot

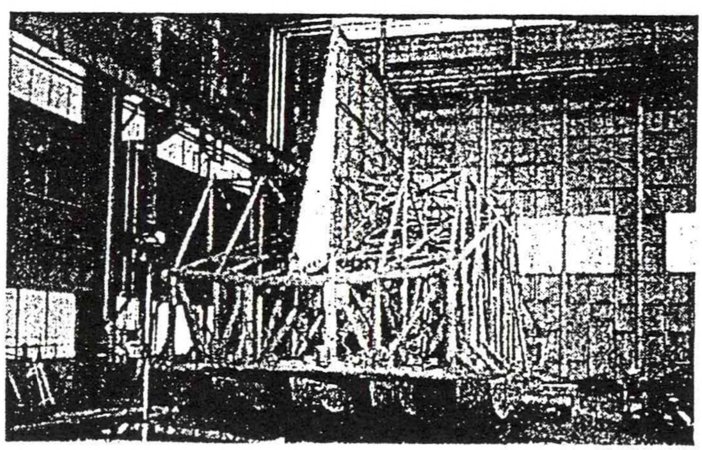

Photo. 1 MINING COLLECTOR (under construction)

UTILIZATION OF THE EEZ: Challenges for the Future

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ABSTRACT

Expanded utilization of the Exclusive Economic Zone presents a variety of technological challenges. Much of the future development will depend on having the necessary tools to survey, map, probe, sample, and monitor the seabed. Improved technology will also be needed for most of the actual uses--whether to mine and process minerals, bury cables and pipelines, or dispose of waste. A carefully conceived and coordinated plan for EEZ development can ensure that the United States will retain leadership in offshore technology for scientific research, resource recovery, and other long-term activities, while minimizing degradation of the environment. A study by the National Research Council/Marine Board resulted in ten recommendations on general and specific issues related to future uses of the seabed; research, information and technology needs; environmental concerns; and coordination and planning. Included is a recommendation for new legislation to create a formal joint planning and coordination process for EEZ development. This three-year study is being followed up with more detailed studies related to information needs perceived by coastal states and territories, offshore industries, and academic and research institutions. The results of these studies are summarized.

1. INTRODUCTION AND BACKGROUND

The United States and essentially all other coastal countries are looking to the ocean regimes for a wider variety of uses and for critical resources. Some sixty nations have now proclaimed jurisdiction over the natural resources within the Exclusive Economic Zone (EEZ), i.e. out to a distance of 200 nm seaward of the coastal baseline. The United States EEZ, established in 1983 by Presidential proclamation, is the largest in the world, covering 3.9 billion acres of submarine land--approximately 1.7 times the onshore U.S. territory (Figure 1).

The seabed regimes within the U.S. EEZ represent virtually all types of ocean seabed features and processes. The varied characteristics, and inherent remoteness of the seabed with attendant difficulties in making direct observations, present interesting challenges to scientists and engineers. Most of what is known about the shape of the seabed, including the configuration of the deeper strata, comes from remotely acquired acoustic data whereas detailed information about the properties of the sediments comes from widely spaced sampling sites. Given the problems of observing and sampling the seabed, it is also extremely difficult to monitor the behavior of the sediments over a long period of time.

Present and possible future uses of the seabed are almost as varied as the terrain itself. In addition to recovery of hydrocarbon and hard mineral resources, the seabed is used for waste disposal, commercial fishing, military needs and communication cables. But there are other less obvious uses related to the seabed, such as ocean energy resources, pharmaceutical research, archaeology, transport and recreation. Most of these uses, as well as the basic research studies on seabed processes, require seabed surveying and mapping information.

Much of this report is derived from a study by the National Research Council/Marine Board special Committee on Seabed Utilization in the Exclusive Economic Zone ("Our Seabed Frontier: Challenges and Choices" 1989). Information is also included from more detailed follow-up studies by the Committee on EEZ Information Needs (Interim Reports: Coastal States and Territories, 1990; and Seabed Information Needs of Offshore Industries, 1991). All of these reports were published by the National Academy Press, Washington, D.C.

2. FUTURE USES OF THE SEABED

The contribution of commercial (non-government) ocean business to the U.S. economy has been estimated at 1.7 percent ($76 billion) of the total U.S. gross national product of $4.53 trillion in 1987. This is the same order of magnitude as other well-recognized segments of the U.S. economy, such as all farms ($76 billion), all mining excluding offshore oil and gas ($74 billion), transportation other than water ($131 billion), and communications ($121 billion) (Pontecorvo, 1989). The seabed represents an area of national opportunity and long term economic growth. Uses of the seabed fall into three broad categories (Table 1): *extractive uses* involving activities that remove resources from the environment, *intrusive uses* that disrupt the seabed or degrade the environment, and *benign uses* that take up space but do not significantly impact the environment.

TABLE 1. Summary of Seabed Uses in the EEZ

Extractive uses
- Oil and gas
- Living resources
- Minerals
- Energy systems

Intrusive uses
- Pipelines
- Waste disposal (dredged mat., sewage, indust. waste)
- Dumping (munitions, scuttling, etc.)

Benign uses
- Instruments, (research, monitoring, security)
- Sanctuaries,
- Recreation

Future uses for the next 20-30 years include: expanded oil and gas development, increased mineral exploration and production, innovative waste disposal solutions, corridors for cables and pipelines, harnessing ocean energy, conserving and developing biological resources, and the discovery of cultural and recreational activities.

a. Oil and Gas Resources: In terms of strategic importance and economic value, the exploration for and production of offshore oil and gas resources will continue as an important economic activity in the U.S. EEZ into the next century. Currently, about 12 percent of total crude oil production and 25 percent of total gas production is produced offshore and it is estimated that U.S. dependence on these resources will continue to increase each year as land reserves decline (Bettenberg, 1987). While current technology is adequate to develop nearshore oil and gas resources, many technical constraints face the offshore oil and gas industry as it moves farther onto the continental slope/rise and into unexplored arctic regions. The environmental hazards of operating in deep and ice-infested waters are considerably greater, and overcoming them will be far more costly than previous offshore oil and gas development operations.

As we have seen in recent years, development of these areas will be affected not only by technical progress but also by nontechnical factors, such as fluctuating world oil prices, the impact of political regimes in oil-producing countries, and a domestic regulatory climate subject to public pressure to protect offshore lease areas. Equally significant will be the extent to which government and industry cooperate to achieve a proper balance between meeting the nation's energy needs, environmental concerns, and maintaining a competitive and technically innovative domestic oil and gas industry. The need for surveying and mapping information, including detailed data on subbottom conditions and accurate positioning of installations, is well known. There is certainly room for technological improvements to enhance efficient operation in the frontier areas.

b. Mineral Resources: Except for construction materials, such as sand and gravel, and some placers, it is unlikely that substantial amounts of hard mineral resources will be commercially recovered from U.S. EEZ within the next decade (OTA, 1987; Broadus, 1987). Depressed market prices, together with high costs of mining have created an unfavorable economic environment for development of most seabed mineral resources.

Future national needs could spur development of offshore mining industries for selected critical materials that are now imported by the U.S., such as cobalt, chromium, manganese, and the platinum group metals (OTA, 1987). Because lead times of up to 15 years are required for developing mining systems, it seems prudent to establish the scientific and technical base necessary to assess and recover strategic materials. An integrated program of technology development is needed for assessment of hard mineral resources in the EEZ seabed. In addition to the general need for bathymetric and subbottom information, there is a need to develop better tools to remotely identify and assess seabed mineral resources.

c. Waste Disposal: The coastal and ocean waters surrounding the United States have been used for disposing of municipal and industrial wastes for many years, particularly sewage sludge and dredged materials (Kester, et al., 1983). Recent legislation places restrictions on such practices; however comparisons between land and ocean disposal options frequently indicate that marine disposal is less expensive and less environmentally damaging than land alternatives (Duedall, et al., 1985). Future pressures on land-based repositories may increase incentives to use subseabed geologic formations for permanent repositories, especially for containerized low volume and highly toxic wastes.

Innovative engineered approaches to isolating and disposing of wastes in the ocean need to be tested and evaluated through pilot or demonstration projects in order to determine their effectiveness. Future use of the seabed for waste disposal will depend on socioeconomic pressures, technologies that will not compromise the use of other marine resources, and better understanding of the processes of dispersal and deposition of waste particulates. Additionally, a comprehensive national policy for selecting long-term waste disposal strategies which includes evaluation and comparison of land- and ocean-based options and their impacts on the marine, terrestrial, and atmospheric components of the ecosystem would provide a framework for making wise choices about waste disposal.

d. Communication Cables and Military Uses: Increasing use of the seabed for the installation of commercial submarine cable systems and a number of military applications is driven primarily by advances in fiber optics and digital transmission, as well as improvements in the technology for secure emplacement of various devices in or on the seabed (NTIA, 1984). Commercial communications cables constitute the majority of ocean cable installations but military activities in the ocean are expected to continue.

Geological processes and the composition of the substrata are the most crucial physical conditions affecting emplacement, maintenance, and survivability of ocean cables and military systems on or in the seabed. Improved geophysical survey equipment, sediment sampling, and in situ testing, along with more effective procedures for interpretation of geotechnical data, would yield benefits to both military and commercial operations in the seabed. A major issue related to the expansion of military uses of the seabed is the conflict between military applications and commercial, recreational, and/or environmental interests. It is therefore important that potential conflicts with other uses be anticipated and that policies be developed for resolving them.

e. Biological Resources: Living resources associated with the seabed fall into one of two categories--commercially important fishery resources and organisms of special scientific interest or of potential importance as biotechnological or genetic resources. The United States is one of the world's largest consumers and importers of seafood products (O'Bannon, 1988). There is potential for expansion of the domestic fisheries industry into deeper waters to capture a larger share of this market. Although most experts believe that traditional fisheries are being harvested at or near maturity, some of the resources of the continental slope can be harvested by extending existing technology into deeper water. Many bacterial species found in chemically unusual marine environments are logical candidates to study for their ability to degrade toxic chemicals; and some marine benthic invertebrates are potential sources of pharmaceutical agents in the treatment of cancer, and other diseases (Felbeck and Somero, 1982; Roberts, 1987).

Research needs to be focused on improving our understanding of the bases of biological productivity, its variations, and the effects of human activities on these processes especially in deep water. Newer techniques based on remotely operated vehicles, better sensors, acoustics, and improved data interpretation may alleviate present assessment problems. Such fundamental knowledge of biological and living resource processes will contribute to expansion of American fisheries, the development of new biotechnology products, and to protecting the quality of marine environments.

It seems certain that future development of biological resources will include expanded mariculture and aquaculture systems to help supply the world's needs. The United States has lagged in pursuing these means of enhancing seafood production and there are many opportunities for managed development, including fish farming and stock enhancement.

f. Ocean Energy Systems: Ocean energy systems and related technologies are in very early stages of development and the commercial feasibility awaits more favorable economic conditions. The most likely candidate for development in the near future is ocean thermal energy conversion (OTEC), a process that harnesses the temperature differences between surface and deeper waters; but other systems are also under study (Cohen, 1982; Baggott and Morris, 1985). The first commercial OTEC installations will probably be shore-mounted facilities on islands with the intake pipe extended to nearby deepwater sources. However there are some significant developments being pursued for large moored, semi-submersible systems that offer attractive features. Moored OTEC facilities will require information on the physical properties of steeply sloping seafloors that border U.S. subtropical and tropical islands and have access to deep, cold water relatively close to their shorelines. In some configurations, the electrical energy would have to be transmitted to shore by seafloor cable, creating a need for detailed seafloor information along cable routes. The surveying and mapping needs are similar to many other existing and potential uses such as offshore oil and gas production platforms and pipelines. One important difference is that OTEC facilities are likely to traverse steeply sloping areas.

g. Cultural and Recreational Resources: Cultural and recreational resources include marine archaeology, treasure seeking and commercial salvage, recreation, and marine sanctuaries. It seems likely that new and improved seafloor exploration technology and availability of affordable submersibles will stimulate interest in both marine archaeology and submarine tourism.

The identification and protection of unique underwater areas and habitats has to date been a limited effort (Foster and Archer, 1988). In order to designate and manage a marine sanctuary, a substantial amount of information is needed on the resources and the physical environment of the area. Early identification of such areas would forestall potential conflict among competing uses by including sensitivity to environmental considerations in advance planning for the development of other resources.

3. SEABED CHARACTERISTICS AND PROCESSES

The EEZ seabed represents a diverse, poorly understood, difficult, and sensitive environment that differs fundamentally from coastal and terrestrial areas, where engineering practice and experience are more advanced. Some important features of the seabed and the processes that affect its utilization are discussed here.

a) Seabed Characteristics and External Effects: The U.S. EEZ embraces a vast range of seabed morphology, water depths, tectonic and transport processes, sediment types, and environmental conditions (McGregor and Lockwood, 1985). Topography varies from relatively flat on the shelf and lower continental rise to very rugged on steeper slopes and canyons. Depths vary from the shallow continental insular shelves, where surface waves affect the seabed, to regions where depths exceed 4,000 m. Included are passive and active tectonic margins and volcanic regions where a variety of tectonic processes, along with other environmental forces, such as currents, surface waves, tsunamis, earthquakes, and ice scouring affect the seabed and reshape and rework its sediments. Seabed materials include rock outcrops, boulders, coarse sands and gravels, biogenic sediments, carbonate reefs, phosphate deposits, silts, clays, gassy sediments, permafrost, hydrothermal crusts, and manganese nodules. These diverse conditions create a highly variable environment with important implications for expanded seabed utilization.

The Atlantic seacoast region is a passive margin with little tectonic activity, a wide shelf, and thick deposits of sediments. The active margin along the Pacific seacoast is quite different, with a generally narrow shelf, and dynamic tectonic processes that have resulted in greater physiographic variability than in other areas of the U.S. continental coast. Around the volcanic islands of Hawaii and the Pacific trust territories are narrow shelves consisting of coral reefs and volcanic aprons that extend to abyssal depths. Offshore of large rivers such as the Mississippi are thick deposits of underconsolidated and gassy sediments, canyons, diapirs, and large fan deposits of sediments in deeper water. Other important regional features include the area off the western coast of Florida, where there are carbonate sediments, and the arctic regions of Alaska, where permafrost, deepwater gas hydrates, and ice packs affect the seabed.

Major environmental forces affecting the ocean floor include seismicity and active faulting at ridge crests and active margins; tsunamis, hurricanes and storm-related waves, bottom currents in deeper water; and ice keel gouging in the high latitudes. Earthquakes are a particular concern along the active margins of the west coast, Puerto Rico, Guam, the northern Marianas, and along the Aleutian trench in the North Pacific. The seismic history of arctic seas is poorly documented. The Atlantic coast is mostly inactive, although recent

(1984) earthquakes have been documented by the USGS Earthquake Information Center. The Gulf of Mexico historically has had only one earthquake of any magnitude. Normally stable slopes can fail when subjected to accelerations caused by earthquakes, and any structures, pipelines, or cables in the vicinity may be displaced or fail.

Surface waves affect the seabed in shallow water, where the water motion impinges directly on the seabed and can lead to seabed failures and erosion. Internal waves may play an important role in deeper water, but little data is available on these. In most of the EEZ, near-bottom currents exist at various scales of motion, duration, frequency, and magnitude. Currents result from tidal forcing, major oceanic-scale current systems (such as the Gulf Stream), wind setup, and storm surge. Episodic currents confirmed on the east coast continental rise are capable of suspending and transporting sediment by "benthic storms" that can occur several times a year (Hollister et al., 1984).

Ice gouging is an important concern in the Arctic. Enormous forces are imparted to the seabed when large ice masses, pushed by winds and currents, contact the seafloor. The depth of most gouges is of the order of 1 m or less, but scour depths exceeding 7 m have been documented (Barnes and Reimitz, 1974). These are active, seasonal processes that have important implications for seafloor structures, pipelines, and instruments.

b) Natural Seabed Processes: In addition to the forces discussed above, the seabed is shaped by the processes associated with the rise and fall of sea level during glacial and interglacial periods, the consequent sediment influx from continents, and changes in bottom current intensity. These forces create a dynamic environment. Two broad categories of active seabed processes are particularly important to seabed utilization because of their widespread effects: mass wasting and slope deformation, and sediment dynamics (erosion, transport, and deposition).

Mass wasting is the downslope movement of sediment or rock, such as a submarine landslide. However a full range of deformation processes can occur; very gradual (creep) deformations may eventually lead to more catastrophic failures (slumps, slides), fluid-like debris flows, and turbidity currents (Figure 2). These processes may encompass enormous masses of sediment and influence areas of more than 100 km^2 and are therefore important considerations in siting offshore facilities. In addition to gravity, the primary causes of slope failure are earthquakes and associated faulting; changes in slope geometry resulting from oversteepening; or scour, wave loading, creep, loading by structures and construction, gassy sediments, and rapid sedimentation.

There are obvious implications of mass wasting for engineered installations on slopes. As oil and gas operations move to deeper water, the full range of downslope processes will need to be better understood in order to avoid potentially hazardous areas or to design structures that can withstand the resulting forces. Horizontal installations such as pipelines and cables are particularly vulnerable to mass wasting because they may traverse varied seabed conditions. If indeed some slopes are gradually being displaced downslope as a result of creep processes, there may be some problems of accurate position and depth determination related to siting of installations and monitoring of the seabed.

Sediment dynamics refers to the erosion, transport, and deposition resulting from interactions between the sediment and the moving waters directly above the sediment-water interface. Knowledge of currents is crucial to understanding dispersal of pollutants; local scour around structures, buried pipelines, and cables; stability of moored arrays or other bottom-mounted installations; the fate of dredged materials; and the possibility that sediment suspended by bioturbation, mining, or excavation will be transported elsewhere.

c) Sediment Properties: Physical properties are the geological and engineering properties of sediments that must be understood in order to make calculations related to seabed processes and uses (Chaney and Fang, 1986). In general, physical properties of marine sediments (with the exception of carbonate and siliceous materials) are similar to those of water-saturated terrestrial soils. Thus, with some important modifications, most geotechnical principles developed for land apply to engineering analysis of the seabed. Special conditions that affect physical properties and seabed behavior are dynamic loading by waves, earthquakes, and sediment-structure interactions; high carbonate content; gas in sediments; high organic content; permafrost and freeze-thaw processes; ice-seabed interactions; and state of consolidation (compaction). Knowledge of compressibility, permeability (perviousness), and strength of marine sediments is important in analysis and design of structures for seabed applications and for other applications such as waste disposal on or in the seabed.

Biological processes can have important effects on the character and behavior of sediments. Physical and chemical alteration of sediments occur when benthic animals move about and feed, and in areas such as steep canyon walls burrowing animals can cause sediment instability. Knowledge of bioturbation processes is important to predicting sediment response to activities such as waste and dredge disposal, since bioturbation can reintroduce materials from sediments into the overlying water and possibly disperse them over large areas. Bioturbation generally acts to increase erodibility of sediment by maintaining a high water content and physically moving material toward the sediment surface where it can be moved about by bottom currents. However, an important counteracting consequence of feeding of sediment-dwelling animals is the packaging of small sediment particles into large fecal pellets, which have different transport thresholds and hydrodynamic properties than the ambient sediments.

4. TECHNOLOGY AND INFORMATION NEEDS

A large body of information is needed for planning efficient use of the seabed including: oceanographic and meteorological data; data on sediment characteristics and engineering properties; knowledge of seafloor geologic processes; and information related to specific uses of the seafloor, including the need for improved environmental monitoring. Obtaining this data in a marine environment frequently requires complex and expensive technologies and techniques specially designed for ocean use. Since there is usually considerable commonality of information needs, and in order to optimize operations, the approach should consider the combined needs of the various disciplines. Only a brief summary of the major technology systems and information needs are discussed in this section. Additional details resulting from the follow-up studies are presented in Section 7.

a) Surveying, Mapping, and Positioning: The seafloor can be mapped using a variety of tools and techniques, at different scales and accuracies and for different purposes. There are four basic types of surveying and bottom mapping required to support development and protection of the seabed; water depth (bathymetry), seafloor imagery (mostly acoustic), subbottom profiling, and sampling of the sediments. Accurate navigation/positions of all mapping data is necessary for the data to be useful.

The acquisition of site-specific seafloor data for mapping is a fundamental necessity for development. Locations and time frames for needed data are determined by the specific activity. For example, mapping in support of oil and gas development is dictated by exploration targets and production schedules. The survey tools and grids vary with the local characteristics of the area and the proposed activity, but for most of the anticipated uses there is overlap and commonality in the maps, scales, and resolutions required. Reconnaissance surveys provide a broad overview of regional geology and features resulting from long-term evolution of continental and island margins whereas higher resolution mapping (with higher positioning accuracy) is required for site-specific surveys. Use of deep water areas (>300m) for resource extraction and activities such as telecommunications or military installations is increasing, and these areas are likely to become the principal location of development in the future. This frontier region poses considerable challenges to survey methodology and practice. Although regional reconnaissance surveys are in progress, resource distribution and bottom conditions of the deepwater areas are generally poorly documented. Seabed mapping technologies include bathymetric survey systems, side-scan sonar systems, swath imaging and bathymetric (combined) systems, subbottom profiling systems, and direct sampling technologies (Kosalos, 1984; Tyce, 1986; Davis et al., 1986; and Prior et al., 1988).

The principal linkage between all survey and sampling measurements is position accuracy of the data. Historically, the accuracy of navigation systems has lagged those of survey and sampling systems. Navigation systems can be characterized by the location of the reference systems: i.e. land-based, ship-based, seafloor-based, and satellite-based systems. Land-based navigation systems have been standard for survey operations conducted within range of shore stations. The Loran C system has excellent repeatability of 15 m, and sufficient range (300 nm) for most EEZ surveys, but has insufficient accuracy (0.25 nm) to support many needs. For accurate nearshore surveys, temporary installations are generally used. These employ user-passive hyperbolic radio transmission systems (Argo, Sylidis), or user-active radar transponder ranging systems (Falcon, Miniranger, Hi-Fix). These systems have accuracies on the order of 1 m, and have ranges of 50 to 100 nm. Ship-based systems generally determine range and bearing to stationary acoustic beacons, benchmarks or structures on the seafloor, or aboard moving vehicles. The accuracy of these systems is a function of both the accuracy of the underwater acoustic transmission and reception, and of the ship's position determined through other means. Seafloor-based navigation systems generally consist of acoustic transponders, either on the seafloor or tethered some distance above. While limited in range by acoustic propagation to tens of kilometers, triangulation in range from bottom transponders produces navigation accuracy ranging from 1 m for near-bottom receivers to 50 m for surface receiver.

Satellite-based navigation systems remain the standard for mid-ocean positioning of ships, and also hold the most promise for future improvements in nearshore ship navigation and positioning. The Global Positioning System (GPS) uses range and time determinations from several of a series of polar orbiting satellites to establish position. When the entire "constellation" of GPS satellites is in orbit, fixes will be available at least once a second with accuracies on the order of 1 to 10 m.

A plan for reconnaissance-level mapping of the entire EEZ with Gloria and Sea Beam bathymetry has been coordinated by the Joint Ocean Mapping and Research (JOMAR) group of USGS/NOAA, and additional EEZ mapping in the 1990s is planned (NOAA, 1987). The relative roles of other government agencies, industry, and academia in setting priorities, as well as participating in coordinated surveys, remains to be addressed. A related issue is the need to balance efforts among high-resolution, site-specific surveys and ongoing reconnaissance. While the specific types of mapped data needed for each development activity require further definition, there is overlap and commonality in the areas, data types, scales, and resolutions required for many different anticipated uses. High-resolution data requirements for oil and gas production, cables and pipelines, military uses, and waste disposal should to the greatest extent possible be collaboratively defined so that multiobjective surveys can be coordinated to achieve cost-effective use of ship time and equipment.

The principal technical constraints to surveying and mapping the EEZ for development are now mainly operational, involving questions of rates of coverage, resolution, system efficiency, and cost-effectiveness. Some of the required technical developments include:

- rapidly traversing bottom vehicles capable of acoustic/in situ property cross correlation;
- deep-tow systems with multifrequency, multisensor packages in autonomous vehicles or improved towing and technology;
- multipurpose systems with vessels dedicated to multipurpose surveying with a wide range of tools aimed at extensive suites of seafloor data acquired in single traverses;
- multipurpose sensors from which simultaneous bathymetry, seafloor imagery, and subbottom profiles can be obtained;
- improvements in acoustic sources, arrays, variable and multifrequency profiling systems, together with real-time processing, to address difficult geologic terrain and the requirements for engineering data at greater depths below the seafloor;
- common, mutually compatible formats for digital recording and processing of data
- new geologic interpretation modes for effective use of survey data.

The principal nontechnical constraints to surveying and mapping of the EEZ are primarily organizational, involving questions of planning; prioritization of surveying technology resources; cooperation among different agencies, groups, and organizations; and data availability. Expense, different time frames for development, and the challenges of a largely unknown, difficult environment all dictate planning and organization of effort for successful and cost-effective mapping.

b) Geotechnical Data: Accurate characterization of a proposed development site requires meaningful measurements of seabed processes and sediment properties. Seafloor samples, using shallow drop-core or deep-penetration downhole samplers, are necessary to provide ground truth informa as part of the mapping programs (McClelland and Ehlers, 1986). As exploration and production moved to depths greater than 300 m, needs emerged for new and improved technology to compensate for increased costs and risks of the deepwater environment.

During the past decade, there has been a major shift to in situ testing, which involves thrusting a sensor (such as a cone penetrometer or vane shear device) into the sediments to measure physical, or engineering properties (Briand and Meyer, 1983; Silva and Wyland, 1987; Zuidberg, et al., 1986). This shift toward more in situ testing is the result of a number of factors. Economic incentives for offshore petroleum development provided the impetus to improve site investigation methods; major technological developments allowed more practical, reliable, and efficient in situ testing equipment; and investigators demonstrated the benefits of in situ test data for engineering analysis and design (Young et al., 1988). Geotechnical data acquisition systems are highly developed for water depths less than 200 m, whereas only moderate or little development has occurred for the Arctic or in water depths exceeding 300 m.

Deployment systems used for sampling or in situ testing can generally be divided into three broad categories: self-contained units, drilling rigs, and submersibles. Self-contained units are the simplest, least expensive, and require the least complex support equipment. Sampling and in situ testing can be performed with these systems and carried out from almost any vessel equipped with the appropriate winches. Various submersible systems can be used to deploy coring devices. It is expected that use of ROVs and eventually AUVs will increase, while use of manned submersibles will not. Operations conducted under ice may be one application with an increased role for manned submersibles, although risk to personnel has limited this use.

Development of the frontier regions of the seabed in the Arctic and in water depths exceeding 200 m will depend on further development of the following systems:

- instruments capable of providing data for analyzing long-term sediment stability;

- improved sampling and in situ testing devices for more difficult environments;

- compact deployment systems that can operate in a rapid transit mode and that will automatically measure seafloor properties or sample the sediments.

A nontechnical issue for acquiring geoscience data is the need to develop a coordinated research and development plan involving different agencies industry groups and academia in an cooperative to develop improved systems for sampling and performing in situ and laboratory tests on seafloor sediments.

c) Seabed Monitoring: The environmental consequences of expansion of activities in the seabed of the are difficult to predict in advance. A monitoring program would establish environmental baseline information which could be used for such predictions. Monitoring of environmental impacts is particularly important in relation to use of the seabed for waste disposal, oil and gas exploration and production, and mining. Required monitoring will fall into three categories: (a) reference monitoring to determine the natural range and variability of environmental parameters of the EEZ seabed; (b) process-related monitoring to understand major EEZ seabed processes; and (c) use-related monitoring to evaluate the suitability of EEZ sites for specific uses and to determine their environmental consequences (NRC, 1989; Rhoads and Germano, 1986). Monitoring priorities and strategies should be established within the framework of a national EEZ program.

Monitoring on the scale of years to decades will be necessary to acquire data on seafloor process activity (Fredette, et al., 1986). Such data on seafloor behavior, processes, and causative factors is a key element in predictive site evaluations and will expand the usefulness of mapped data. Technology will, in a sense, "drive" environmental studies. As new measurement technologies are perfected so that they can be routinely used, new monitoring will be possible. Technology needs associated with monitoring programs include, a satisfactory method of measuring pollutants in the sediment and, the ability to quickly assess populations or organisms.

5. ISSUES AND RECOMMENDATIONS RELATING TO THE US/EEZ SEABED

The recent study by the National Academy of Sciences/Marine Board (NAS/MB, 1989) resulted in two major conclusions about the future uses of the seabed in the EEZ. First, it is highly probable that the present uses of this region are likely to increase in the next twenty years. These include exploration for and development of oil and gas resources, waste disposal, emplacement of cables for civilian and military purposes, harvesting of fisheries resources, recovery of certain hard minerals, and identification of cultural resources such as marine sanctuaries. Significant expansion of activities related to a broader spectrum of mineral mining, other biological resources, development of ocean energy systems, and recreational uses will probably become more important in the time frame beyond twenty years.

The second major conclusion of this study is that for all foreseeable uses of the EEZ seabed, improved coordination and increased joint planning are needed to implement effective and efficient programs for systematically mapping and surveying the EEZ, developing new or improved technology to support EEZ mapping, surveying and research programs, improving access to and sharing of EEZ data, developing approaches for multiple uses, and identifying and resolving potential conflicts between the various users. Such a strategy would provide the nation with the foundation for a coherent plan for developing its ocean territory. Following are summaries of the findings and recommendations of the Committee on Seabed Utilization in the EEZ.

Coordination and Planning

Economic and institutional pressures will lead to increasing use of the U.S. EEZ for a variety of purposes. Additional planning efforts among federal and state governments, industry, academia, and public interest groups will lead to more efficient, orderly, equitable and environmentally sound development of EEZ resources.

1. Congress should enact legislation that creates a formal joint planning and coordination process that includes a lead agency mandated to develop a national EEZ plan, and an external commission composed of representatives of industry, academia, and public interest groups, and an internal interagency committee. The federal government should formulate a national management policy for EEZ uses that identifies the needs of specific user groups and determines ways of enhancing cooperation and efficiency of operations among the various agencies and industries and identifying and resolving potential conflicts among users.

2. As part of the planning and coordination process, federal agencies should pursue cooperative and joint agreements with coastal state governments in planning and implementing EEZ activities.

Specific Uses

Certain Uses of the EEZ will require special policy action at the federal level in order to plan for future development. For example, development of mineral resources and use of the EEZ seabed for waste disposal are potential activities that are unlikely to proceed until more comprehensive national policies are devised. Other uses will also benefit from improved regulatory policies.

3. The U.S. Congress should ensure that a coherent policy is developed that addresses specific concerns of industry and coastal states with regard to economic and environmental issues affecting the development of EEZ mineral resources. Appropriate agencies should ensure development of the necessary science and technology for assessment, evaluation, and verification of critical hard mineral resources.

4. A comprehensive long-term national waste management policy based on an evaluation of waste disposal in all media, including land and ocean options, should be formulated by Congress to provide a predictable framework for planning and developing acceptable ocean waste disposal strategies.

Research and Technology Development

The seabed of the EEZ is a new frontier that includes a broad range of seafloor morphology, water depths, sediment types, and environmental conditions that affect its use. The complexity of the seabed requires multidisciplinary research efforts that are costly in terms of both technology and time to obtain and analyze data. The various potential uses of the EEZ share the need for reconnaissance survey data and for task and site-specific data. The mapping priorities and geographic areas of interest in the EEZ require further definition as a first step toward planning the efficient sharing of mapping activities, survey and ship time, and equipment.

5. Research activities in the EEZ should be coordinated through a designated agency to enhance cooperation and efficiency of operations among various agencies, industries, and academia, and promote basic research efforts that will increase our understanding of seabed processes.

6. As a part of the national plan, a government/industry/academia EEZ program should be established to set priorities for seabed surveying and mapping activities and promote development of technologies for obtaining seabed data.

7. The agency designated to coordinate research activities should ensure that programs are

set in place to develop the necessary technology for geotechnical and geological data acquisition in concert with the projected uses and needs.

8. Government should provide leadership in fostering communication and exchange of data among all agencies and other organizations conducting research in the EEZ.

Environmental Monitoring

A clear need is emerging for a nationally coordinated effort in monitoring those portions of the EEZ seabed that may be effected by future uses. The required monitoring will fall into three categories: (a) reference monitoring to determine the natural range and variability of environmental parameters of the EEZ seabed, (b) process-related monitoring to understand major EEZ seabed processes, and (c) use-related monitoring to evaluate the suitability of EEZ sites for specific uses and resultant environmental consequences.

9. In conjunction with the joint planning and coordination process and the research efforts recommended above, a national EEZ monitoring program should be established with input from industry; federal, state, and local governments; academia; and public interest groups to determine EEZ monitoring priorities and strategies. Such a program should be based on the framework of projected uses of the seabed and should include long-term reference monitoring, seabed process-related monitoring, and use-related monitoring at specific sites. It should also incorporate the capability to respond to detrimental impacts.

Protection of Unique Areas

Identification and protection of unique underwater areas and habitats under the National Marine Sanctuaries Program has to date been a limited effort. In order to designate and subsequently manage a marine sanctuary, a substantial amount of information is needed on the resources and physical environment of the area.

10. Federally sponsored activities should include a marine sanctuary reconnaissance component for discovery and identification of unique areas of the seafloor deserving long-term protection. Designations should occur in advance of resource development to forestall conflict among competing uses.

6. COMMENTS RELATING TO MARINE SURVEYING AND POSITIONING NEEDS

Expansion of research and development activities to deepwater and Arctic frontier areas presents new and exciting challenges for accurate navigation, for precision positioning--both vertically as well as laterally--for bathymetric and subbottom mapping, and for monitoring of seabed processes and seabed installations. The study on utilization (NAS/Marine Board, 1989) has identified several areas for technological development of surveying and positioning systems to assist in seabed applications. This study pointed out quite clearly that the one common information need for essentially all seabed uses is mapping of the seabed, including the subbottom strata. Because of the complexity and expense of operating in the ocean environment, it seems logical that all potential users of such systems - governmental agencies, industry, and academia - should join forces and coordinate efforts to improve systems and to operate them in an efficient manner so that information can be shared. The JOMAR program (NOAA, 1987) is an excellent example and good start but certainly more can be done to encourage cooperative programs.
In terms of the relation between seabed utilization and surveying, mapping and positioning systems there are three main issues that need to be considered: the use of the seabed for the location of permanent position markers, operation of systems to study and monitor seabed processes, and the use of systems for specific applications. Some comments and suggestions are offered here.

a) Seabed Mounted Systems: One of the potential problems of using the seabed for siting of positioning systems is that the seabed is often not fixed. This is especially true on some submarine slopes that may be experiencing gradual downslope deformations (possibly of the order of 10's of centimeters per year) and others that may be subjected to mass wasting processes such as debris flows and submarine landslides. Not all slopes are vulnerable to these downslope processes but certainly this factor needs to be considered in the deployment of instruments resting on or in the seabed. Another factor is that many marine sediments are in a very "loose" or soft condition and therefore very compressible. In some cases the sediment column may be compressing due to the natural overburden conditions and in others the effect of loading from the bottom installation may cause additional settlement of the system. Therefore both the lateral and vertical movements of bottom supported systems should be evaluated for each site.

b) Seabed Processes and Seabed Monitoring: We still have much to learn about processes within the seabed--especially in the frontier areas. The research community needs both reconnaissance type mapping data to look at regional conditions and precise information at particular sites. Although bathymetric data and side-scan imaging often provide insights on seabed processes, it is usually also necessary to have detailed data on subbottom conditions. The ideal system would have the capability to simultaneously map and "image" the seafloor, and map the configuration of subbottom strata. Another pressing need is to be able to precisely monitor the behavior and deformations of and within the seabed over long periods of time (several years). In some cases it is sufficient to determine relative movements but in others (such as those involving very large masses of sediment) we need to know the absolute lateral and vertical displacements. The accuracy needed for some studies in frontier deepwater areas is of the order of 5-10 centimeters.

c) Systems for Specific Uses: There are a wide range of accuracies required for the many existing and potential uses of the seabed. Even for a given use, there may be more than one required accuracy depending on the specific application for the data. For example in deepwater areas the multibeam bathymetric maps and mid-range side scan data may be sufficient for preliminary site evaluations but more accurate data is necessary for designing and constructing an oil production platform. While specific uses may require some special data, there is often overlap and commonality in terms of types, scales, and resolutions required for many applications. Data requirements should be collaboratively defined so that multiobjective surveys can be coordinated to achieve cost-effective use of ship time and equipment.

7. CONCLUSIONS FROM SUBSEQUENT STUDIES

The NRC/Marine Board has formed the Committee on EEZ Information Needs to survey the various constituencies interested in offshore areas. As of Summer, 1992, two interim reports have been published that present the results of questionnaires and workshops that assess the needs of two groups--coastal states and territories and offshore industries. Excerpts from the conclusions sections of these reports are presented here.

Coastal States and Territories

The priority of concerns of the coastal states and territories in relation to present or future uses of their offshore areas are: biological resources (including fisheries), mineral development (including sand and aggregates), environmental assessment (including waste monitoring), oil and gas development, and shoreline management. Of lesser concern are data for geohazards, cables, pipelines, cultural, recreational, ocean energy, and military uses. The focus of attention in this study was on data related to geology, mapping, and bathymetry and on non-living resources.

a) Data Type Priorities of EEZ Activities

Priority of data required varies with both type of use and stage of development. The overall priorities were as follows: bathymetry, characterization and distribution of the sediments, seafloor imagery, high-resolution profiles, and geophysical data, especially deep seismic profiles.

Sediment sampling and analysis is presently laborious, expensive, and slow. Automated techniques capable of supplying such data would entail substantial reductions in cost and improve standardization of output and should be explored. Sediment characterization by sampling should be preceded by systematic shallow penetration high-resolution seismic profiling. The samples to be taken then should be collected along a subset of the profiles to permit extrapolation of sediment properties by the relationship of acoustic signature.

Based on the state responses and independent committee analysis of information needs, the next systematic emphasis of data gathering should be on bottom sediment characterization (including associated high-resolution near-surface profiling), while ongoing programs on bathymetry and bottom imaging are pursued to satisfactory completion, to provide essential ground truth calibration for remote measurement technologies. Strategies for best accomplishing this task, either on a site-specific or regional basis must be further evaluated.

b) Geographic Focus of EEZ Activities

While each state or territory prefers a focus on the blocks offshore their particular coastline, the committee took a broader prospective. From the committee's overall investigations it concludes that the most effective focus for information gathering activities is on corridor swaths extending from the shoreline to the EEZ boundary as a first priority.

c) Data Management Issues

An issue of high priority for establishing a responsive and effective national data program for the EEZ is the definition and implementation of a data and information system. This system must support data acquisition, preprocessing, display, distribution, archival, and applications-oriented processing. To be efficient, the requisite system must be user transparent and support change in user requirements and evolution in technology.

Offshore Industries

The findings and conclusions presented here are based primarily on the results of a questionnaire and discussions at a workshop.

a) Data Needs

The data types ranked as essential by industry for a systematic federal survey program include bathymetry, imagery, and characterization of the seabed with a limited number of calibration sample sites. These priorities were similar to those documented by the survey of the coastal states. The following suggestions for improving the usefulness of USGS/NOAA EEZ activities are indicated:

- Imagery collected by high-resolution side-looking sonars on the continental shelf could benefit from an overlap with existing reconnaissance-scale side-looking sonar imagery obtained from 200 m to >5000 m.
- High-resolution seismic reflection profiles are an important component in integrating samples obtained by coring/testing with imagery and bathymetry.
- Bottom samples and borehole testing are key to verifying the remotely sensed data and are required for certain descriptive properties that cannot be obtained through geophysical methods alone.
- Systematic sampling programs over large regions are not economically justifiable as part of an overall reconnaissance study of the EEZ. More limited sampling programs would be beneficial to small-scale regional and site specific studies, and essential for calibrating indirect survey methods.
- Seabed maps are needed with detailed information on geological characteristics.

b) Technology Needs

For the most part, the survey instrumentation presently used in the federal survey activities is not capable of effectively covering the shallow nearshore sector of the EEZ (< 200 meters). When the USGS/NOAA program moves to substantial survey activity on the continental shelf, investment will be necessary in new technologies capable of being more efficient in shallow water. The following general technology needs were identified:

- accurate, simple, and inexpensive subsea navigation systems that could be deployed beneath the sea surface;
- small unmanned vessels equipped with multiple geophysical, geochemical, and geotechnical sensors that could be deployed, controlled, and monitored in groups over large areas from a single command ship for maximum and timely reconnaissance data-gathering efficiency;
- new high density power sources for remote technologies;
- seafloor sampling tools that could be deployed rapidly, be remotely operated from the support vessel, have short turn-around times, give maximum representative sample recovery, and work in both unconsolidated and hard rock substrata to penetration depths exceeding ten meters.
- for improved shallow water capability, swath bathymetric and imaging systems capable of providing lateral coverage of several times the water depth, possibely ecompassing multispectral sensors.

c) Data and Information Management

The one need common to all industries surveyed is the requirement for the development of an electronic data system that would be easily accessible, could accommodate historical as well as newly collected data, and would be flexible to keep it as complete and up-to-date as possible. The following guiding principles are important to the development of an evolutionary data system:

- Involve the end user community at the outset and throughout all subsequent activities through a representative group of active users with oversight and review responsibilities.

- Establish formats, standards, and guidelines at all levels, beginning with data acquisition, as early as possible and update them as often as needed.

- Begin planning and implementing an evolutionary EEZ data and information management system as early as possible for maximum benefits.

d) Program Implementation

A successful national program for exploring and understanding the EEZ will require cooperation among all major participants in activities in this region: federal agencies, the coastal states, offshore industries, and the ocean research community. It is in the nation's interest to encourage the successful development of the U.S. ocean technology and service industries, possibly through partnerships for capitalization and deployment of new technologies. Priorities for federal surveys could be set and updated through a structure of advisory panels that include representatives of all EEZ users (federal, state, industry, and academia). The expertise of such panels could also be useful in defining standards, procedures, and protocols for EEZ data acquisition and management activities.

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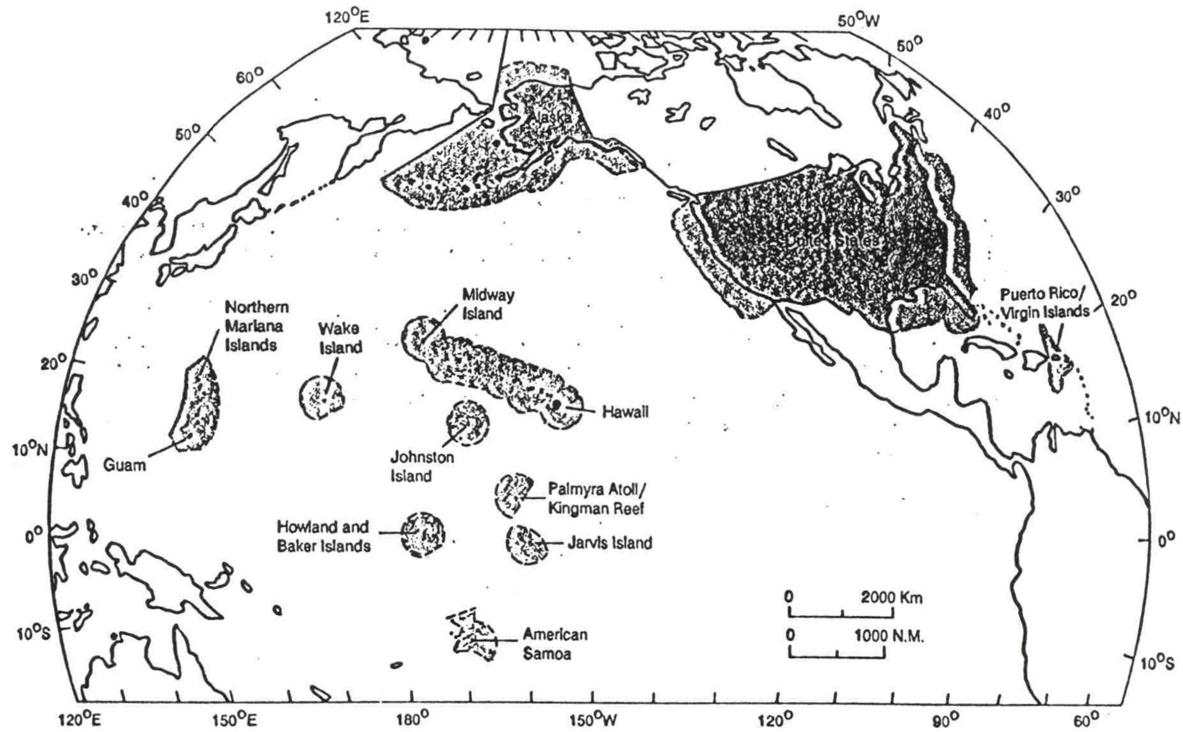
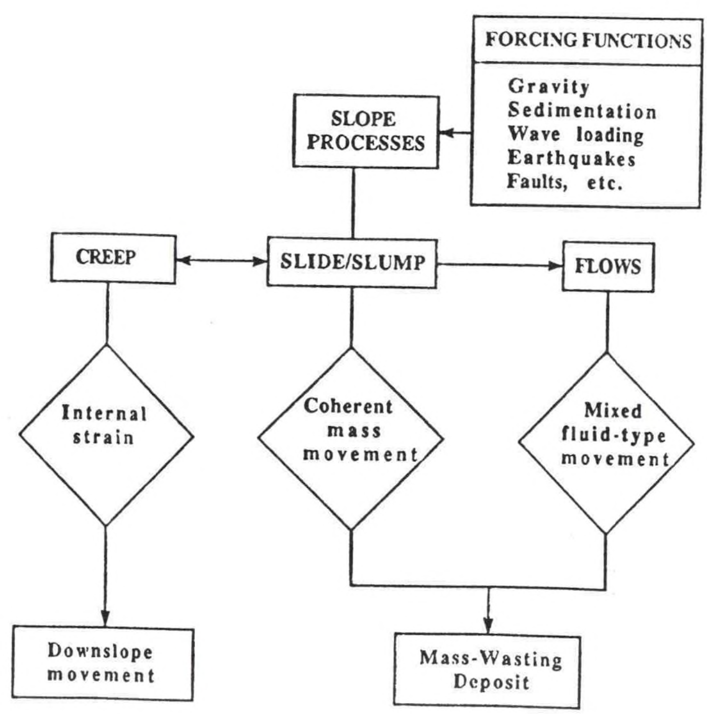


FIGURE 1. The Exclusive Economic Zone of the United States and its trust territories. SOURCE: McGregor and Lockwood, 1985, p. 2.

Figure 2. Interrelationships of slope deformation and failure processes. Slope processes can be viewed as a continuum ranging from very gradual downslope deformations (creep), submarine landslides that involve rapid movement of fairly coherent masses, and fluid-sediment flows. Any one type of process can lead to another depending on site conditions.



Advanced Ship Technology Development

A TENTATIVE ANALYSIS OF THE SEA TRIALS OF THE SUPERCONDUCTING MHD SHIP YAMATO-1

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Setsuo TAKEZAWA — Ship & Ocean Foundation

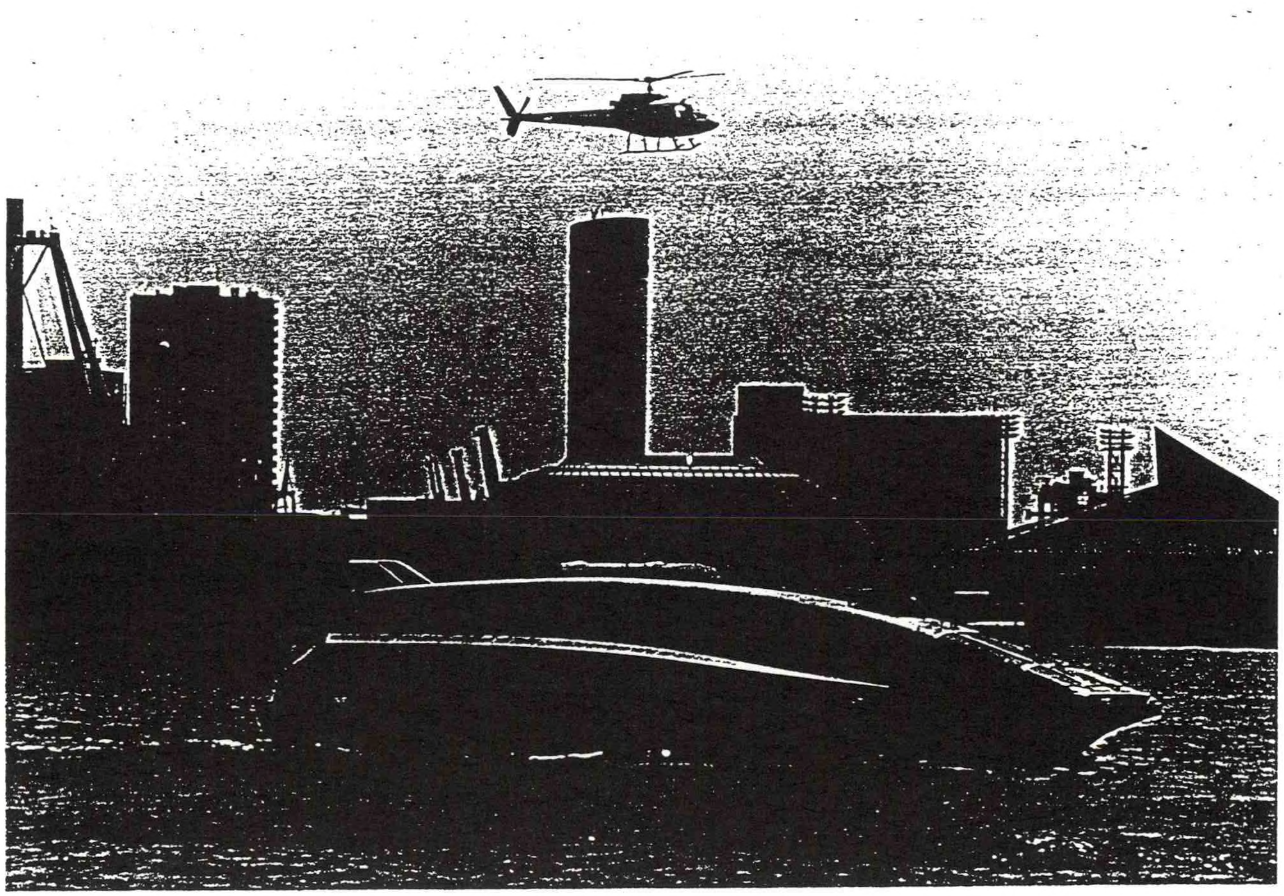

Fig. 1 YAMATO at her debut

1. Introduction

Ship & Ocean Foundation has been conducting an extensive research and development project on superconducting magnetohydrodynamic ship propulsion funded by Sasakawa Foundation since 1985.

The purpose of this project is to develop fundamental technologies which are necessary to develop superconducting MHD thrusters, and finally to construct a prototype experimental ship and demonstrate that a ship can really be propelled by MHD thrusters with all the necessary apparatus on board.

It is also expected that through actual design and construction of the experimental ship, problems to be solved in developing higher performance MHD ship in the future, can be extracted.

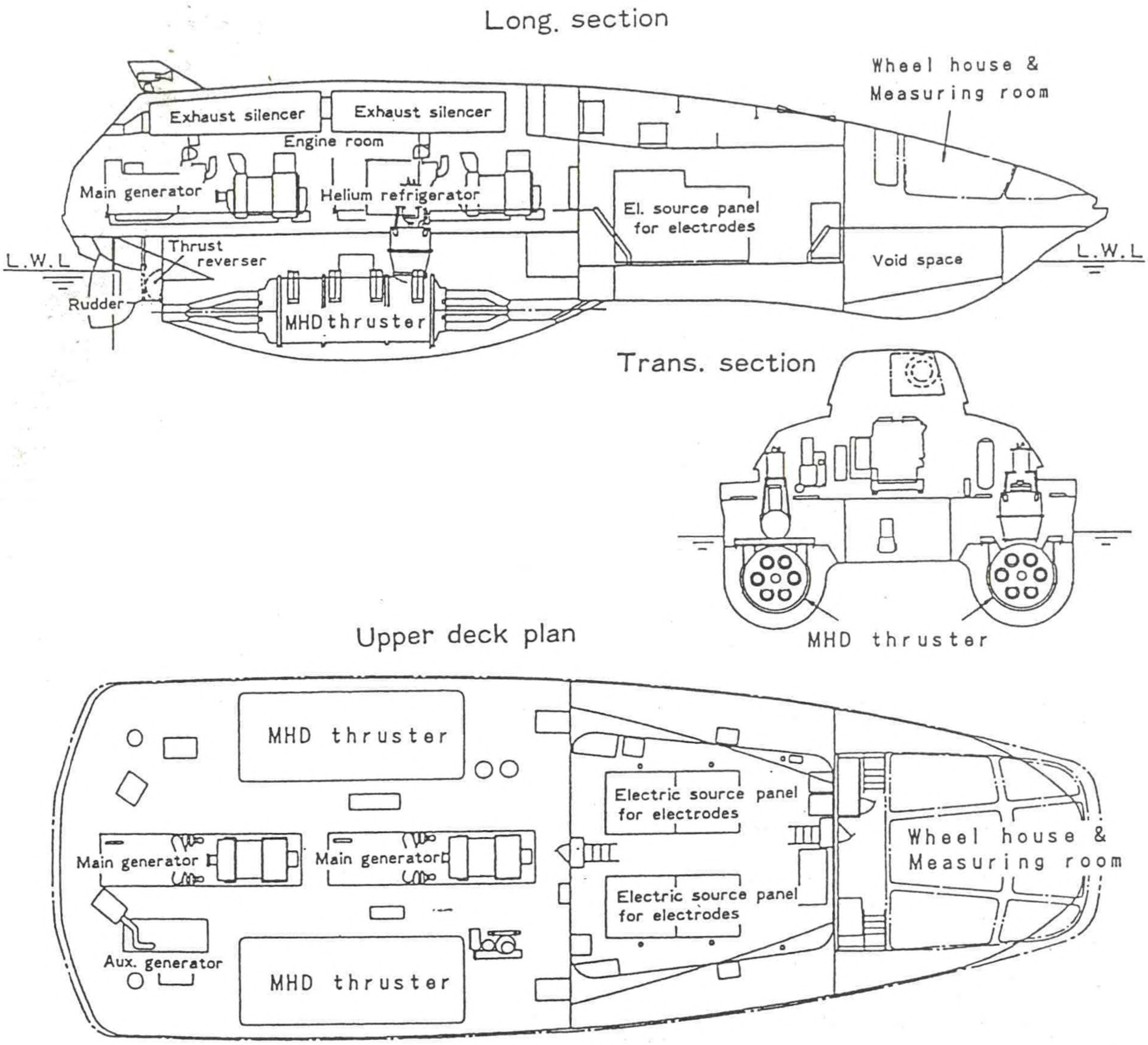

Fig.2 General arrangement of YAMATO-1

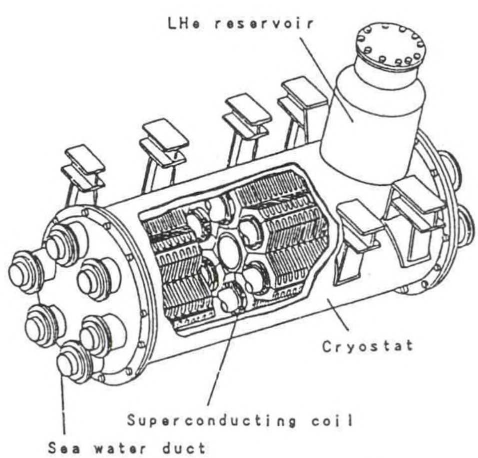

Fig. 3 Openview of the MHD thruster

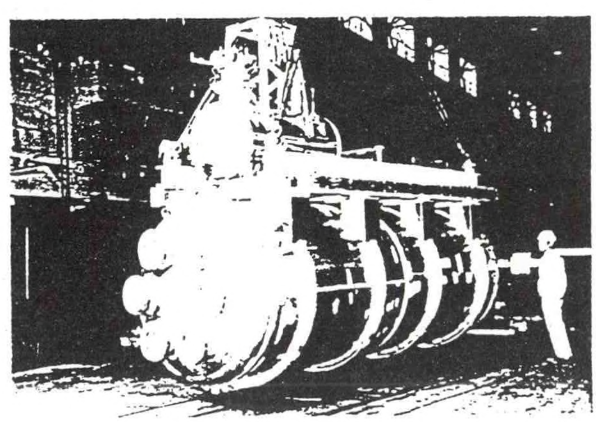

Fig. 4 Outside view of the right thruster

The experimental ship YAMATO-1 was completed in November 1991, and after prudent tests and adjustments on land, she appeared in Kobe harbour on 16th June 1992, and ran successfully by MHD thrusters before many invited guests and press people (Fig.1). After her debut, a series of sea trials has been performed until the end of July this year, and all the necessary data to evaluate superconducting MHD ship propulsion have been obtained. YAMATO-1 also performed an official trial under the presence of surveyors from the Ministry of Transport and secured the certificate of vessels nationality.

In this paper, a tentative analysis of the sea trials will be reported.

2. Outline of YAMATO-1

As the detail of YAMATO-1 was already reported at the International Symposium on Superconducting Magnetohydrodynamic Ship Propulsion (MHDS 91) held in Kobe Japan in October 1991 (refer to Proceedings of MHDS 91, Kobe, Japan 1991 by Ship & Ocean Foundation), only an outline of YAMATO-1 will be described here.

2.1 Principal particulars

Principal particulars of YAMATO-1 are as shown in Table 1.

Table 1 Principal particulars of YAMATO-1

Length overall	30 m
Length between perpendiculars	26.4 m
Breadth (moulded)	10.39 m
Depth (max)	3.69 m
Draft (max)	2.69 m
Displacement (including water in the ducts)	185 t
Speed (at Lorentz force 16,000 N)	about 8 kts
Material of the hull	Aluminium
Number of person	10 including 3 crew

2.2 General arrangement

The general arrangement of the ship is shown in Fig.2

The ship is equipped with twin MHD thrusters which are contained in bulges hanging down from after part of the main hull. Two sets of main engines 2,030 KW each and generators which will produce electric current through seawater in the duct of the thrusters are accommodated at the center of the rear part of the ship. Liquefied helium refrigerators are mounted on each MHD thruster.

2.3 MHD thrusters

Each MHD thruster consists of 6 unit coils forming a fringe type arrangement to avoid excessive leakage of magnetic flux outside the thruster. Principal particulars of unit coils as well as the thrusters are shown in Tables 2 and 3 respectively, and the arrangement and outside view of one of the thrusters are shown in Figs. 3 and 4.

Table 2 Particulars of unit coil

Inner diameter of the coils	0.360 m
Inner diameter of the duct	0.240 m
Length of the coil (total)	3.70 m
Length of the coil (parallel part)	3.00 m
Number of turns	220 × 2 layers × 2 poles
Normal electric current	4,600 A
Magnetic flux density at center (per single unit)	3.5 T

Table 3 Particulars of the MHD thruster

Compound magnetic flux density at center	4 T
Electrode current (normal)	2,000 A
Lorentz force	8,000 N/set
Thrust	4,000 N/set
Weight	18 T/set

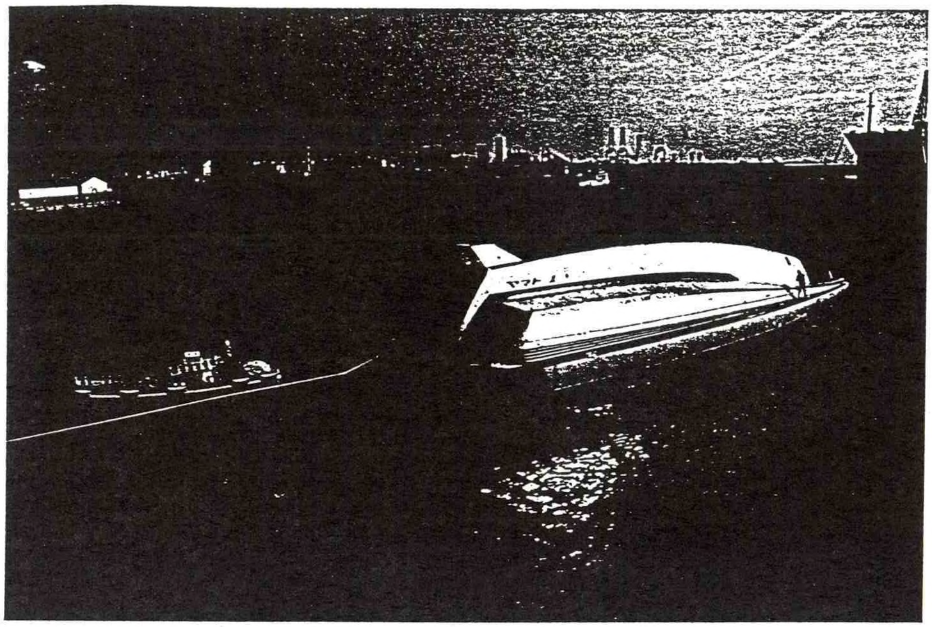

Fig. 5 YAMATO-1 at the bollard pull test

3. Result of the sea trials

3.1 Trial condition

1) The ship
   Displacement: 184 tons
   Trim : 0.42 m aft

2) Weather and sea condition
   (at the speed trial on 24th July)
   Wind: WNW 5m/sec
   Temperature: 22.5° C
   Wave height: 0.5m choppy waves
   Specific gravity of seawater: 1.022
   Water temperature: 20.2° C
   Conductivity of seawater: σ =3.64 s/m

3.2 Mooring test and bollard pull test

Preceding to speed trials, a mooring test and a bollard pull test were conducted. At the mooring test, the ship was moored at a pier and electric current through seawater was applied to examine whether the electric current induced any trouble to the magnets or not.

As it was confirmed that electric current up to 2,000 Amp did not give any adverse effect to the magnets, a bollard pull test was conducted to measure the total thrust.

At the bollard pull test, the ship was moored at a bollard on a pier, and a tensionmeter was inserted in the towing rope. The towing force which was equal to the total thrust generated by the ship was measured by the tensionmeter.

The test was performed with two kinds of magnetic flux density, viz; B=1 Tesla and B=2 Tesla, and electric current through seawater being varied from 500 Amp up to 2,000 Amp. Hydrodynamic pressure at inlet and outlet of the thruster duct was also measured. The result is shown in Fig.6.

In Fig. 6, F shows the measured value of towing force, in other words, the total thrust of the ship, T_R shows the thrust generated by MHD thrusters including the duct system which was calculated from measured flow speed and hydrodynamic pressure in the duct, and L shows the Lorentz force which was calculated using actual magnetic flux density B and the electric current Js through seawater.

The relation between F, L, and T_R is as follows;

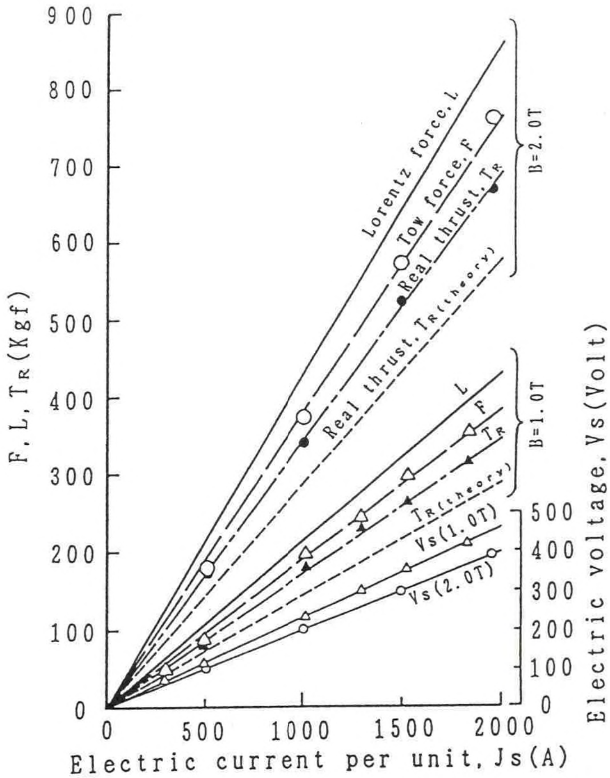

Fig. 6 Result of the bollard pull test

L - loss in the duct = T_R

T_R - pressure induced force around the hull (negative in the present case) = F

In Fig. 6, $T_{R\,(theory)}$ is also shown together with T_R. $T_{R\,(Theory)}$ was calculated deducting head loss of the duct from the head gain generated by the Lorentz force. To estimate the head loss of the duct, the experimental value was used for branching and integrating part of the duct, and for the other parts empirical formulae were used (The initial estimation at design stage was shown here).

$T_{R\,(Theory)}$ should coincide with measured T_R if the estimation of head loss due to the drag of the duct and pressure induced force is correct. Therefore the difference between $T_{R\,(Theory)}$ and T_R means that the initi al estimation of head loss was not appropriate.

One of the purposes of the bollard pull test is to get more accurate estimation of head loss inside the duct so that more accurate estimation of the thrust generated by the MHD thruster can be calculated.

The Lorentz force could be measured directly if hydrodynamic pressure at the both ends of the working part of the MHD thruster was measured. However at the sea trial it was not practical. Therefore, the Lorentz force was calculated using the measured B and Js. According to the model experiment at Tsukuba Institute, the calculated Lorentz force agreed quite well with the measured value. Therefore, it was expected that the Lorentz force as calculated agreed with the real Lorentz force.

During the mooring test as well as the bollard pull test, it was observed that powerful milky jet stream came out of the nozzles of the thrusters. In Fig.7, pictures of the jet stream generated at B=3 T, Js=1,800 Amp as described in 3.4 are shown. Though sea surface was covered by sparkling micro bubbles, there was no trace of smell of chlorine gas.

3.3 Speed trials

Speed trials were conducted several times from 16th June through 20th July, with test conditions of B=1 T, 1.5 T, and 2 T with combination of electric current Js=500 Amp, 1,000 Amp, 1,500 Amp and 2,000 Amp. Among the trials, those conducted on 24th June and 26th June were official trials at B=2T under the presence of surveyors of the Ministry of Transport. Results are shown in Fig. 8. In Fig. 8 ship speed attained is plotted on the basis of electric current applied through seawater. The mean speed of 5.3 kn obtained at B=2 T, J_s =2,000 Amp is an official record so far.

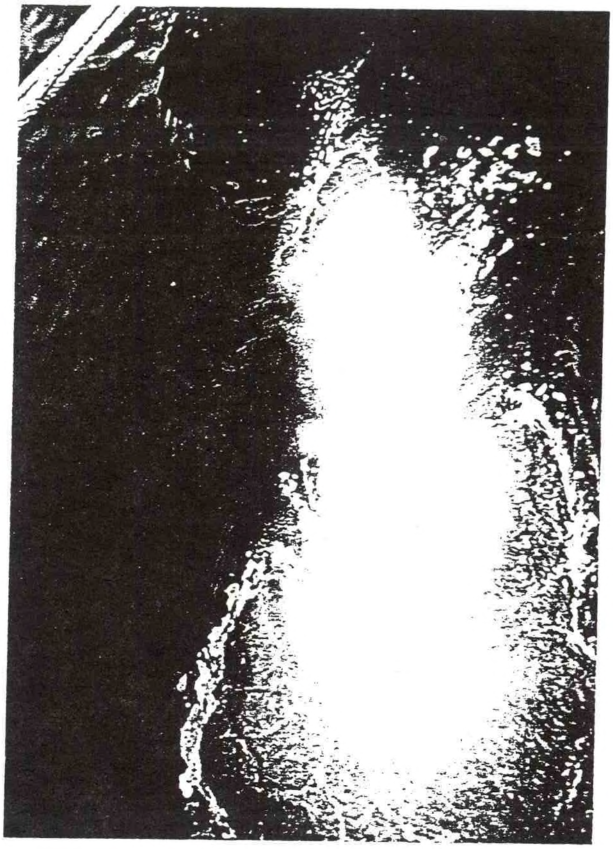

Fig. 7-1 A jet stream generated by the MHD thruster

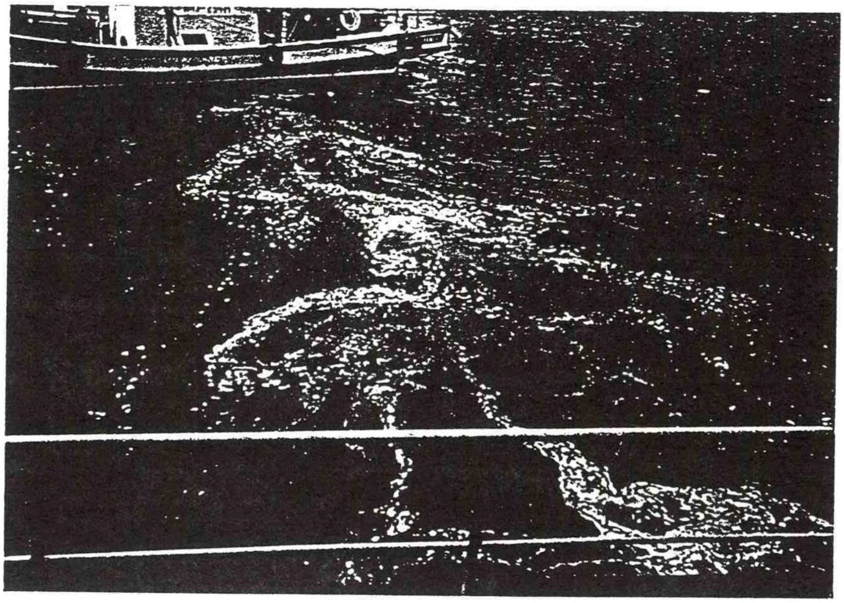

Fig. 7-2 A jet stream generated by the MHD thruster

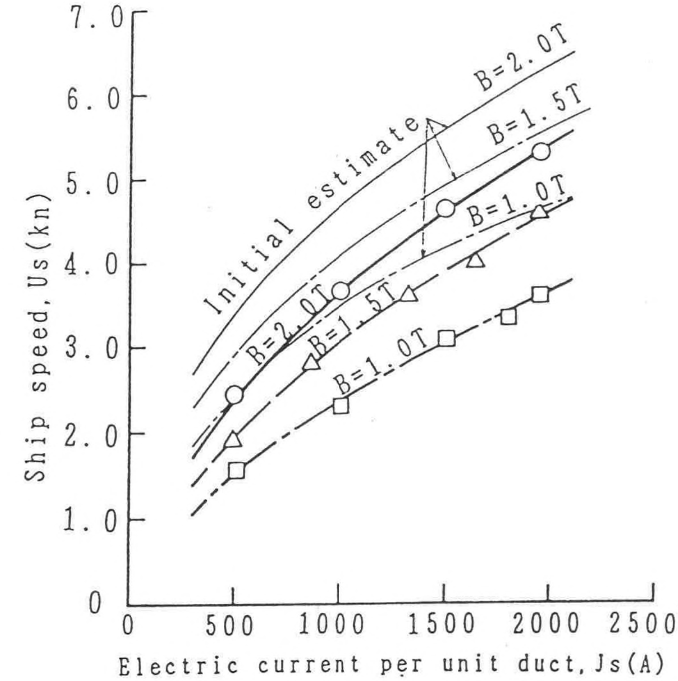

Fig. 8 Result of speed trials (1)

As seen in Fig.8 the attained ship speed is much lower than the initial estimation at the design stage. The cause of this discrepancy would be one or combination of the followings;

a) Resistance of the ship hull is greater than the initial estimation.

b) The efficiency of converting the Lorentz force into thrust is lower than the initial estimation which was 50 %.

To confirm a), the ship was towed by a tug boat and the resistance was measured. The result is as shown in Fig. 9.

In Fig. 9, the measured resistance values are plotted on the basis of ship speed and the resistance estimated from the model test is also shown.

As seen in Fig. 9, the measured resistance agreed quite well with the resistance obtained by a model test. Therefore it is most probable that item b) would be the main cause of the discrepancy. This matter should be clarified in later days by precise analysis.

In Fig.10 the ship resistance R, calculated T_R based on measured flow speed and hydrodynamic pressure, and the Lorentz force are plotted on ship speed basis.

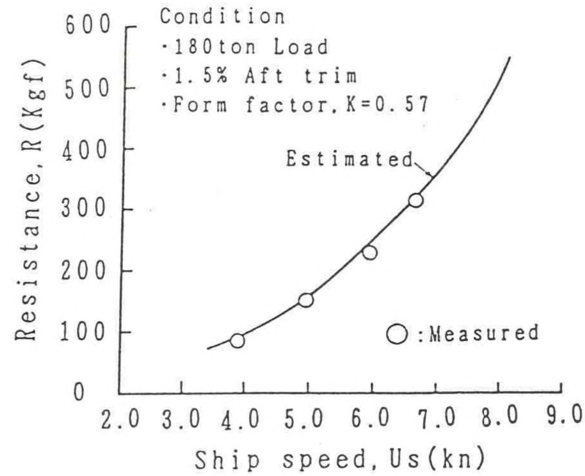

Fig. 9 Measured resistance of YAMATO-1

As Lorentz force is a product of B and Js, there must be many combination of B and Js to get the same Lorentz force. Therefore, it is interesting to see in Fig. 10 that the attained ship speed is the same for a specified value of Lorentz force independent of the value of B and Js.

From Fig.10, it can be seen that measured thrust (resistance) is about 40 % of the Lorentz force. Since the initial estimation of the thrust was 50 % of the Lorentz force, actual thrust is about 20 % less than the initial estimation. Most probable cause would be greater loss in the duct than the initial estimation. This matter will be pursued in later days.

Since the thrust deduction factor is deemed to be practically zero by a model test result, the resistance should be practically equal to the total thrust (real thrust) of the ship. A little discrepancy is however found in Fig. 10. The reason is as follows;

If the flow speed and the hydrodynamic pressure in the duct were measured exactly at inlet and outlet of the duct, T_R caluculated using the measured flow speed and the pressure should be equal to the total thrust i.e. resistance. However, due to technical reason, the position of the sensor at inlet was not exactly at the mouth of inlet but fairly inside. Therefore, T_R shown here does not agree with the total thrust.

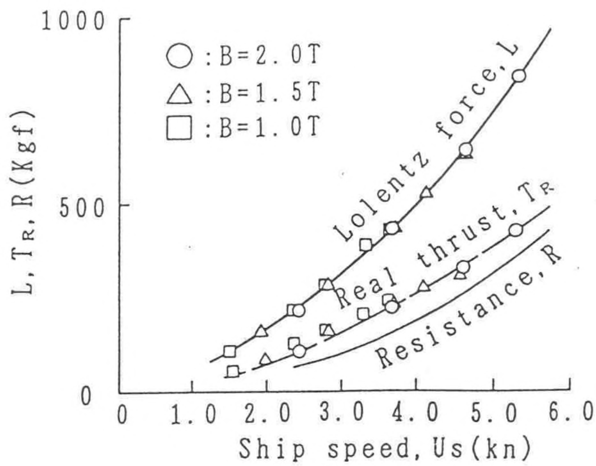

Fig. 10 Result of speed trials (2)

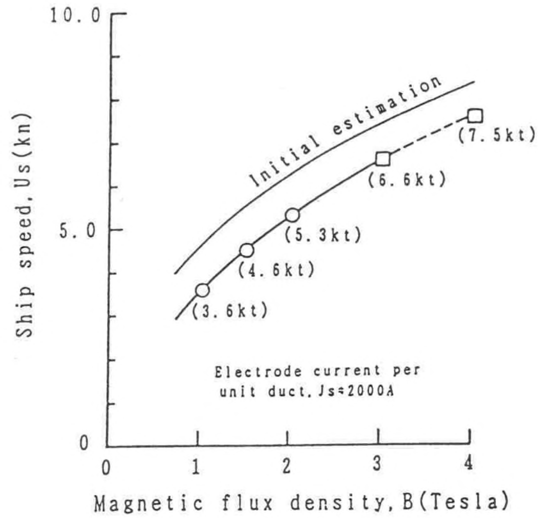

Fig. 11 Ship speed estimation

3.4 Trials at higher magnetic flux density

To avoid a fatal damage of the MHD thrusters due to quench of a superconducting coil or coils, trials had been conducted at the magnetic field up to 2 T which was 1/2 of the designed value. As necessary data had been obtained, trials at higher magnetic field were challenged at the end of July.

Superconducting coils of both right and left MHD thrusters were energized up to 3 T and kept at a persistent current condition. But after 20 minutes, a quench occured at one of the coils of the right thruster. The left thruster maintained a persistent current condition long enough to perform a mooring test.

Therefore, a mooring test was conducted only on the left thruster varying the electric current in seawater from 500 Amp up to 1,800 Amp. Hydrodynamic pressure and flow speed in the duct were also measured.

Though the quenched coil seemed not to be damaged, for safety reason, the speed trial at B=3 T by both thruster was cancelled. Though the ship could not run at B=3 T, ship speed at B=3 T, Js=2,000 Amp can be estimated fairly exactly using the measured hydrodynamic pressure and flow speed in the duct during the mooring test at B=3T. Result is shown in Fig.11.

As seen in Fig.11, it is quite possible that YAMATO-1 can run at 6.6 kn at B=3 T, Js=2,000 Amp. It is also estimated with a little less accuracy that she may run at 7.5 kn at B=4 T, Js=2,000 Amp.

4. Summary

4.1 YAMATO-1 was really propelled by magnetohydrodynamic force. The attained ship speed was little less than the initial estimation due to probable lower efficiency in converting the Lorentz force into thrust than initial estimation.

4.2 It was noticed that response of the ship to a change of electric current was rather sluggish because the Lorentz force is almost constant for a specified electric current. (No overloaded thrust generated like conventional screw propellers).

4.3 It was ascertained that a reverse thrust was generated by reversing the electric current in seawater. Effect of reversing on the electrodes has not yet been clarified.

4.4 Though speed trials at over B=2 T could not be performed due to a quench of the right MHD thruster, valuable data for further development of MHD ships were obtained.

Feasibility studies on the displacement type mono hull high speed ship

Naonosuke Takarada (Sumitomo Heavy Industries, Ltd.)
Shuichi Nagamatsu (Sumitomo Heavy Industries, Ltd.)

1. Introduction :

Recently, many time-variable products required high speed transportation, so these cargoes are air-freighted. However, taking into account the air transportation costs and the small-lot, displacement type high speed ships are one of the vessels which could carry lots of cargo efficiently, while dynamically-supported vessels as hydrofoils and hovercrafts have restrictions in terms of deadweight and cruising range.

Since 1979, Sumitomo Heavy Industries, Ltd. has been developing a superconducting propulsion motor, in close cooperation with Japan Marine Machinery Development Association (JAMDA) and the Yokohama National University. SHI has established a laboratory sized prototype 37 kW (50 HP) DC homopolar motor to confirm its performance at 1982 and the 480 kW (650 HP) DC homopolar motor, including many key factors for commercializing, has also been developed and successfully tested in well agreement with the design parameters at the spring of 1990.

The authors published a paper titled "Development of a marine superconducting motor and high speed ship" at 15th UJNR and discussed on that possibility.

Based on these results, a conceptual design study of a super high-speed displacement type monohull ship driven by super-conducting propulsion motors has been conducted by SHI.

2. Development problems necessary for displacement-type mono-hull high speed ship :

In the designing of a displacement type mono hull high speed vessel, there are conflicting problems. The ship hull form should be slender to minimize the hull resistance, while the hull must enclose a high power propulsion plant. The multi-shaft system will be also considered.

One of countermeasures to overcome said subjects is an application of super-conducting motor to electric propulsion system. It can afford to relieve the restrictions of the stern shape and the arrangement of the shaft system. Moreover, it can lighten a hull weight. For the optimum design of hull structure, it is necessary to estimate wave loads and impact loads in high speed range precisely. And in case of high speed vessel, we should also take care of some phenomena arising from high encounter wave frequency.

Moreover, applying this kind of vessel as a container ship, efficient loading system and operational performance will be studied in all its soft and hard ware aspects.

Considering these subjects which are mutually related, extensive trade-off studies will be required to ditermine the final configuration of a high speed vessel.

3. Resistance :

3.1 Theoretical hull form ;

To minimize the wave-making resistance of hull at high speed, we started from a theoritical study using the linear semi-submerged ship theory. The theoretical hull consists of ovoid and strut and we can find out analytically the hull form having a minimum wave-making resistance when waves are nicely interfered between them.

As an example, we conducted a towing test to confirm the resistance using the basic hull form at designed ship speed 30 knots(Fn=0.367).

Its hull dimensions and body plan are shown in Table 1 and Fig.1

respectively. And the towing test of an existing SR108 container ship model were also carried out and these results were compared as shown in Fig.2. This basic hull form clearly showed the minimum resistance at Fn=0.367.

3.2 Practical hull form ;

As in the foregoing paragraph, it is difficult to make a practical hull form directly by the semi-submerged ship theory because the hull is symmetrical. However, we have to take full advantage of said theory from the view point of wave-making resistance because the results obtained at towing test were low level even at high speed range compared those of existing vessels and this kind of hull form is named hereafter as OVOID hull form.
The practical hull form was designed in the following respects :

(1) to satisfy the requirements for basic dimension of hull

(2) to reduce the wave-making resistance
(3) to satisfy the stability of ship

And the towing tests were conducted using more than 20 practical ovoid type model ships which were designed on above three conditions.

3.3 Propulsor ;

We conducted the detail examination of two propulsion systems including shaft arrangement of high power vessel.

in case of single shaft ;
contra-rotating propeller (CRP)
in case of triple shafts;
center shaft : contra-rotating propeller (CRP)
wing shaft : conventional propeller with pod

As for the design of CRP, we carried out its design on the following conditions as fundamental examinations, using the method of propeller characteristic analysis and design procedure.

Design conditions :

ship speed (Vs)	50 knots
delivered horse power (ps)	142,000 ps (single shaft) or 85,500 ps (center shaft of triple)
revolution (RPM)	120 rpm ~ 180 rpm
wake fraction (1-W)	0.8~0.9

Regarding the CRP, the propeller open test to confirm its propeller efficiency and cavitation test have been conducted.

3.4 Tank test of improved ovoid type practical hull form ;

After some examinations of the hull form, we have designed the improved ovoid type hull form. It was derived from the reduction of diameter of ovoid, the reduction of wetted surface area and the simplification of the frame line.
To confirm its performance, resistance and propulsion tests have been carried out, using the 3.2 m ship model. Wave pattern around bow at towing test is shown in Fig.3.
Based on the above experimental results, it is estimated that this ship needs about 180,000 ps when running at 50 knots.

In case of triple shaft system, the increment of power can not be avoided because resistance increases due to appendages such as pods and the change of self-propulsion factors. From results of tank test and SUMT method (Sequential Unconstrained Minimization Technique) however, an optimized pod position showed about 10 ~ 20% increase in required horse power compared with that of the single shaft system.

4. Seakeeping and hull structural strength :

4.1 Seakeeping test ;

Seakeeping model tests in head sea condition were carried out in regular and irregular waves using two kinds of solid model and three kinds of segmented model. An example of test results are shown in Fig.4 and

principal particulars of model are shown in Table 2.
The results obtained are as follows.

(1) in head sea condition, heave response becomes remarkable with ship speed
(2) waveloads in high speed range are as much as those in low speed range and the effect of ship speed on it is small
(3) deck wetness in high speed range can be reduced by a special bow form (Whale-back) and comparatively large freeboard
(4) a slight springing vibration is recognized at high speed range in model tests using the elastic backbone ship model
(5) as for the slamming, ship's bottom is exposed when running in high waves but the impact level is considerably low because there is no flat bottom

4.2 Examination of hull structural strength ;

As for the evaluation of longitudinal strength, the examination of final strength of midship section was carried out based on the reliability study using safety index (ß) and model experiments using the elastic backbone model.
As a result, we confirmed that the longitudinal strength of this ship is safe as much as existing ships are.

5. Maneuverability :

From the results of tank tests and numerical simulations, maneuvering performance was estimated as follows.

1) Rolling and transverse inclination at high speed can be reduced within 3 degree by fitting control fin with area of 20 ~ 25 m2.
2) Course keeping and Z-maneuvering abilities are sufficient because of slenderness of hull form.
3) As for the turning ability, the advance is about four times of ship length (4L) which satisfy the IMO tentative criterion but the tactical diameter becomes 6L and is beyond its criterion. So, one of countermeasures to solve this subject is to apply a high lift rudder having the same rudder area.

6. The trial design of superconducting electric propulsion plant :

6.1 Manufacture of 480 kW superconducting motor and performance tests ;

As mentioned before, an application of superconducting motor to electric propulsion system was target for a displacement type ship.
We have been proceeding the development of superconducting homopolar of 480 kW output.
The bird's-eye view of the 480 kW superconducting DC homopoler motor and the particulars are shown in Fig.5 and in Table 3 respectively.
We carried out the characteristics tests as the DC homopolar motor. Fig.6 shows the relation between the output torque and the armature's current measured by a torque transducer under the fixed condition of 480 kW rpm. It output the torque of 8,650 N·m at a maximum under the armature's current of 2,610 A. The loss torque was about 2,000 N·m and was not influenced by the output.
During the test, we obtained the stable cooling and excitement of the superconducting field coil which will make a great progress toward the practical use of that one in the future.

6.2 The examination of the main element;

Originally, AC machines are superior in size and weight to DC machines but are inferior in a peculiar AC loss to these one.
So, it is necessary to consider the influence on the cooling system for superconducting coil. Moreover, when the miniaturization and lightening are assumed to be top priority, it is possible to think of the fully superconducting synchronous motor which also makes the armature coil superconducting coil.

We made a conceptual design of the DC machine about the electric motor itself and the attached facilities. From the result, we chose the propulsion plant which is most desirable for practical use.

On the assumption that the total output is about 150,000 ps the output is distributed to three axis and distribution ratio is 60% for center axis corresponding to 63,000 kW and 20% for each wing axis corresponding to 21,000 kW.

6.2.1 Examination of supercondicting propulsive motor ;

(1) Fully superconducting synchronous motor
The feeding and exhausting mechanism of liquid helium was needed on the rotation axis.
Since two or more tandem arrangement was impossible, we made a concept design with a central axis of 63,000 kW/120 rpm, and each one wing axis of 21,000 kW/ 120 rpm.

(2) Superconducting DC homopolar motor
Main axis was the tandem of the structure with three motors of 21,000 kW/120 rpm. Each wing axis was one motor of 21,000 kW/120 rpm. Fig.7 shows the concept design of the superconducting DC homopolar motor.

(3) Comparison on parameters of the superconducting motor Table 4 shows the parameters of a electric motor itself based on the concept designs of both AC/DC types.

6.2.2 Examination of superconducting generator ;

Both motors and generators have AC type and DC type, and one of the best choice is the combination of "AC generator + AC motor" because of easy maintenance and control.
On evaluation, we made the concept design of the following AC superconducting generator/DC superconducting generator themselves.

AC generator ... 23,000kWx3,600rpm
Superconducting synchronous generator

DC generator ... 23,300kWx600rpm
Superconducting DC homopoar generator

6.2.3 Examination of cooling equipment;

We examined the possibility of installing cooling equipment to the superconducting ship type, including the space demanded for the equipment. The model and the scale of the cooling equipment differ according to the method of AC/DC on the superconducting motor and the superconducting generator. Therefore, we examined the combination based on the knowledge we gained through the concept design and the following three cases are determined.

	superconducting motor	superconducting generator
<CASE-1>	DC homopolar motor (Total output of the five: 105,000 kW)	DC homopolar generator (23,300 kW x 5)
<CASE-2>	Fully superconducting synchronous motor (Total output of the three: 105,000 kW)	Synchronous generator (23,300 kW x 5)
<CASE-3>	DC homopolar motor (Total output of the five: 105,000 kW)	Synchronous generator (23,300 kW x 5)

In the above mentioned three cases, we examined the amount of helium consumption and the heat loads for the helium recondensing refrigerator and the size/the weight of equipment.

6.2.4 Comparison of propulsion systems ;

(1) Comparison of electric motors for propulsion
Generally in normal-conducting, <CASE-2> the combination of "AC generator + AC motor" is superior in maintenance and the control, and has many actual results. In also superconducting, the motor itself is attractive for its small size and light weight. However, the <CASE-2> requires the large-scale helium liquefaction equipment, which occupies large area and it will

be fatal for the existence of the high speed container ship.
The cooling equipment in <CASE-1> "DC generator + DC motor" and <CASE-3> "AC generator + DC motor" can be installed within the range for the arrangement inboard. This respect becomes a main reason on the choice of the motor, and the motor for propulsion necessarily become DC type.

(2) Comparison of generators
When the superconducting synchronous generator and the superconducting DC generator are compared, size and weight of the latter becomes much greater because of the necessity of low speed.
Moreover, from the viewpoint of the leakage magnetic field and the cable size,the synchronous generator is preferable. The synchronous generator of the AC type is selected for these reasons.
<CASE-3> "AC generator + DC motor" can be proposed as the combination of a generator and a electric motor. However, when taking the necessary helium liquefaction equipment's scale into consideration, normal-conducting type synchronous generator can be thought of additionary. As a result of the examination, the superconducting synchronous generator was 1/2 of weight, and 1/9 of the capacity against the normal conducting synchronous generator when compared with the generators themselves. But, when including the helium liquefier necessary for cooling the superconducting field coil, it becomes 1.3 times in weight, and 7 times in capacity, and there will be no merit for making superconducting.
Therefore, we took the normal-conducting machine for the generator.

6.3 Basic concept of the propulsion system ;

Based on the results of initial examinations for hull from/machinery/ electricity, we conducted the re-plan for the superconducting, electric propulsion system as a high speed ship with a 50 knots/CRP/shaft power of 180,000 ps.
Fig.8 shows the basic concept for the electric propulsion system which were reflected in the foregoing results.

7. Concept design of displacement type monohull high speed ship :

7.1 Choice of hull principal dimensions ;

At an early stage of basic design of this kind of ship, the followings shoud be noted.

1) in viewpoint of propulsion performance, the ratio of wave-making resistance against total resistance is relatively large. In particular, the ratio of L/B largely influences on it.
2) the ratio of cargo DW, lightweight and fuel by displacement are about 10 %, 70 % and 20 %, respectively
3) Hull steel weight is about 1/2 of light weight
4) stability requirements influences sensitively on principal particulars

Taking into consideration above-mentioned subjects the ship was designed at the basic conditions with a 50 knots, cruising range 5000 N.M, draft 8.5 m and CRP for single propeller shaft.
In order to select the optimum ship length, we conduted iterative calculations of displacement, DHP, Cargo DW and GoM which related to all together. Finally, we found that the optimum ship length (Lpp) was between 220 m and 240 m.

7.2 Rough specifications and general arrangements ;

Based on the development of ship hull form, experimental model tests, numerical simulations and R & D of the laboratory sized superconducting motor,

we conducted a conceptual design of a superconducting-motor containership which is imagined as an actual one with a speed of 50 knots.
The rough specifications and general arrangements are shown in Table 5, Fig.9 and Fig.10, respectively.

8. Conclusion :

We would like to avoid to mention the findings one by one because problems arising from the design include many examinations to evercome such as wave resistance, compactness and lightweight of super-conducting propulsion plants, etc., but we are convinced that this research will be usefull for realization of displacement type mono-hull high speed ships and for another design of future ships with an alternative propulsion system to meet growing sea transportation demand.

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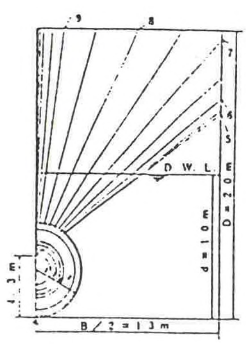

Fig.1 Body plan

Lpp	1.8000 m
B	0.2600 m
Bw	0.1500 m
d	0.1000 m
C_B	0.3503

Table 1 Principal dimensions of theoretical semi-submerged model ship

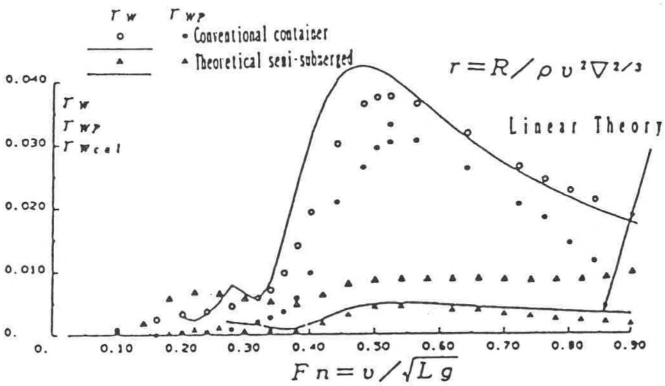

Fig.2 Comparison of residual wave-making resistance coefficient,etc. for conventional ship and throretical semi-submerged ship

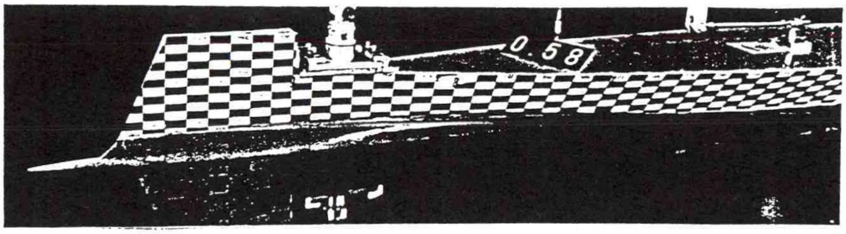

Fig.3 Wave pattern around the bow of Improved-Ovoid-Type model (F=0.58)

Table 2 Principal particulars of model ships for seakeeping & maneuvering tests

Model No.	0179	0186	0187	0211	0216
Ship type	Conventional 35 kt DD	50 kts High Speed Ship			
Segmented Model	4 sgmts	-	2 sgmts	-	9 sgmts
L_{pp} (m)	2.0	3.200	2.500	2.000	2.500
B_{max} (m)	0.1878	0.400	0.3125	0.250	0.2875
B_{wl} (m)	0.1123	0.240	0.1875	0.150	0.200
d (m)	0.0654	0.136	0.1063	0.085	0.1063
$L/\Delta^{1/3}$	8.61	9.37	9.37	9.37	9.16

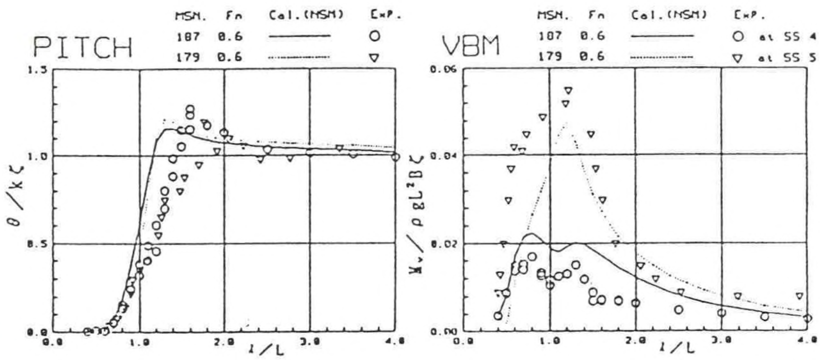

Fig.4 Comparison with the conventional high speed vessel about pitch and vertical bending moment at high speed (F=0.60)

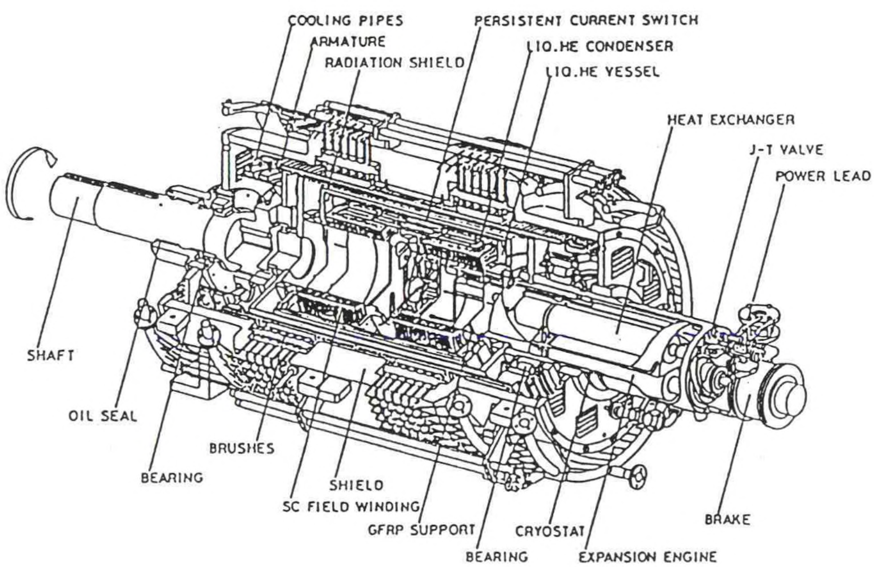

Fig.5 A bird's eye view of the 480kw superconducting motor

Table 3 Particulars of the 480kW supercoducting motor

Type	DC homopolar motor with superconducting field winding
Output power/speed/efficiency	480 kW / 480 rpm /82.7 %
Input voltage/current/power	218 V / 2,660 A / 580 kW
Size	1,040 mm dia. × 2,865 mm length
Weight	4,200 kg
Field winding	
type	superconducting solenoid coil with persistent current mode
cooling	liquid helium pool cooling with helium refrigerator
current	400 A
effective magnetic flux	0.866 Wb
Armature	
type	segmented drum type
number of segments	stator armature : 60 rotor armature : 150
induced voltage	208 V at 480 rpm
cooling	water cooling
Current collector	
type	solid brush type
number of brushes	5 × 120
current density	41.5 A/cm²
brush pressure	air cylinder type
Loss	
mechanical loss	72.4 kW
electrical loss	27.3 kW
total	99.7 kW

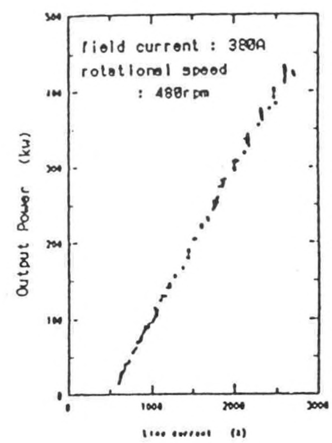

Fig.6 Output chracteristic

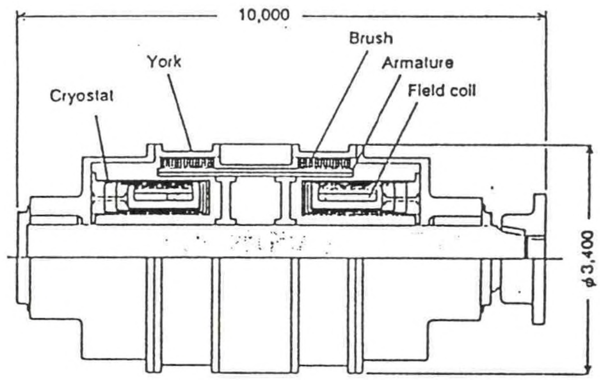

Fig.7 Superconducting D.C. homo-polar motor
(21,000kW/120rpm)

Table 4 Comparison table of superconducting motor
for ship propulsion

Particulars	Main-propulsion motor		Wing-propulsion motor	
	A.C. motor	D.C. motor	A.C. motor	D.C. motor
Motor type	Fully superconducting synchronous motor	Superconducting D.C. homopolar motor	Fully superconducting synchronous motor	Superconducting D.C. homopolar motor
Motor output Output power (W) Rotational speed (rpm)	 63,000 ×1 120	 21,000 ×3 120	 21,000 120	 21,000 120
Field coil Type Number of poles Max. flux density (T) Cooling method	 Race track 8-poles 6.33 Liquid helium	 Split solenoid homo-pole 8.0 Liquid helium	 Race track 8-poles 6.33 Liquid helium	 Split solenoid homo-pole 8.0 Liquid helium
Armature coil Type Current Cooling method	 Superconductor A.C. 3 phase, 8Hz Liquid helium	 Normal conductor D.C. Water	 Superconductor A.C. 3 phase, 8Hz Liquid helium	 Normal conductor D.C. Water
Motor dimension and weight Width (m) Height (m) Length (m) Weight (ton)	 2.500 2.800 16.200 350	 3.400 3.800 10.000 330	 2.300 2.700 11.000 100	 3.400 3.800 10.000 330
Helium consumption rate (l/hr)	630	28	210	28

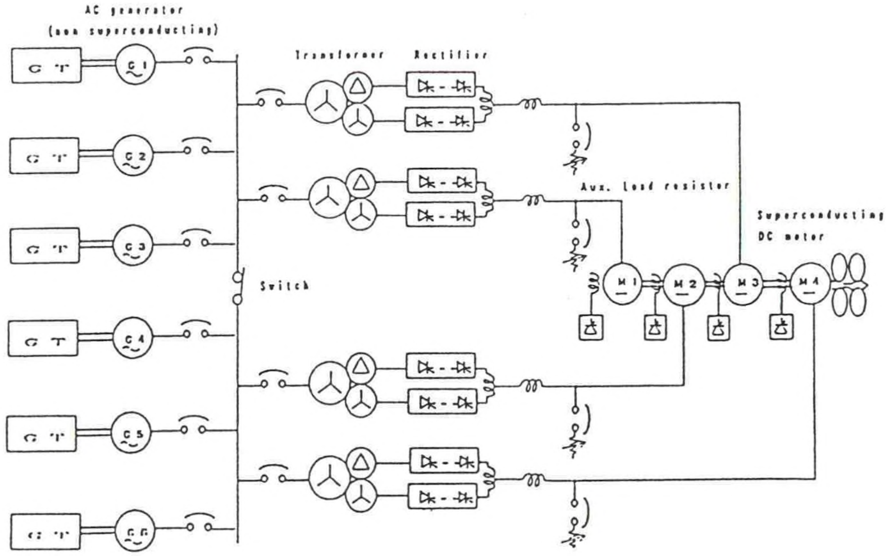

Fig.8 Wiring diagrams of electric propulsion systems

Table 5 Rough specificaton

(1)	General		
	King of ship	: container ship	
	Route	: Tokyo ~ West Coast (USA)	
(2)	Hull form, principal dimension		
	Hull form	: displacement type OVOID hull form semi-aft bridge, whale-back bulbous bow, single rudder, mariner stern	
	Lpp	: 228.0 m	
	B	: 23.0 m	
	D	: 18.0 m (upper deck)	
	d	: 8.5 m	
(3)	Speed speed, cruising range		
	Vs	: 50 knots	
	range	: 5000 N.M	
(4)	Main engine, propulsor		
	Type	: Superconducting electric motor propulsion system	
	Generator	: normal-conducting AC generator (23,350 kW x 3,600 rpm)	6 sets
	Prime mover	: Gas turbine (32,400 ps x 3,600 rpm)	6 sets
	Motor	: DC motor (33,100 kW x 120 rpm)	4 sets
	Propulsor	: CRP (fixed pitch)	
(5)	Container		
	Number	: 200 TEU	
	Max. payload	: 1000 ton	
(6)	Crew	: 11 persons	

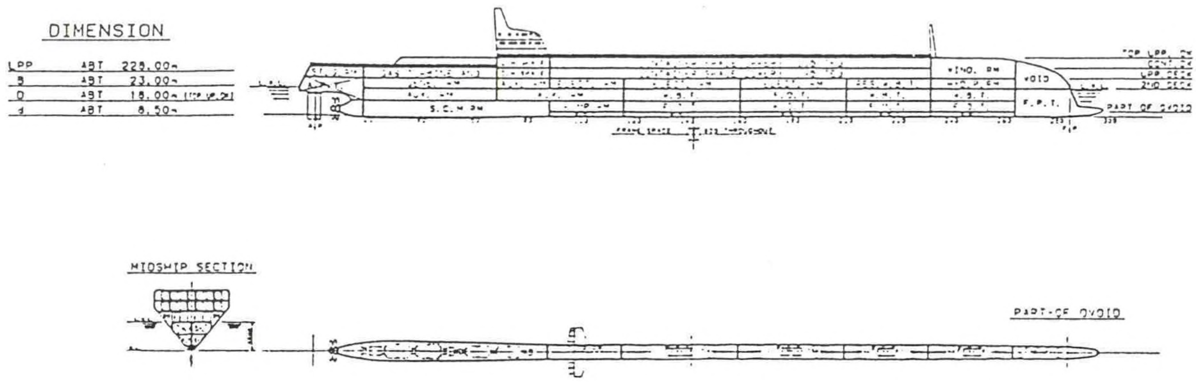

Fig.9 General Arrangement

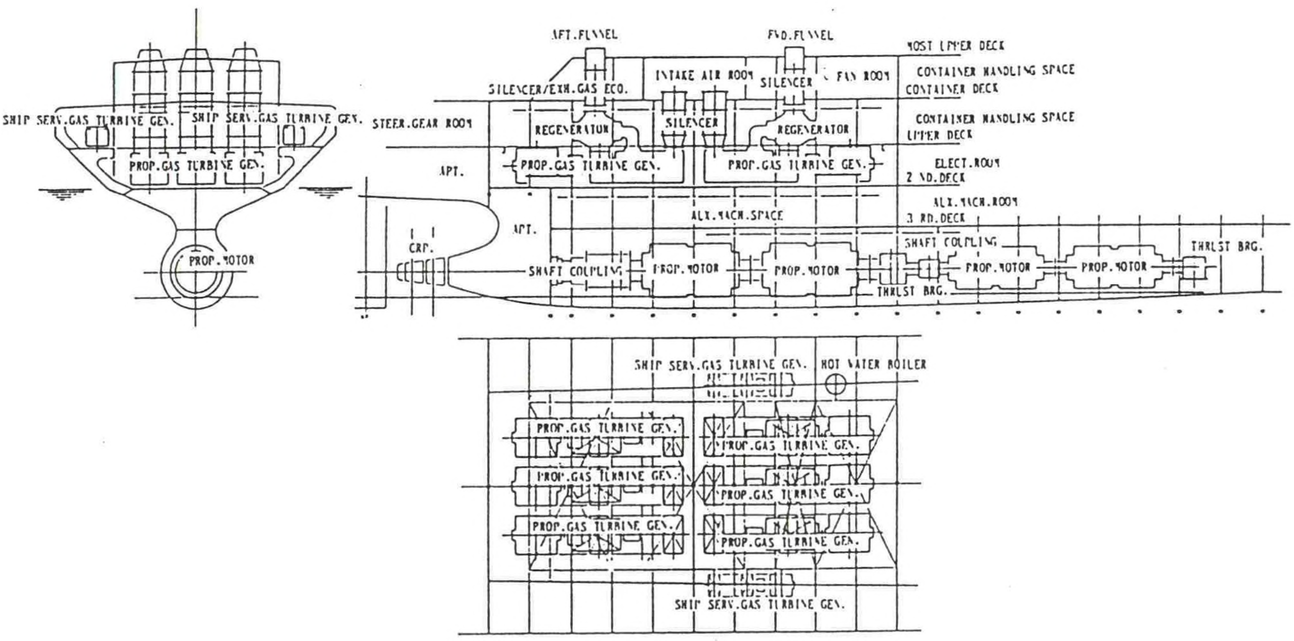

Fig.10 Arrangement diagram of engine room

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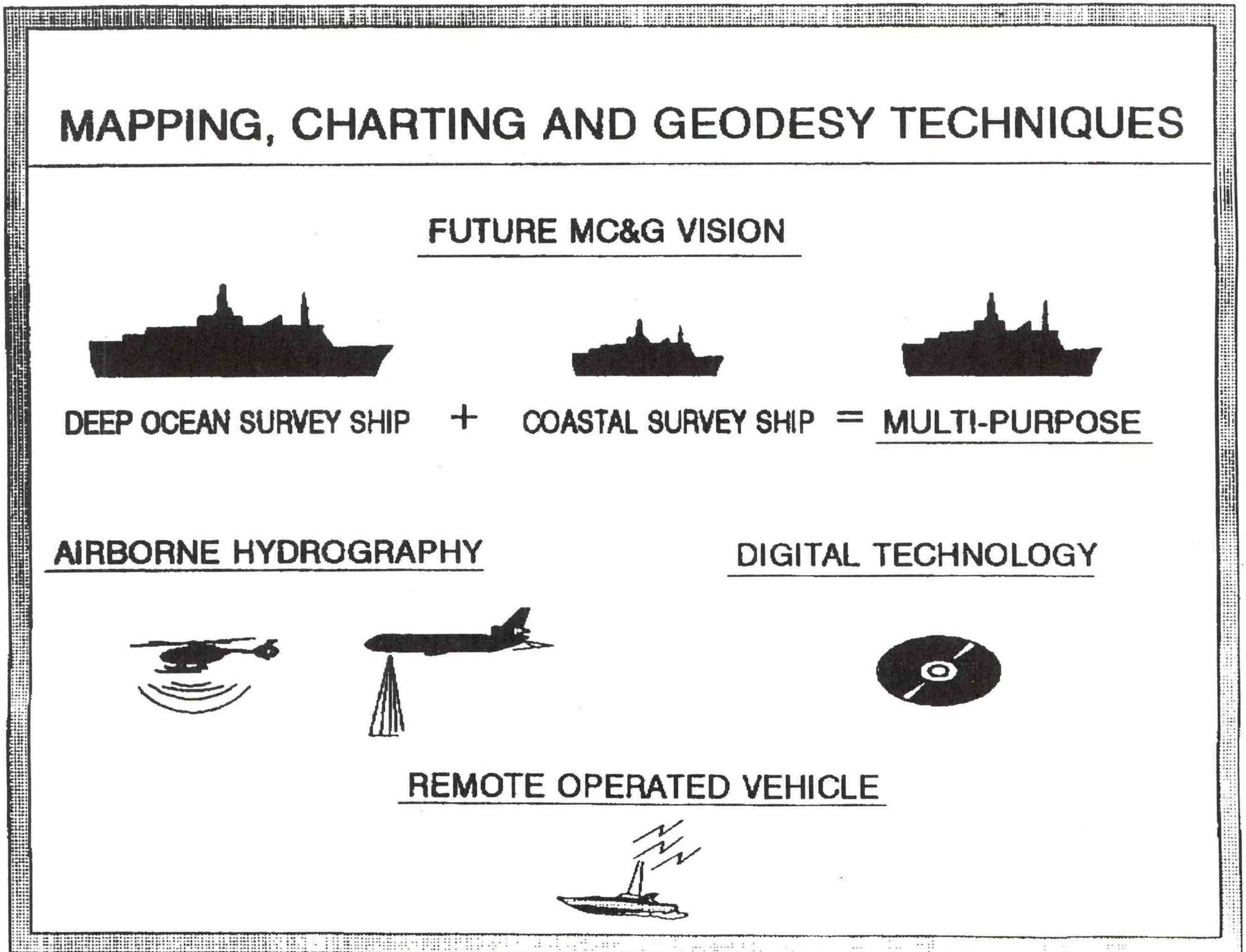
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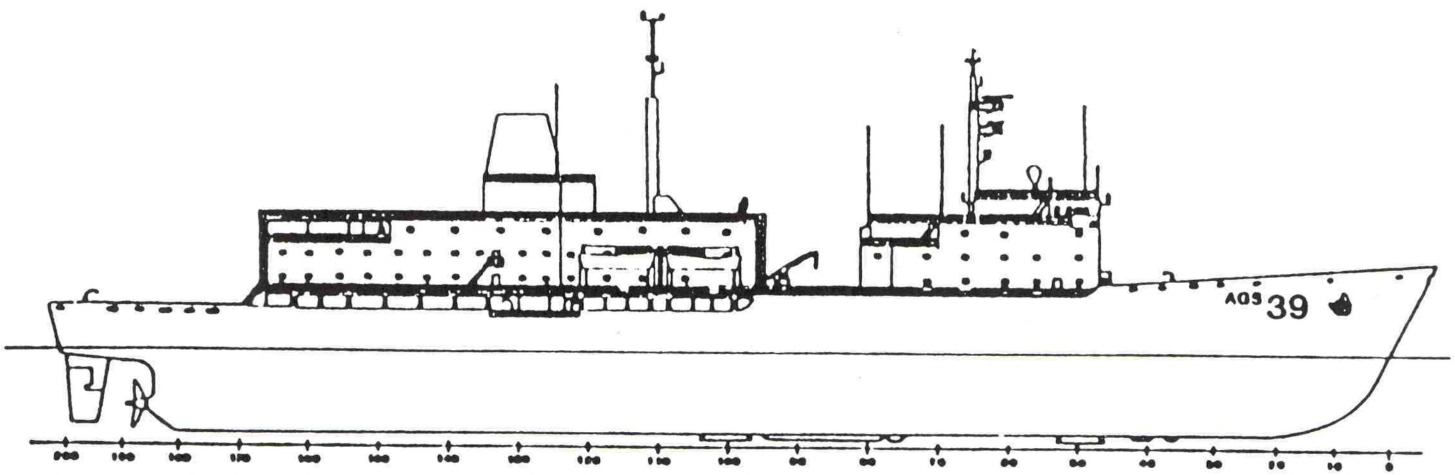
OCEAN SURVEY SHIP

T-AGS 39/40



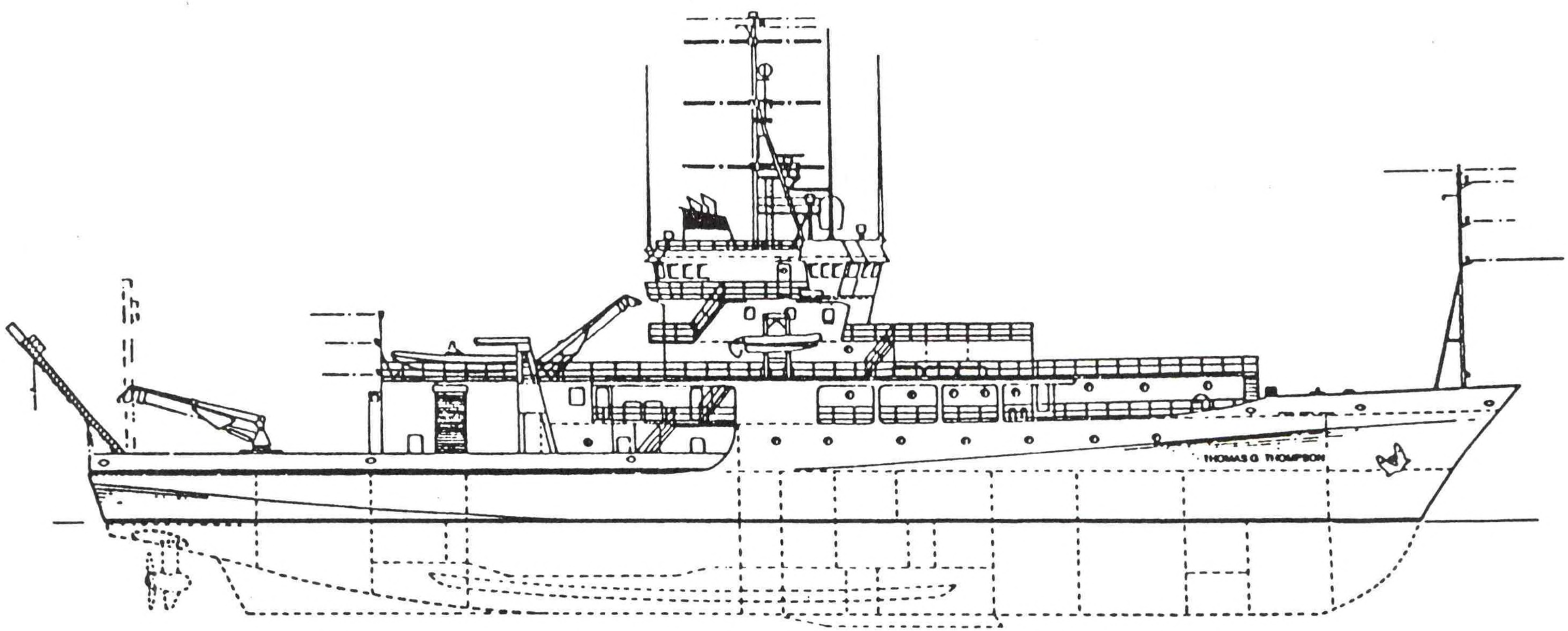
OCEAN SURVEY SHIP
T-AGS 39/40

AUTHORIZATION YRS:		FY 85
NUMBER OF SHIPS:		2
PROJECT BUDGET:		
STATUS:		PSA
BUILDERS:		BETH SHIP, SPARROWS POINT, MD
CHARACTERISTICS:	- LOA	499'10"
	- BEAM	72'
	- DRAFT	30'6"
	- DISPLACEMENT (FL)	15,820 LT
	- SHAFT HP	25,000 BHP
	- SPEED	20 KTS
	- MACHINERY	GEARED REVERSING DIESEL, SINGLE SHAFT
	- CREW (MSC)	56
	(USN)	32
	- SCIENTIFIC PERSONNEL	20

FEATURES:

- PRECISION NAVIGATION
- PRECISION BOTTOM MAPPING DEEP OCEAN
  - HAS SAME PRIORITY AS TRIDENT (BRICKBAT)

OCEANOGRAPHIC RESEARCH SHIP
AGOR 23



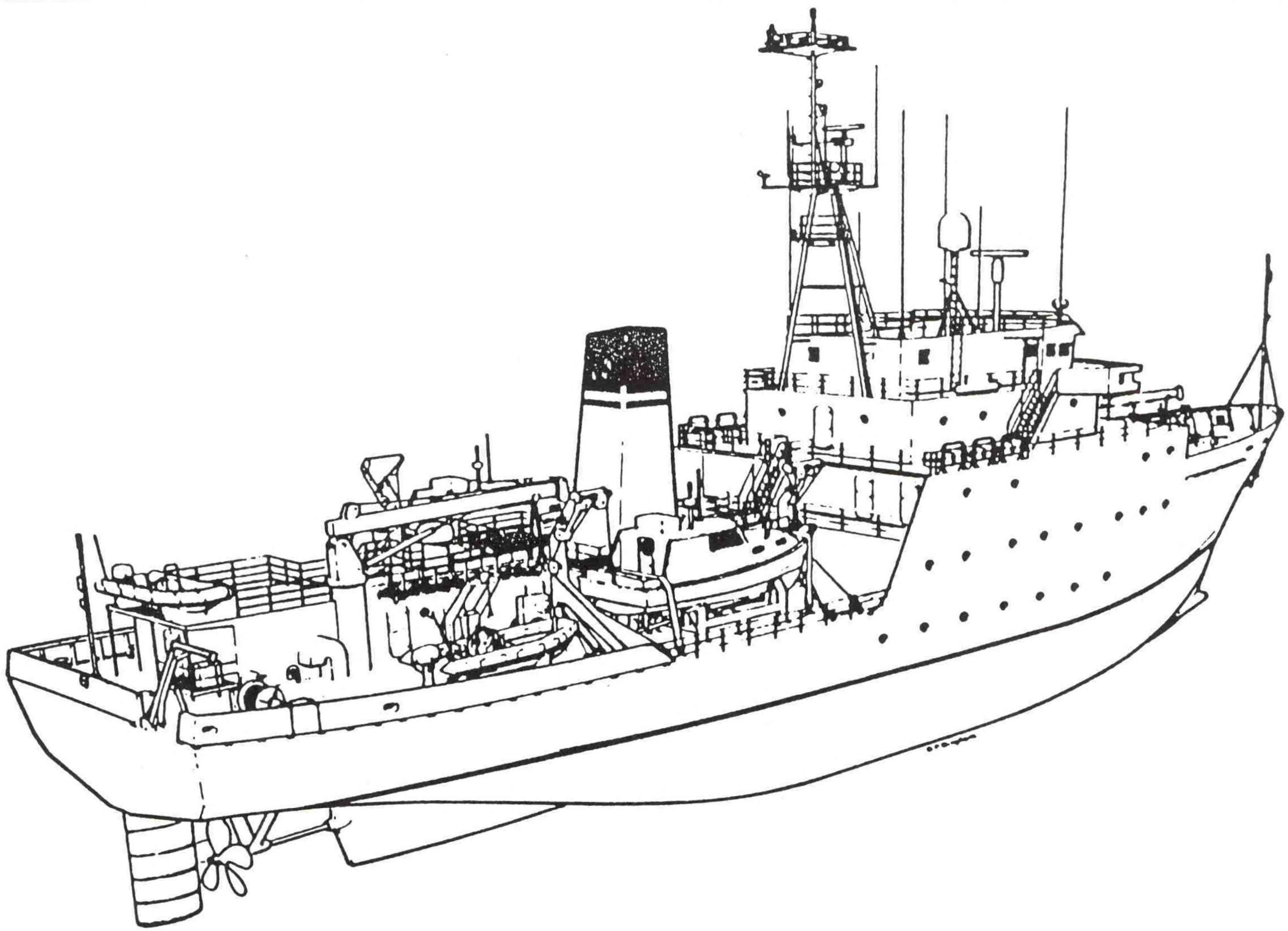
OCEANOGRAPHIC RESEARCH SHIP
AGOR 23

AUTHORIZATION YRS:		FY 87
NUMBER OF SHIPS:		1
PROJECT BUDGET:		
STATUS:		DELIVERED
BUILDER:		HALTER MARINE, MOSS POINT, MS
CHARACTERISTICS:	-LOA	274.5'
	-BEAM	52.5'
	-DRAFT	19'
	-SPEED	15.0 KTS (SUSTAINED)
	-MACHINERY	DIESEL ELECTRIC, TWIN-Z-DRIVES

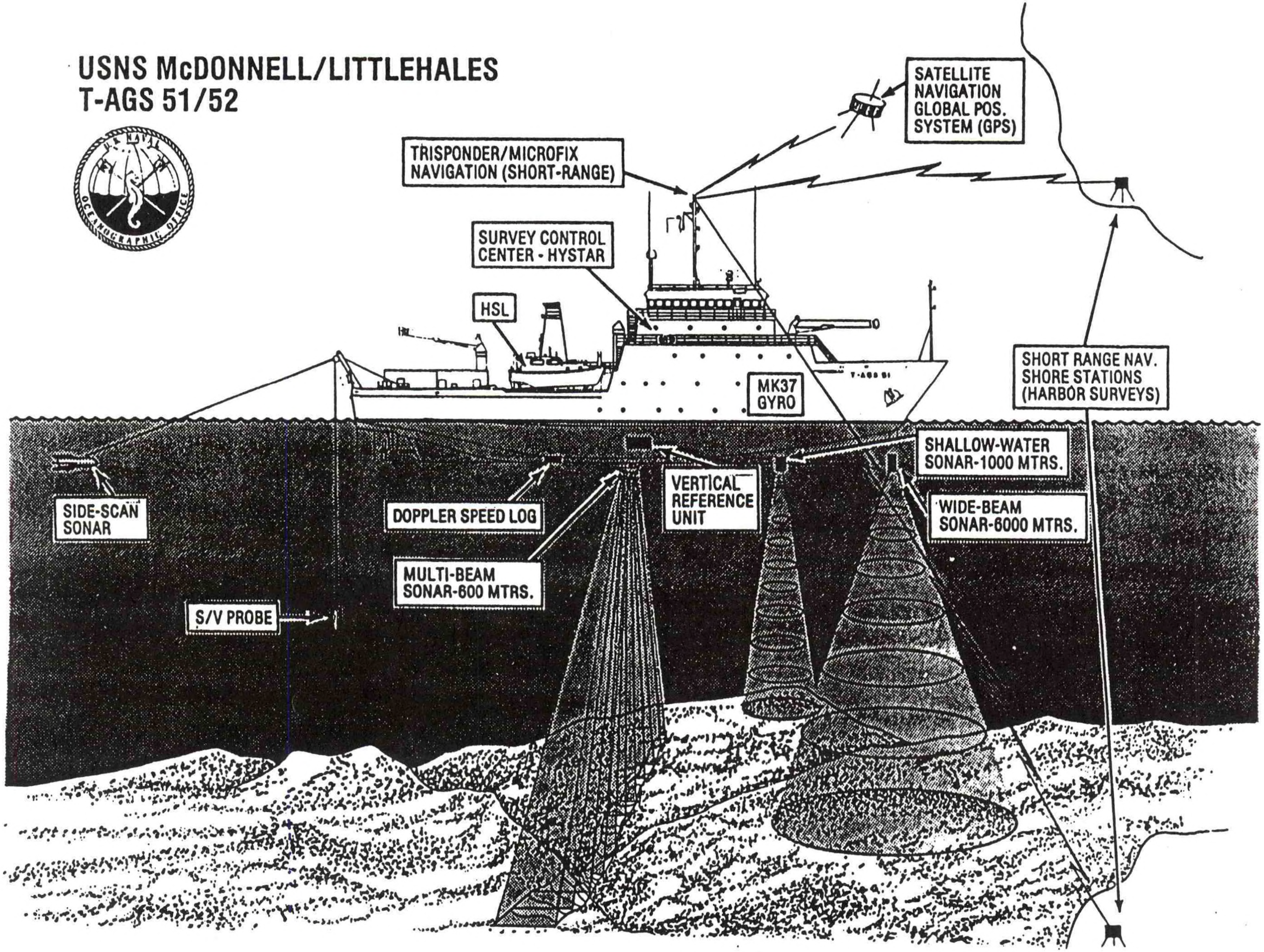
FEATURES:
- OPERATED BY THE UNIVERSITY OF WASHINGTON (RESEARCH SHIP)
- OCEANOGRAPHIC SAMPLING AND DATA COLLECTION
- PRECISE NAVIGATION (STATION AND TRACK KEEPING)
- KRUPP ATLAS MULTIBEAM SONAR SYSTEM

COASTAL HYDROGRAPHIC SHIP

T-AGS 51/52



USNS McDONNELL/LITTLEHALES
T-AGS 51/52



COASTAL HYDROGRAPHIC SHIP

T-AGS 51/52

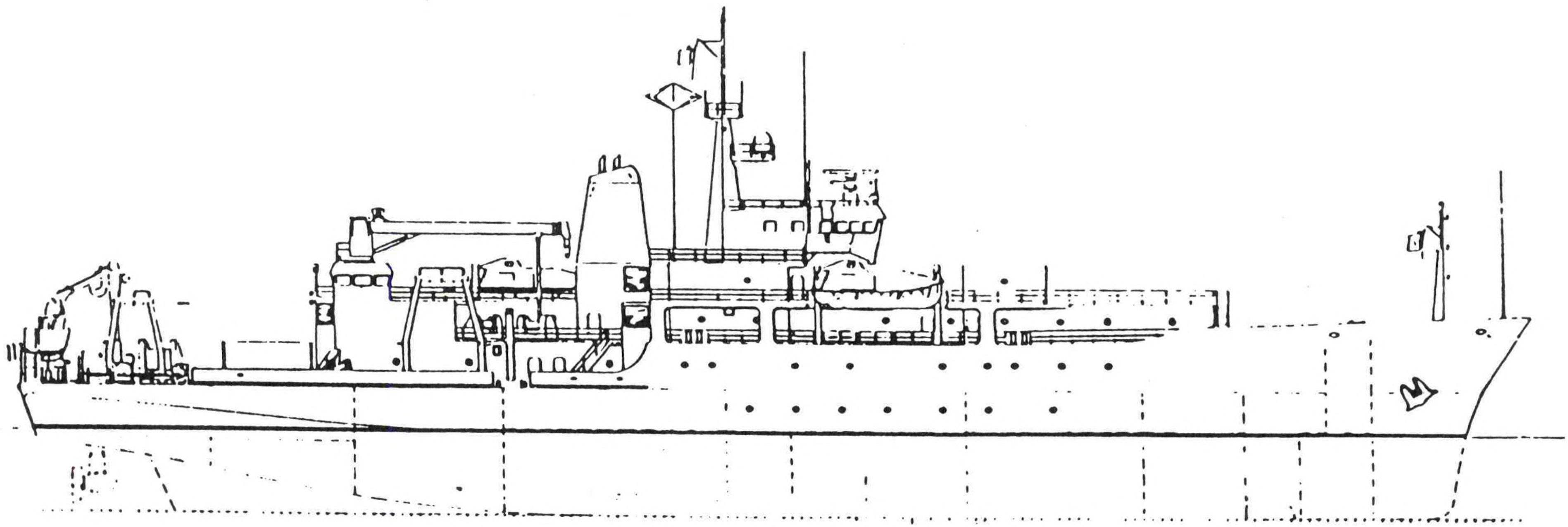
AUTHORIZATION YRS:		FY 87
NUMBER OF SHIPS:		2
PROJECT BUDGET:		
STATUS:		DELIVERED
BUILDERS:		HALTER MARINE INC. (HMI), MOSS PT., MS
CHARACTERISTICS:	- LOA	208'
	- BEAM	45'
	- DRAFT	14'
	- SPEED	12 KTS (SUSTAINED)
	- MACHINERY	GEARED FATHER/SON DIESELS

FEATURES:

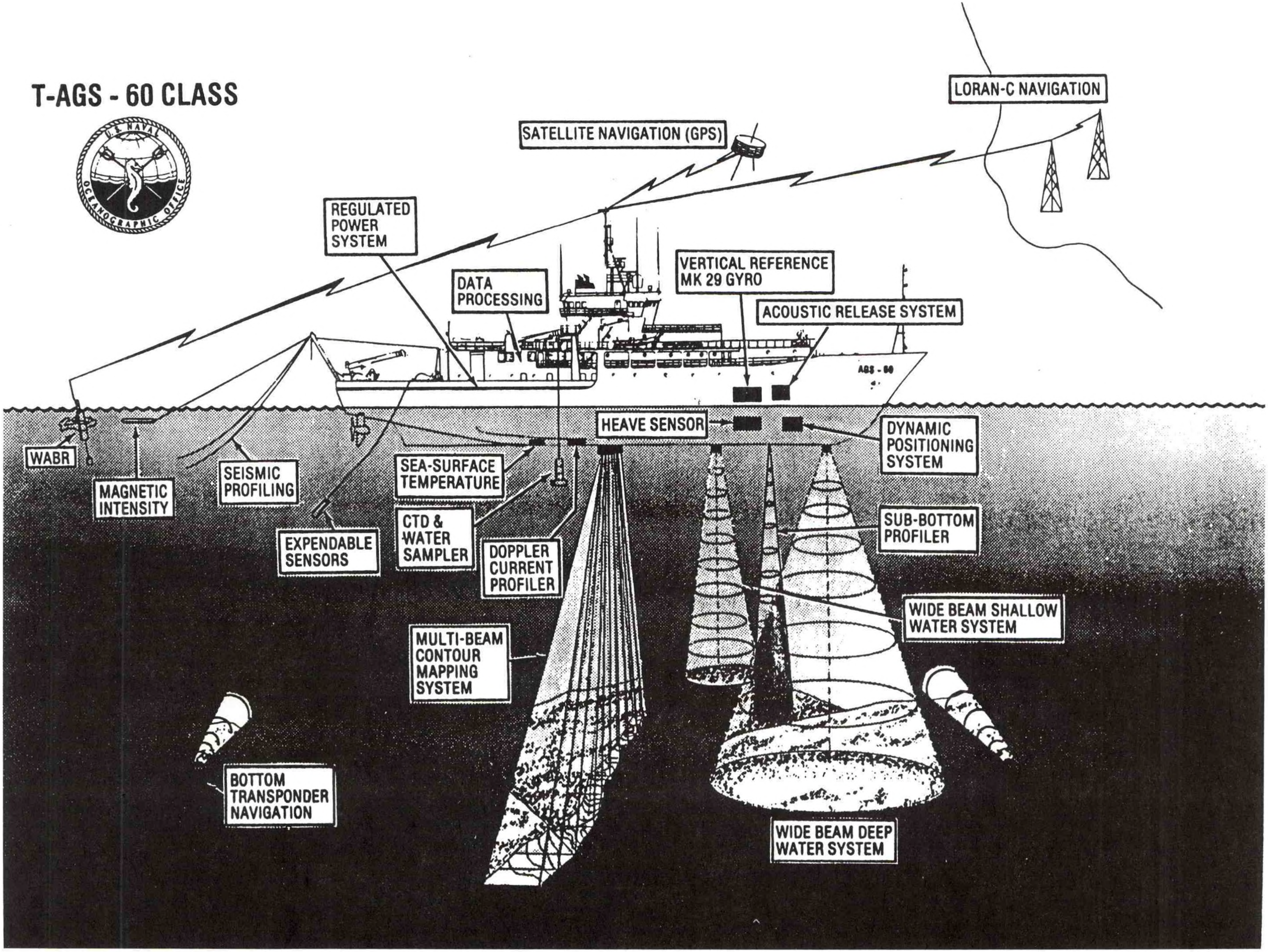
- COASTAL HYDROGRAPHIC SURVEYING WITH SHALLOW WATER WIDE BEAM SONAR
- (2) HYDROGRAPHIC SURVEY LAUNCHES (HSL) PER SHIP

OCEANOGRAPHIC SURVEY SHIP

T-AGS 60/61/62



T-AGS - 60 CLASS



OCEANOGRAPHIC SURVEY SHIP
T-AGS 60/61/62

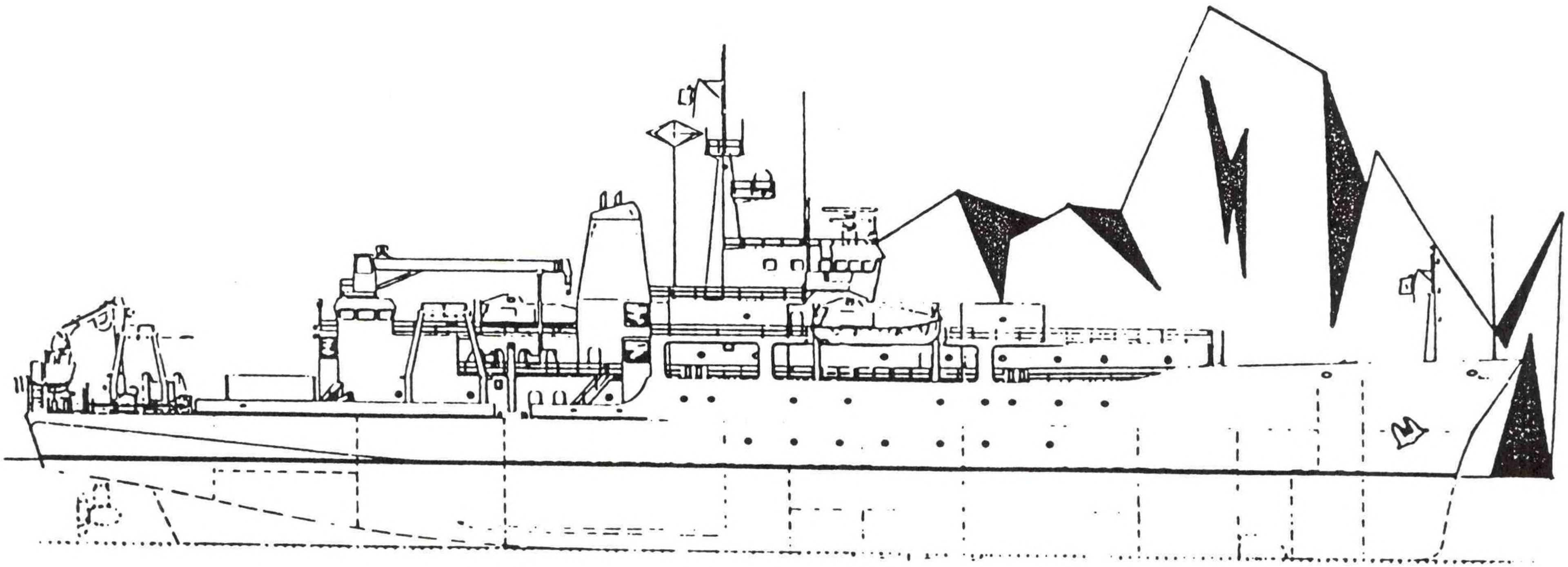
AUTHORIZATION YRS:	FY 90 AND 92
NUMBER OF SHIPS:	
PROJECT BUDGET:	
STATUS:	DETAIL DESIGN AND CONSTRUCTION
BUILDERS:	HALTER MARINE, MOSS POINT, MS.

CHARACTERISTICS: - LOA	328.5 FT
- DRAFT	19 FT
- BEAM	58 FT
- SPEED	16 KTS SUSTAINED
- CREW	55 PERMANENT + 5 TEMPORARY IN VANS

FEATURES:

- OPERATION IN COASTAL AND DEEP OCEAN AREAS
- PHYSICAL, CHEMICAL AND BIOLOGICAL OCEANOGRAPHY
- MARINE GEOLOGY AND GEOPHYSICS
- SURVEYS (BATHYMETRY, GRAVIMETRY AND MAGNETOMETRY)

ICE CAPABLE OCEAN SURVEY SHIP
T-AGS (O) ICE



ICE CAPABLE OCEAN SURVEY SHIP
T-AGS (O) ICE

AUTHORIZATION YRS:		TBD
NUMBER OF SHIPS:		1
PROJECT BUDGET:		TBD
STATUS:		SOURCE SELECTION (ON HOLD)
BUILDERS:		TBD
CHARACTERISTICS:	- LOA	TBD
	- BEAM	TBD
	- DRAFT	TBD
	- DISPLACEMENT (FL)	TBD
	- SHAFT HP	TBD
	- MACHINERY	INTEGRATED DIESEL ELEC. PLANT
	- CREW	62
	- SPEED	16 KNOTS SUSTAINED IN CALM WATER (80% MCR)

FEATURES:

- OPERATION IN COASTAL AND DEEP OCEAN AREAS INCLUDING THE MARGINAL ICE ZONE (ARCTIC)
- PHYSICAL, CHEMICAL AND BIOLOGICAL OCEANOGRAPHY
- MARINE GEOLOGY AND GEOPHYSICS
- SURVEYS (BATHYMETRY, GRAVIMETRY AND MAGNETOMETRY)

SHIPBOARD PILOTING EXPERT SYSTEM

Paul Mentz and John Dumbleton, U. S. Maritime Administration
Martha Grabowski, Rensselaer Polytechnic Institute

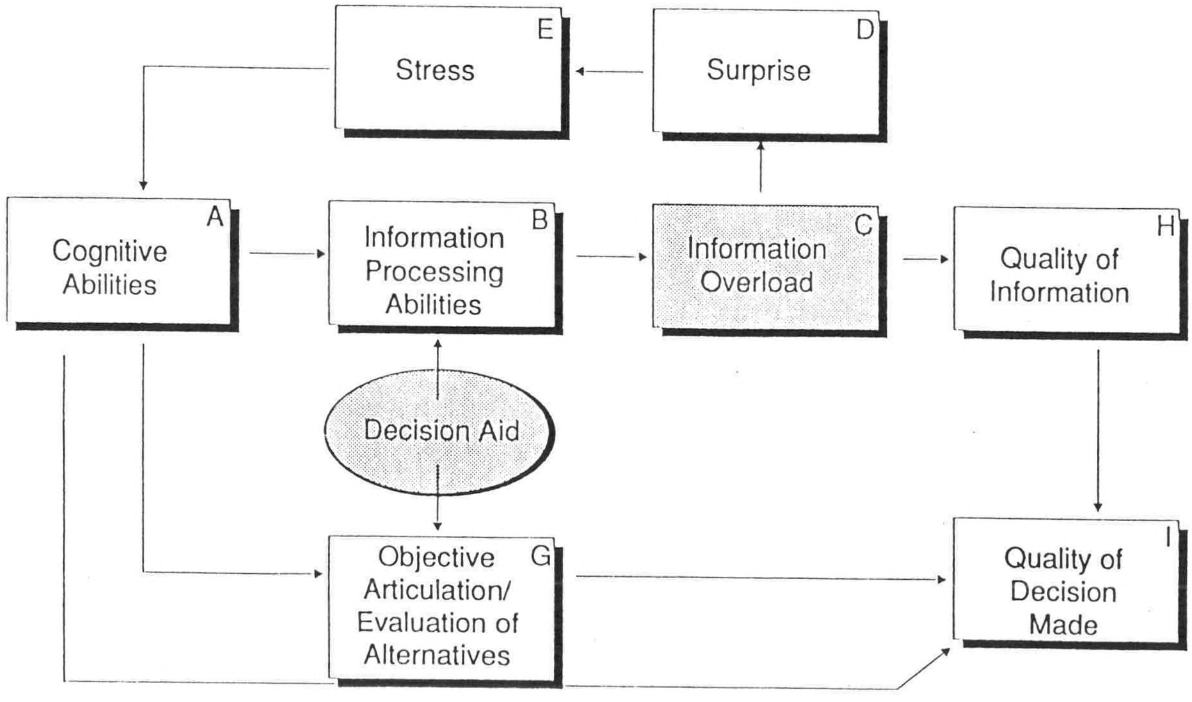
Introduction

Ships' masters, mates, and pilots navigating in congested waters are confronted with data from a variety of sources, and are required to make crucial piloting decisions in very short periods of time. These decisions are made in a stressful marine environment by increasingly smaller bridge watch team complements. As a result, the majority of maritime collisions, rammings, and groundings occur in harbor or harbor approach waters, with about eighty percent of these accidents caused by human error. As ships increase in size and complexity, and ship's piloting in congested waters becomes more complex, there has been a corresponding increase in the resulting cost and damage to the environment, and increasing interest in decision aids to assist in these dangerous situations.

The decision processes involved in responding to a restricted waters navigational situation are represented in Figure 1. The quality of a decision made by an individual in stressful conditions (Box I) is a function of the quality of the information received (Box H), the decision-maker's cognitive capabilities (Box A), and an assessment and evaluation of the tradeoffs associated with the various alternatives (Box G). The quality of the information used in the decision process depends on the ability of the information system to monitor and to reduce data flows to prevent information overload (Box C), as well as on the ability of the system to ensure that the data are in a form meaningful to the user.

FIGURE 1

ROLE OF DECISION AIDS IN INDIVIDUAL CRISIS DECISION-MAKING



Decision Support for Ship's Piloting - Piloting large ships in restricted waters requires substantial training and preparation. Even with this preparation, piloting is an inherently judgmental activity, and pilots and ships' captains invariably develop "rules of thumb" for piloting vessels on particular waterways. As vessels become larger, the cargo more hazardous, and the waterways more congested, decision aid technology is being introduced to improve the decision process in these stressful and potentially catastrophic situations.

To assist navigational officers in effecting safe passages through congested waters, integrated bridge systems (IBS) have been developed and implemented extensively in the last few years. These integrated bridges make the ship's wheelhouse the operational center for navigational and supervisory tasks; the bridges in many cases become "ship's operation centers" incorporating controls and monitors for all essential vessel functions -- navigation, engine control, cargo control, and communications. Accordingly, in IBS many routine navigational tasks, such as chart updating, position plotting, and steering are automated, and the IBS is designed as a federation of subsystems supporting vessel navigation, communications, steering, administration, collision avoidance, safety, and vessel monitoring and control.

In an effort to incorporate decision aid technology into an advanced IBS, the Shipboard Piloting Expert System (SPES) project was begun in 1989 as a joint venture research and evaluation project. Participants included Rensselaer Polytechnic Institute, Exxon Shipping Company, Sperry Marine, the U.S. Maritime Administration, the U.S. Coast Guard, and the National Oceanic and Atmospheric Administration. The objective of the SPES project is to develop and demonstrate a real- time, embedded, intelligent piloting aid which will provide decision support to ship's officers and pilots while maneuvering large vessels in restricted waters. As part of our on-going research, we will empirically assess the contribution of this embedded intelligent piloting system to an IBS, and to the watchstanders using it.

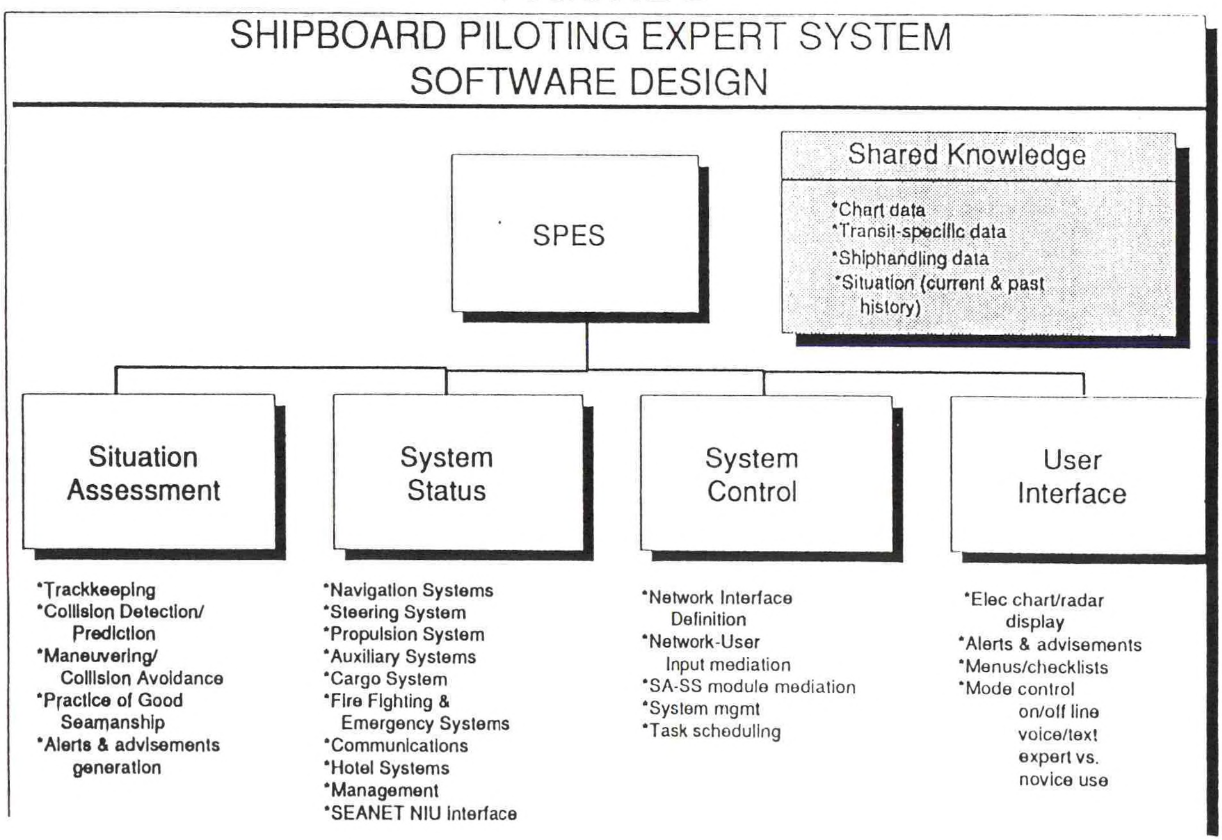
System Design

The SPES is one node in the Sperry Marine SEANET local area network (LAN) being used for the Exxon IBS. Real-time SEANET information flows into the SPES, and SPES output is provided to the SEANET network. The software includes three applications:

1. A communications program which provides for interchange between SPES and the Sperry Voyage Management System,
2. A set of electronic charts which provides a real-time plan view of the vessel's position in the waterway, and
3. The SPES software.

The SPES software is comprised of five primary modules: a Situation Assessment (SA) module, a System Status (SS) module, a System Control (SC) module, a User Interface (UI) module, and a Shared Knowledgebase (SKB) module. (Figure 2)

FIGURE 2



Situation Assessment Module - The Situation Assessment module houses the "expert" of the SPES. This module evaluates the piloting situation of your ship, assessing collision and grounding situations, required maneuvers, and generating action plans to resolve detected problems. This module uses chart knowledgebases as well as the maneuvering knowledgebase as part of the reasoning process.

System Status Module - The System Status module is the link between the SPES and SEANET. It acts to monitor SEANET messages for the SPES, insuring that the information is as real-time as possible.

System Control Module - The System Control module is the focus of SPES control and supervises all activities of the other modules, including user interface with the system. It ensures that SPES operates at peak efficiency, using its ownoperating speed to determine when tasks are performed, thus avoiding bottlenecks and idle time.

User Interface Module - This module is the area of information interchange between the user and the SPES; it issues text and graphics output, and handles all user input. Visually, its graphics-based, modular design allows ease of comprehension and interaction. (See Figures 3 and 4)

FIGURE 3
SPES USER INTERFACE OVERVIEW

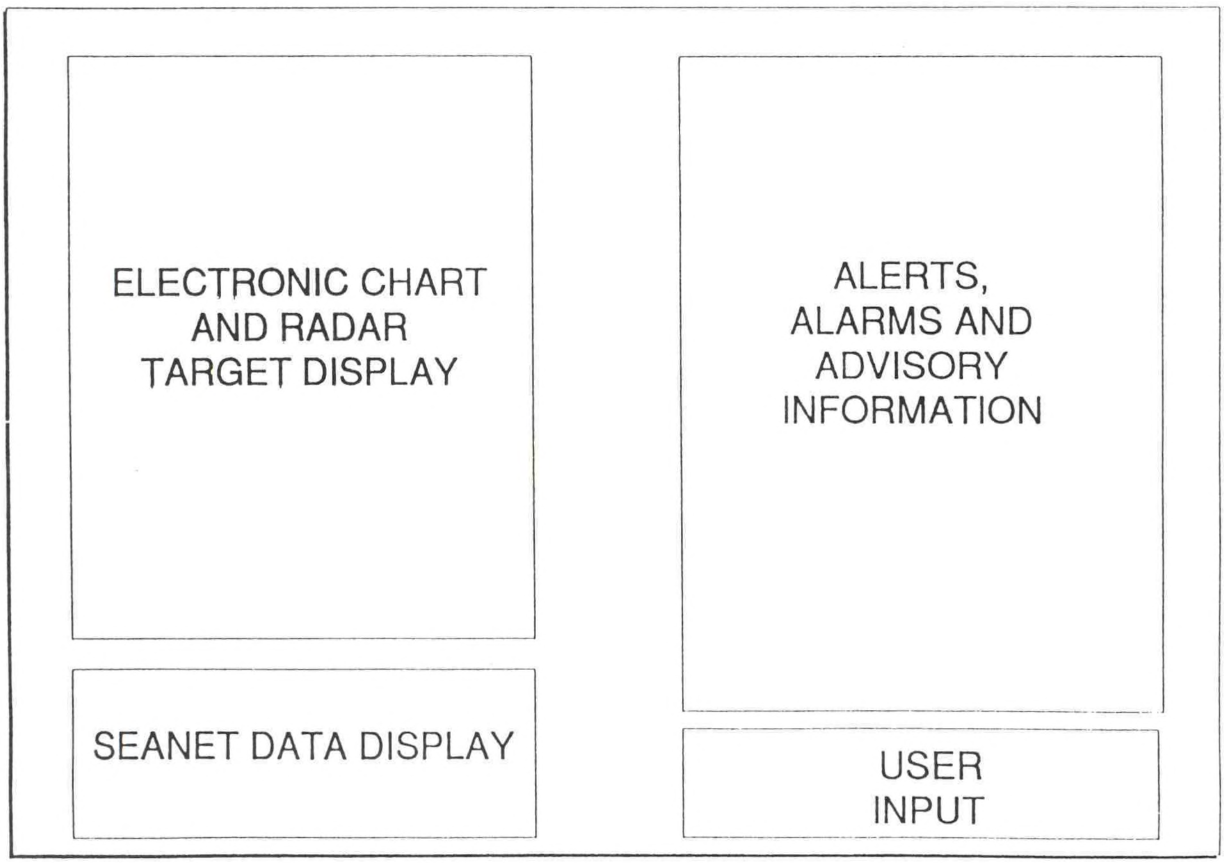
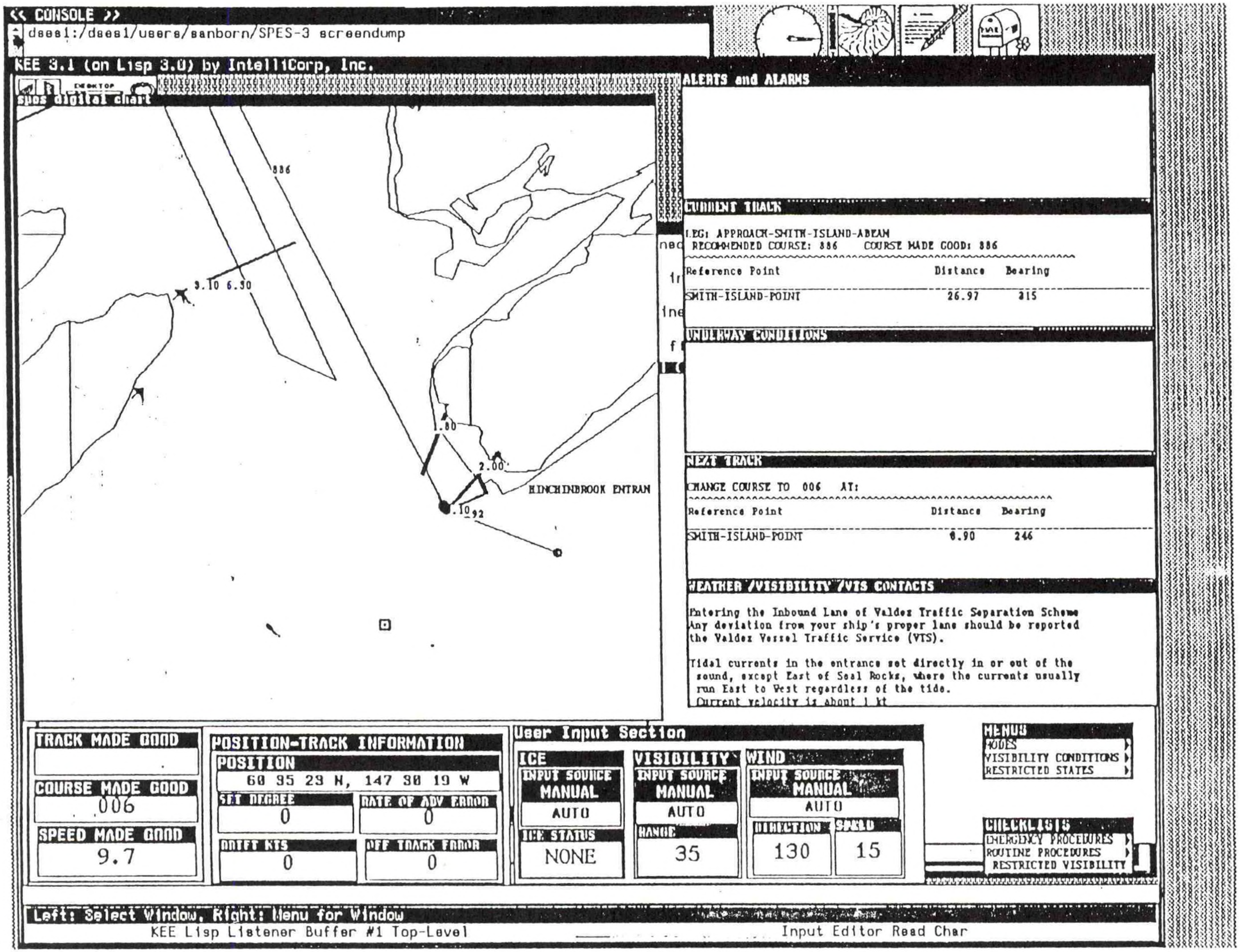


FIGURE 4
SAMPLE DISPLAY SCREEN



Shared Knowledgebase Module - the knowledgebases are designed to group related objects together in knowledgebases which are accessible to all of the SPES functional modules. This module includes shared knowledgebases for piloting situation, chart objects, local waterways, shiphandling, and user interface information common to all modules.

Knowledge Representation and Reasoning

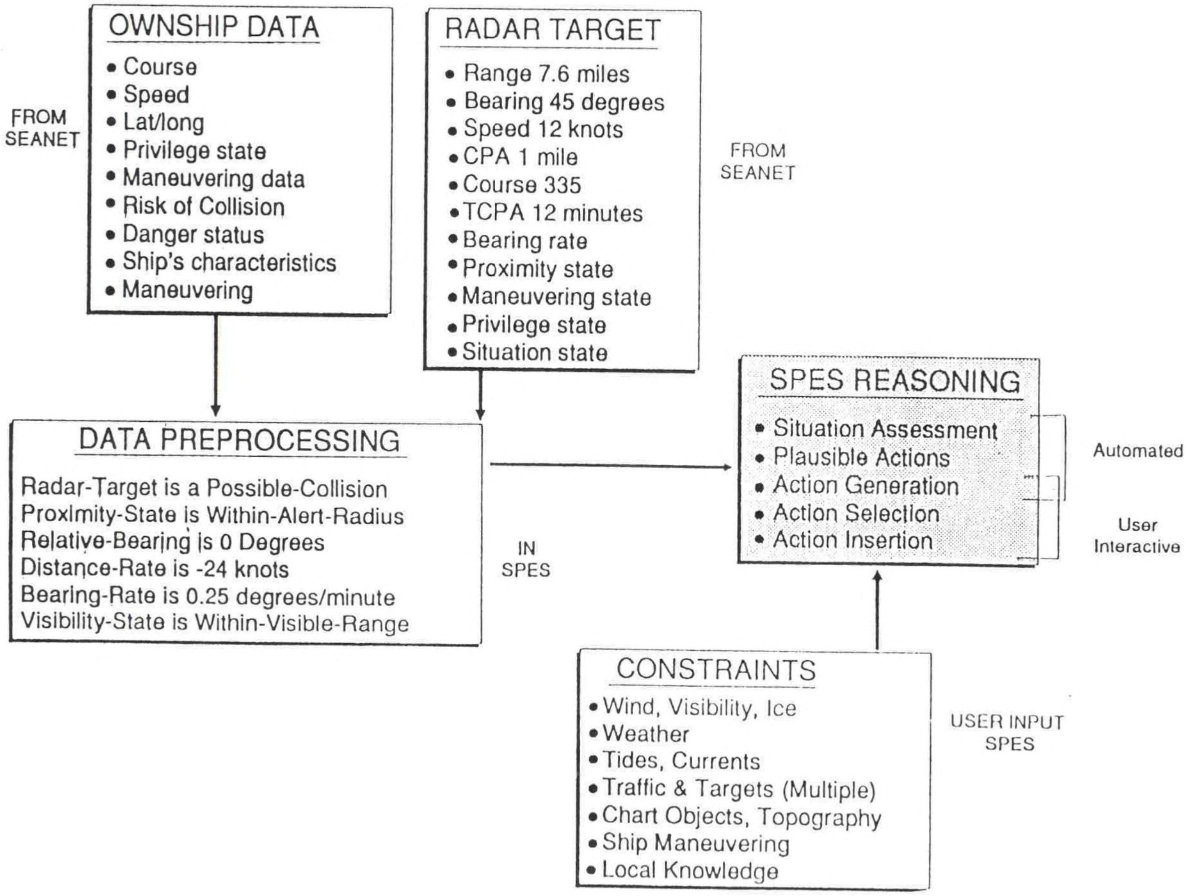
The SPES general reasoning strategy is comprised of three primary activities:

1. collecting data from SEANET,
2. performing situation assessment and plausible action generation to detect risks of collision or grounding, and
3. developing recommended ownship actions in the form of voyage plan alterations.

The results of this reasoning activity are then displayed on the SPES User Interface. This reasoning cycle runs continuously, driven by the data flow on the SEANET.

The SPES reasoning strategy is shown in Figure 5. Real-time situation data is collected from the SEANET, providing the current status of ownship, and all targets currently being tracked by the radars. The data preprocessing functions are applied to the ownship and radar target data to compute additional attribute information needed for SPES reasoning. This function also searches the local waterways knowledge base to find those chart objects close enough to be of interest to the SPES. The SPES situation assessment rules then are applied to the preprocessed data to generate the appropriate alarms, advisories and recommended ownship actions.

FIGURE 5 - SPES REASONING STRATEGY



Shipboard Installation and Evaluation

The goal of the SPES project is to install the system aboard an Exxon tanker operating in the Valdez trade, integrated with the Sperry IBS. In order to do this, there are three primary tasks to the shipboard installation effort; develop the SPES-IBS interface definition, implement and test the SPES-IBS interface in a controlled shoreside facility, and implement and test the interface aboard ship.

At the time this paper was going to press, the first task had been completed and the second task was about one month away from completion. Shipboard installation is scheduled for early September 1992.

In addition to providing a formal operational assessment of the embedded SPES, the shipboard tests provide an opportunity for shipboard crews to exercise and critique the shipboard SPES and to provide formal and informal feedback on desired improvements. The test cases and scenarios cover a range of piloting situations, as well as a set of "tough": cases, developed in cooperation with the Southwest Alaska Pilot's Association. These cases and scenarios will be encoded in scenario driver software to enable semi-automated testing of the SPES knowledgebases.

The SPES contract is scheduled to conclude in January 1993; however, further testing and refinements, as well as development of knowledgebases for other ports beyond Valdez, is expected to be continued. Finally, if the system is found to be commercially viable, work will continue on commercialization into the IBS product.

INTELLIGENT SHIP AS A LARGE SYSTEM

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Yasuyoshi Itoh, Kunihiko Tanaka, Nobuo Arimura,
Nobuo Kiriya, Junji Fukuto and Keiko Miyazaki

Ship Research Institute, Ministry of Transport

1. INTRODUCTION

Recently, many merchant ships are made intelligent and systematic gradually because of decreasing manning and increasing marine transportation. The name intelligent ship has many images or concepts now, for example, a fully automated unmanned ship, an information fully supported ship, a one man controlled ship and a sailing boat with the GPS. When some new technical item or system is going to be grown up, it is important to make a standard concept of it and to prepare a way to assess its safety. The intelligent ship is now coming on this stage. In this paper it is tried to make a systematic concept of an intelligent ship as a large system. Moreover, a ship can be also considered as an element of a large intelligent marine traffic system which would be called the intelligent ship system.

2. CLASSIFICATION OF SHIP FUNCTIONS

It is assumed that a ship is not fully unmanned in near future. Even an intelligent ship should be considered as a man-machine system. The ships functions which are expected to be automated are considered as a hierarchical structure under the captain as the top level of decision making shown as Fig. 1. The second level consists of the information processing, the planning and the mission achievement. And lower level items are classified more exactly. Each function should be automated by each subsystem.

On the other hand, a ship is operated in several modes such as the mooring, the loading & unloading, the taking off and berthing, the harbor navigation, the coastal navigation and the ocean-going. In these operational modes, above mentioned functions act different respectively. The automation for the intelligent ship is realized by an automated subsystem of each function in each operational mode. The navigating ship should be regarded as an isolated system. When one of these subsystems is failed other subsystems or upper level subsystem must substitute the failed subsystem's function.

The system structure of the intelligent ship functions should be designed and standardized from the view point as above mentioned. If this standard includes the signal forms and the methods to assess the system safety, it will bring the rational development of the worthwhile intelligent ship and the worldwide supporting system. This is the reason why the Japan and United States cooperative research project, initiated by the UJNR, of the intelligent ship system starts.

3. AUTOMATION OF SHIP NAVIGATION

The automation of the ship navigation is the most expected one among the intelligent ship's functions. Some sub-functions are partially realized, for example, the supporting system for the one-man controlled bridge using GPS and ECS.

The navigation in a port, a narrow channel and other congested sea area and the high speed navigation are urged to be automated using an intelligent system. It is considered that the automations of the navigations will be realized by the following procedures:
(1) The automation of the collecting and processing of the information of the navigation environment to be understood easily.
(2) The automation of the navigation planning which keeps safety and high performance.
(3) The automation of the maneuver following the navigation plan.

These procedures would be automated as the data searching system, the danger evaluation system, the route planning system and the maneuvering system.

It is important to be able to avoid the ill-functioned effects of these subsystems by the operators when one of these subsystems is failed down. In general, it is difficult to find the ill-function of such a large automated system. To assure the automated ships' safety they should be equipped the intelligent man-machine interface which tells the informations about what happened in the system and how the system safely operates to avoid the operators fall in to the panic situation. To assure the large system safety it is also important to design and to build up the large automated system understandable easily.

4. INTELLIGENT SHIP SYSTEM

As mentioned above, the intelligent ship is considered as fully automated ship with many prepared safety systems. Many fundamental techniques and elementary subsystems of the intelligent ship are going to be developed.

In spite of these developmental situations, there are two important problems left. One is the world-wide navigation information supporting system and another the safety assessment system for assurance the intelligent ship's behaviors.

The navigation information supporting system will bring the searching system and information processing system of the fully automated ship easily in high reliability. This is an ideal intelligent ship as a large system truly.

The safety assessment system of the intelligent ship behavior will bring the less manning automated ship which is easily acceptable in the world wide.

5. SAFETY ASSESSMENT OF INTELLIGENT SHIP

The computer simulation technique can be used to assess a new large system safety. To assess the subsystems functions of the intelligent ship this technique can be also used. It is not sufficient to assess the safety of the system using several results by the computer simulations, because the concept of safety is so subjective one. Another difficulty of the assessment of the safety is that the concept of the probability is not useful. To avoid these difficulty the concept of the safety is constructed with the concept of the margin in the operation to achieve safe conditions.

On these thoughts simulation scenarios can be set and done to make the concept of the man-machine system safety to assess the intelligent ship. The scenarios would be set for many circumstances of sea and traffic. Many kinds of faults in the intelligent ship occur as the man-machine system. Most important thing in the safety assessment is to explain about the concept of safety from various view points on the system.

6. CONCLUSIONS

The intelligent ship will be one of the useful solutions for the increasing requirement on a high speed marine transportation.

The intelligent ship should be thought as the large system as the fully automated ship system and as the element of the total marine transportation system that is fully supported on the information.

The safety of the intelligent ship system can be thought as the structure of the margins of the operations to achieve the safe situations and the computer simulations using properly selected scenarios are useful for the assessments.

7. REFERENCES

(1) Numano et al.,"Concept and Safety Evaluation of Intelligent Systems in Future Ship Navigation", Proceedings of MARSIM and ICSM '90, pp.209-215, 1990. 6.
(2) Kaneko et al., "Computer Simulation of Ship Navigation in Realistic Marine Traffic Flow", Proceedings of MUSEUM and ICSM '90, pp.219-226, 1990. 6.
(3) Murayama, "Problems in Large Systems"(Japanese), Proceedings of Safety Engineering Symposium '92, 1992. 6.

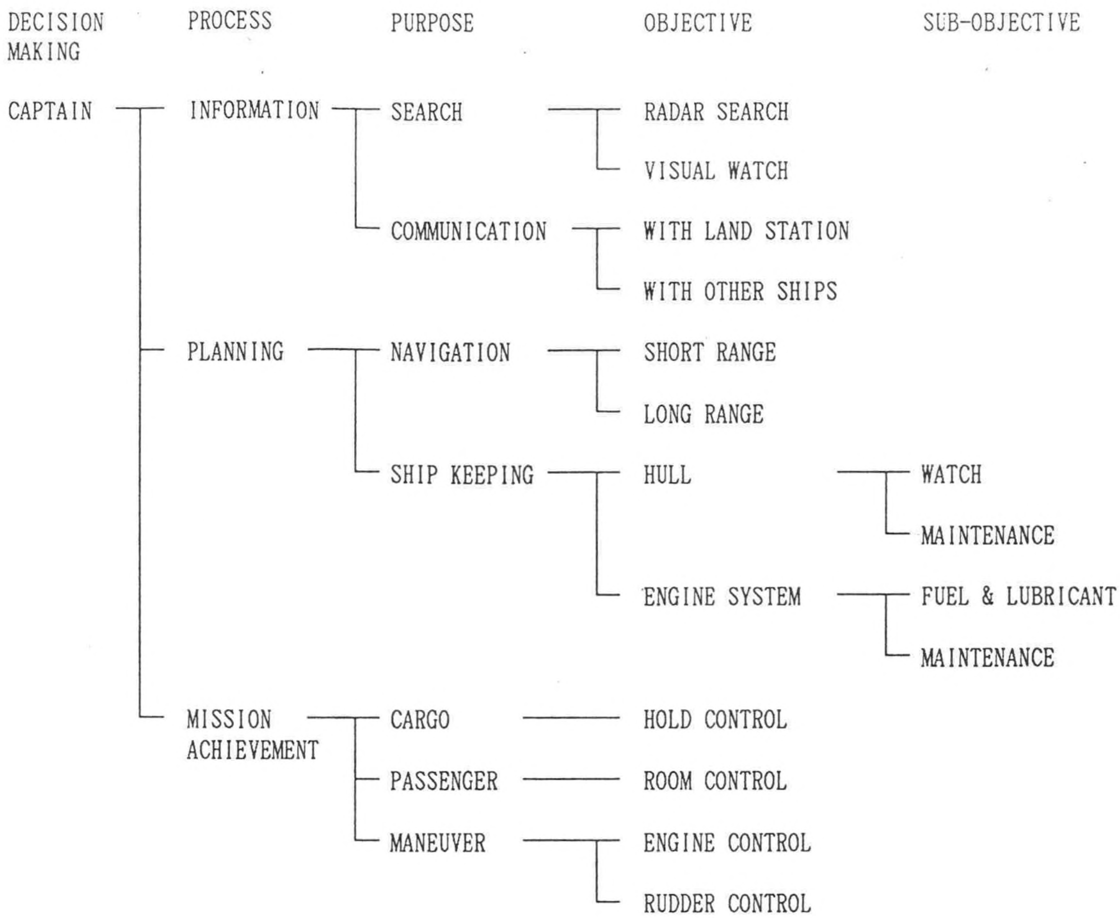

Fig.1 An Example of Functional Hierarchy of Ship System

Offshore and Undersea Technology Systems

LEGAL RESTRAINTS LIMITING MARINE DEVELOPMENTS IN THE USA

John E. Flipse
Distinguished Professor of Civil and Ocean Engineering Emeritus,
Texas A&M University and Director Emeritus, Offshore Technology Research Center

Introduction

The need for innovative facilities in the waters adjacent to the United States is clear and economically promising if a realistic and stable legal environment can be established. Opportunities exist in near coastal waters under state and local jurisdiction, the US territorial sea, the US Exclusive Economic Zone and the "high seas" of the world. Examples include piers, breakwaters and pipelines; offshore airports, oil drilling and production structures, waste incineration and cargo transfer platforms; weather observation stations, floating military bases, and ocean mining systems. Areas of concern include limiting technology exchange, complex permitting, multiple jurisdictions, contradictory laws and regulations, excessive environmental requirements, punitive liability limits, threats of legal actions and the use of the courts to delay use of facilities upon completion. Let us briefly examine several of these issues.

Technology Exchange

Historically, the failure of a critical component in a bridge, building, aircraft, or ship led to a prompt investigation of the failure, and an in-depth discussion and prompt dissemination of the cause(s) through the appropriate technical society publications. Fear of liability law suits, both real and frivolous, has effectively stopped this process encouraging the "cover up" of defects and the costly repetition of often serious failures with attendant loss of life. The willingness of the insurers to "settle out of court" , often an economic necessity, has encouraged this negative phenomenon.

Permitting

More than fifty permits were required to build and put in service a 500 acre container terminal at the port of Charleston, South Carolina. Twenty-two city, state, and federal agencies were involved in the seven year process. The cost of the permits including engineering and legal fees, disclosure of strategies, interest on the monies spent and a budget contingency (unspecified) which, from time to time threatened the economic viability of the project. Potential changes in the permit regulations and fees are a continuing threat to the future earnings of the terminal. The port facility is owned by a agency of the state of South Carolina which materially simplified the permitting process.

Multiple Jurisdictions

To install a pipeline in the US territorial sea or its E.E.Z. two major federal agencies, the Minerals Management and Service of the Department of the Interior and the Office of Pipeline Safety of the Department of Transportation, must be satisfied. To bring the pipeline to shore involves many state and local agencies as well as the Environmental Protection Agency and the National Oceans and Atmospheric Administration of the Department of Commerce. Although these agencies attempt to cooperate they must respond to committees of the US Congress, both the US Senate and the US House of Representatives, resulting in illogical responses to particular political pressures. This problem often results in further complications of the permitting process discussed above.

Contradicting Laws/Regulations

To determine the economic viability of an offshore petroleum discovery, one or more exploratory wells must be tested to determine the rate at which the oil and gas in the deposit will move through the rock and/or sediments to collection points. As the gas flow is established and becomes constant, it has been industry's practice to burn (flare) the gas at the well. The Minerals Management Service decided to make the company pay for the flared gas, at its usual royalty rate, a regulation which only slightly increased the cost of the reservoir development. At a later date, the Environmental Protection Agency limited the flaring to forty-eight hours to protect the atmosphere and to limit the "greenhouse" effect. Although both of these regulations appear innocuous in themselves, the result is a lack of information about the petroleum or gas prospect which can and does preclude its development in the US domestic offshore.

Excessive Environmental Requirements

During the last decade the US has become extremely conscious of the need to protect our world's environment. Designers and buyers of ocean facilities recognize the need to provide for possible environmental impacts of the system but usually cannot develop a design that has ZERO impact on the environment during its construction, installation, and operating life. The need for and value of the USA's rapid expanding environmental program is being seriously questioned by all sectors of our population. A recent headline in a respected US business journal read: "US environmental policy is out of control, costing jobs, depressing living standards and being run by politicians, scheming business people and social extremists." Some of our originally well-intentioned environmental organizations have adopted the thesis that "the end justifies the means" thereby taking some of their activities beyond our laws and justifying the title of "social extremists". A severe misuse of the US judicial process is the extremists' use of the injunction and law suit to delay use of facilities thereby destroying the economic viability of a project. An unused Chevron oil production platform in California waters is an example of a decade of delay in the utilization of a hundred million dollar investment due to extended sequential legal actions which are technically totally unjustified.

Punitive Liability Limits

The passage of a US law requiring the owners of tankers bringing petroleum or petroleum products into US waters to assume unlimited liability for the clean up of any spill has resulted in an increased threat to the environment. It is impossible to buy insurance to cover an unlimited liability. It is also unrealistic to expect any major US or foreign ship owner to risk his company's existence by shipping petroleum to the US. The result of this law has been that companies whose net worth is limited to the ship and cargo are rapidly becoming the exclusive entrants to US ports when carrying petroleum. These are not the newest and safest tankers nor the most safety conscious companies resulting in increased, rather than decreased, risk to the marine environment.

Conclusion

The cases cited above are but a few of the myriad of problems the US has created for our marine community through too many poorly conceived, socially driven laws promulgated by technically ignorant politicians, misused by unethical business people through unscrupulous and greedy lawyers. You, our Japanese colleagues, may have beaten us in automobile manufacturing, at least temporarily, but we have beaten ourselves in the development and use of ocean-marine facilities.

A HIGH-RESOLUTION SUBBOTTOM IMAGING SYSTEM

by

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Abstract

This paper addresses a long-standing need of the Corps of Engineers—that of accurately and economically assessing site conditions underlying rivers and harbors. A high-resolution subbottom imaging system utilizing principles of acoustics is proposed as a tool to fulfill much of this need. The authors discuss the theoretical foundation of the approach, limiting mathematics to basics, while providing references for those readers desiring full details. Acoustic impedance, the product of sound velocity and density of the host material, is advocated as the most useful parameter in determining subbottom characteristics. High-resolution seismic data acquisition and processing techniques are described in general terms. Case histories including ground truth comparisons are presented along with examples of two- and three-dimensional data visualization.

Introduction

Each year, the U.S. Army Corps of Engineers spends millions of dollars on river and harbor maintenance and ship channel realignment projects. Currently, the Corps relies on drilling and laboratory testing programs to assess marine sediments in terms of material type, density, and thickness for purposes of characterizing proposed dredging sites. But sampling and coring programs are costly, provide only discontinuous information about material characteristics, and cannot effectively address situations where actual subbottom conditions are highly variable.

In an effort to improve subbottom characterization and dredging efficiency, the Corps of Engineers launched a major research and development initiative called the Dredging Research Program (DRP). The U.S. Army Engineer Waterways Experiment Station (WES) heads this initiative. The focus of one DRP work unit is to develop a technique to remotely and efficiently determine characteristics of subbottom marine sediments as they relate to dredging.

A low-noise, high-resolution subbottom imaging system is essential to this program. To fulfill this requirement, a digital data acquisition system has been combined with specialized processing software to accurately assess bottom and subbottom in situ conditions.

Acoustic Impedance Method

The acoustic impedance method is a modification of the seismic reflection technique commonly used in offshore oil exploration but tailored to shallow water environments. As energy generated from an acoustic source (in the form of a plane wave) arrives at a boundary between two layers of differing material properties, part of the energy will be reflected back towards the surface and part transmitted downward (see Figure 1). Portions of the transmitted energy will undergo absorption or attenuation in the layer while the remainder propagates through to the next stratigraphic boundary. Ratios between transmitted and reflected energy, called reflection coefficients (Equation 4), are dependent on the density and velocity of the materials through which the energy is propagating.

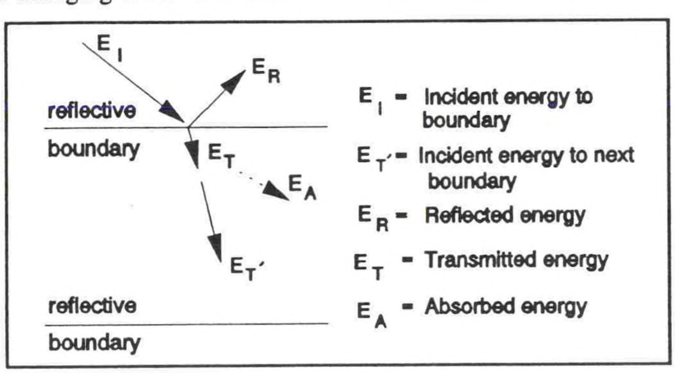

Figure 1. Energy Path Schematic

Wave velocities are controlled by elastic properties of the two-phase sediment mass (sea water in pores and mineral structure). Properties such as porosity and grain size affect sound velocity only through their effects on the elasticity of the sediment. In previous studies (Hamilton, 1970, 1972), it was concluded that elastic properties of water-saturated sediment could be expressed through Hookean elastic equations, unless attenuation is considered; in which case, linear viscoelastic equations are recommended.

The basic equation for the velocity of a compressional wave V_p is:

$$V_\rho = [(k + 4/3\,\mu)/\rho]^{1/2}, \tag{1}$$

where

- k = *incompressibility or bulk modulus and equals* $(1/\beta)$,
- μ = *shear (rigidity) modulus,*
- ρ = *saturated bulk density,*
- β = *compressibility.*

When a medium lacks rigidity, Equation (1) becomes:

$$V_\rho = (\kappa/\rho)^{1/2}, \tag{2a}$$

or

$$V_\rho = (1/\beta\rho)^{1/2}. \tag{2b}$$

Compressibility β and density ρ in Equation (2b) have been expanded into:

$$V_\rho = \left(\frac{1}{[\eta\beta_w + (1-\eta)\beta_s]\,[\eta\rho_w + (1-\eta)\rho_s]}\right)^{1/2}, \tag{3}$$

where η is the volume of pore space occupied by water (fractional porosity), and subscripts s and w indicate mineral solids and water.

The influencing parameters of this basic seismic wave equation suffice to answer the question: ***"Why acoustics to characterize bottom/subbottom materials?"*** To continue, the acoustic reflection coefficient (R) is defined as:

$$R = \sqrt{\frac{E_R}{E_I}} \tag{4}$$

where

E_R = *reflected energy*
E_I = *total energy incident to the boundary (see Fig. 1).*

The reflection coefficient is also equal to:

$$R = \frac{(Z_s - Z_w)}{(Z_s + Z_w)} \tag{5}$$

where

$$Z_w = \rho_w C_w = \text{water impedance}$$

$$Z_s = \rho_s C_s = \text{soil impedance}$$

$$\rho_w = 1\ g/cm^3$$

$$C_w = 150000\ cm/sec$$

Hence, it is clear that the acoustic impedance (Z_s) of the surficial layer can be calculated readily. ***The product of transmission velocity and density of material is the acoustic impedance*** and represents the influence of the material's characteristics on reflected and transmitted wave energy. The relationship between acoustic impedance and specific soil properties has been empirically based on an extensive data base of world averages of impedance versus sediment characteristics (Hamilton, 1970, 1972; Hamilton and Bachman, 1982). Table 1 displays Hamilton derived (Hamilton, 1972) sediment type/acoustic impedance relationships.

At this point, it must be emphasized that Hamilton's pioneering efforts were limited to ***surficial*** bottom materials. In order to extend the depth of investigation into multi-layer subbottom environments, Caulfield and Yim (1983) devised a model correlating to Hamilton's work. The model is used to correct for absorption and other losses in bottom sediments as a function of frequency so that the reflection coefficients and acoustic impedance of sediments can be calculated as if they were surficial sediments (reflectors). In practice, the concept is extended to each subsequent layer until the signal-to-noise ratio is at a level from which information cannot be extracted with accuracy (normally 5 db). The model is then combined with classical multilayer reflection mathematics to yield reflection coefficients equivalent to surficial sediments for subbottom layers. Since some assumptions must be made regarding attenuation factors (determined from site-specific borings and laboratory data), this approach ***must be defined as empirical.***

DESCRIPTION	ACOUSTIC IMPEDANCE
	$\frac{\text{X } 10^2\text{g}}{\text{cm}^2\text{sec}}$
Water	1450
Silty Clay	2016 - 2460
Clayey Silt	2460 - 2864
Silty Sand	2864 - 3052
Very Fine Sand	3052 - 3219
Fine Sand	3219 - 3281
Medium Sand	3281 - 3492
Coarse Sand	3492 - 3647
Gravelly Sand	3647 - 3880
Sandy Gravel	3880 - 3927
(Corrected for Temperature and Salinity)	

Table 1. Soil Classification Versus Acoustic Impedance Range (Hamilton, 1972)

Data Acquisition and Analysis

A seismic source of known energy content as a function of frequency, deployed just below the water surface, generates acoustic waves that propagate downward through the water column and sediments. High-resolution profiling systems specifically designed for shallow water use and operating at frequencies below 12 kHz are typically used. As a rule, lower operating frequencies allow greater energy penetration into the subbottom, but due to longer wavelengths, lack the vertical resolution of higher-frequency systems.

As transmitted energy propagates through sediment of varying densities and acoustic velocities, energy is reflected at geologic boundaries where there is a distinct contrast in the acoustic impedance between layers. Reflected signals are amplified, filtered, and recorded with a specially designed shallow seismic, digital data acquisition system developed in conjunction with Caulfield Engineering (Caulfield, 1991a). Energy loss as a function of frequency is then determined. The system also provides real-time presentation of the seismic signal for acquisition quality control.

Due to the non-uniqueness of seismic reflection signatures, several combinations of geologic conditions could conceivably yield similar signal characteristics and computed impedance values. But in specific geologic regions such as the Mississippi Sound or San Francisco Bay, differing sediment units usually have a characteristic and relatively narrow range of impedance values. Therefore, using calibration procedures incorporating local core and laboratory data, seismic reflection data are processed at known sample locations to yield acoustic impedance values of the known reflection horizons. Estimates of in-situ density are derived from computed impedance values and correlated with ground truth information. Figure 2 shows the acoustic predictions versus core data for consolidated materials in Mobile Ship Channel. The results are within 1 percent. Figure 3 shows acoustic impedance density predictions versus nuclear densitometer data for fluff/fluid mud type materials in the Gulfport Ship Channel. Again,

Density Estimations - Mobile Bay
Acoustic Core Versus Core Logs
Line MOB7

Depth Below Bottom	Density gm/cm^3 Acoustic	Density gm/cm^3 Core	Percentage Difference
-1.83	1.51	1.51	0.00
-3.66	1.51	1.51	0.00
-4.60	1.54	1.51	-1.95
-7.34	1.54	1.51	-1.95
-9.18	1.54	1.56	1.30
-11.02	1.54	1.56	1.30
-12.86	1.54	1.56	1.30
-14.70	1.52	1.47	-3.29
-16.54	1.52	1.47	-3.29
-18.37	1.48	1.47	-0.68
-20.20	1.48	1.49	0.68
-22.03	1.48	1.49	0.68
-23.87	1.52	1.49	-1.97
-25.72	1.60	1.57	-1.88
-27.59	1.62	1.57	-3.09
Average percentage difference			-0.86

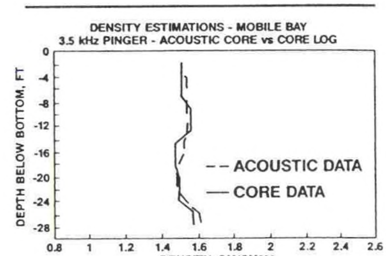

Figure 2. Ground Truth Comparison for Consolidated Sediments

Density Estimation Comparison
Gulfport Harbor
Mean Nuclear Probe and Acoustic

Tide Depth	Density gm/cm³ Probe	Density gm/cm³ Acoustic	Percentage Difference
-26.65	1.02	1.01	-0.99
-27.54	1.03	1.04	0.96
-28.43	1.06	1.05	-0.95
-29.32	1.08	1.07	-0.93
-30.21	1.09	1.07	-1.87
-31.10	1.09	1.08	-0.93
-31.99	1.10	1.08	-1.85
-32.88	1.13	1.08	-4.63
-33.77	1.13	1.09	-3.67
-34.66	1.13	1.10	-2.73
-35.55	1.14	1.14	0.00
Average percentage difference			-1.60

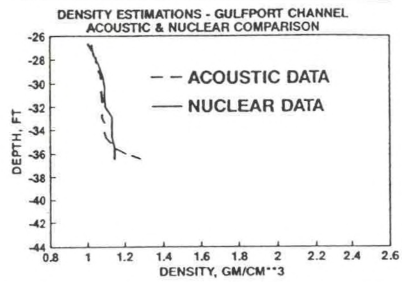

Figure 3. Ground Truth Comparison for Suspended Sediments (Fluid Mud)

correlation is excellent. A continuing program of data base expansion coupled with ground truth information obtained using a wide variety of conditions is necessary. Testing to date has shown that density estimates to within 5 percent of in situ values are obtained (Ballard and McGee, 1991). A plot of the impedance function versus laboratory measurements of density from core samples taken in the Mississippi Sound is presented in Figure 4. Hamilton's data represented by the solid line in Figure 4, even though obtained along the shelf and slope of the continental terrace, show remarkable agreement.

Presentation of Results

In the normal course of data acquisition, field records related to amplitude of recorded signal, time, and distance provide the geophysicist/engineer with quick-look assessments of data quality and subbottom conditions. Data are oftentimes dually recorded by both analog and digital systems. Analog presentations are usually in shades-of-gray while digital data are displayed in color. Figure 5 is a typical 3.5 kHz pinger amplitude cross section reproduced from a

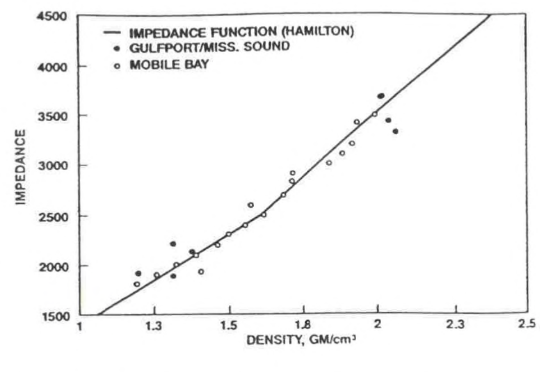

Figure 4. Computed Impedance Versus In-Situ Density Compared to Hamilton (1972)

color field record obtained in Oakland Harbor. Note the top of the graph is not the water surface, but an assigned water column delay. This offset allows full vertical expansion of the subbottom display, which in this case extends into the subbottom more than 50 ft. Changes in stratigraphy are readily apparent. Records of this type are used as guidance in boring placement.

Upon determination of the reflection coefficients and impedance function at known locations, the virtually continuous seismic profiles are processed. The single-channel, digitally recorded data are read into

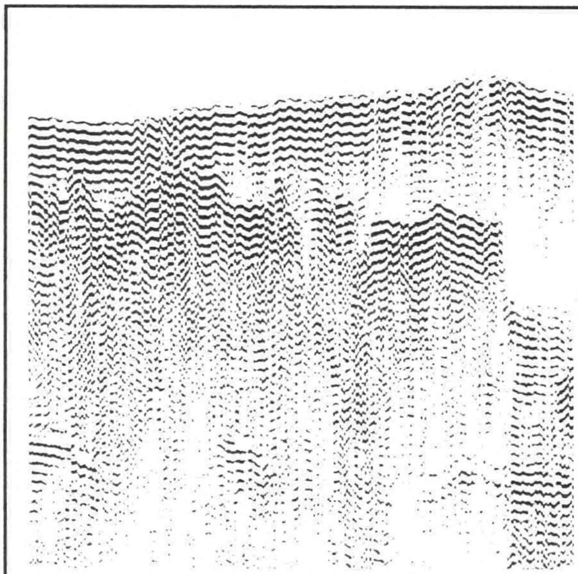

Figure 5. Reflected Signal Amplitude Cross Section - 3.5 kHz (Oakland Harbor)

the processing software developed with Caulfield Engineering (Caulfield, 1991b), and corrected for transmission losses due to spherical spreading and compensated for absorption losses in each layer. Classical multilayer algorithms are used to compute equivalent reflection coefficients and impedances along the profile. This in turn provides density estimates of shallow subbottom layers and classifies the lithostratigraphy (Hamilton, 1972; Caulfield and Yim, 1983). The results are corrected for tidal fluctuations and correlated with survey positioning data. Processed results are presented in the form of annotated amplitude cross sections or two- and three-dimensional views color-coded according to material density.

Three two-dimensional (2-D) profile views representative of a segment of the Gulfport Ship Channel are illustrated in Figure 6 with survey line 9 positioned along the center line of the proposed channel. Lines 1 and 18 are parallel to each toe. This type display delineates the extent of pertinent density zones of interest to the engineer, and the virtually continuous data coverage greatly decreases the possibility of significant material changes being undetected. Displays of this type provide much improved data interpretation and visualization for the end product user as compared to standard two-dimensional presentations generated exclusively from boring information.

By incorporating the virtually continuous coverage of subbottom materials with digital terrain modeling techniques, rapid and accurate computations can be made of volume and material-type to be removed by dredging. Furthermore, a detailed data base has now been established for project monitoring and long-term planning. Computed sediment densities within the project area can be displayed in a color-coded, three-dimensional (3-D) view as shown in Figure 7 if desired by the user. In this example, lighter shadings are indicative of less dense material. Again, note that this publication format does not allow for color presentation of results, and therefore all displays are black-and-white copies of color originals. At the project planner's discretion, he may elect to view an area of interest from other angles or create different displays by stripping or slicing at any desired coordinate. Volume of any material to be removed can be easily calculated and displayed as shown in Figure 8. This example predicts the configuration of sands underlying a section of the proposed channel realignment area of Gulfport Ship Channel shown in Figure 7.

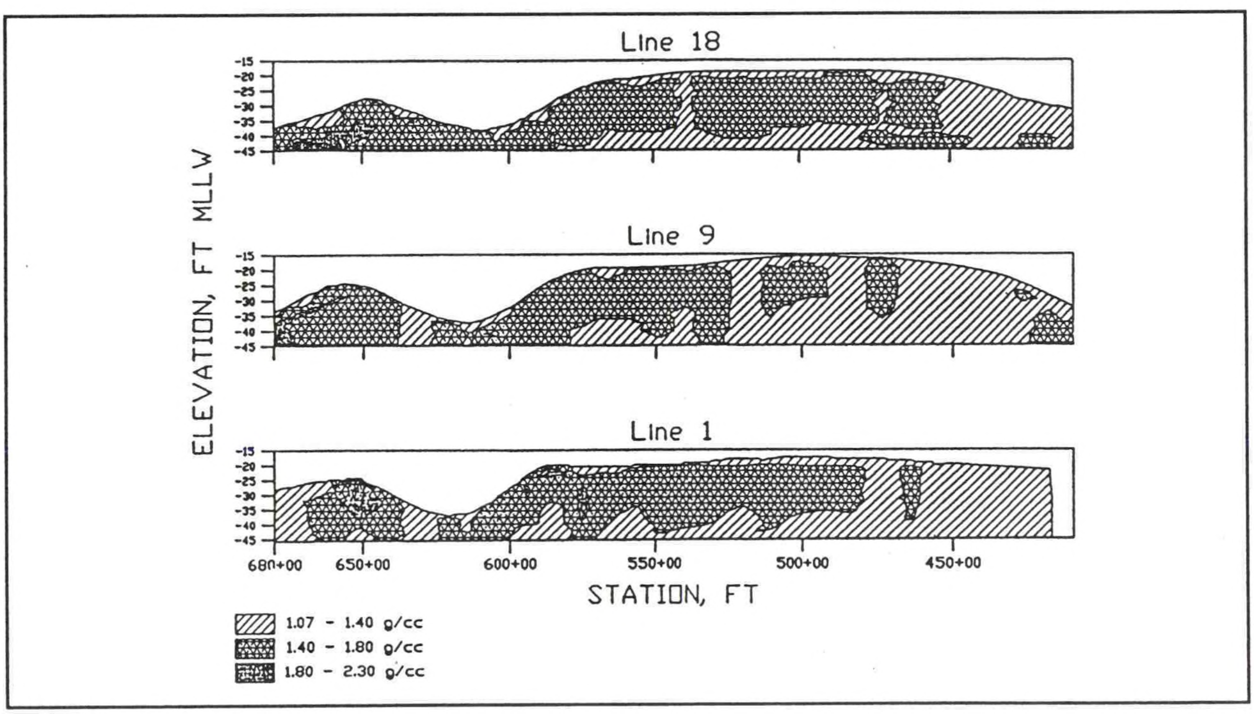

Figure 6. Density Cross Sections in Gulfport Ship Channel

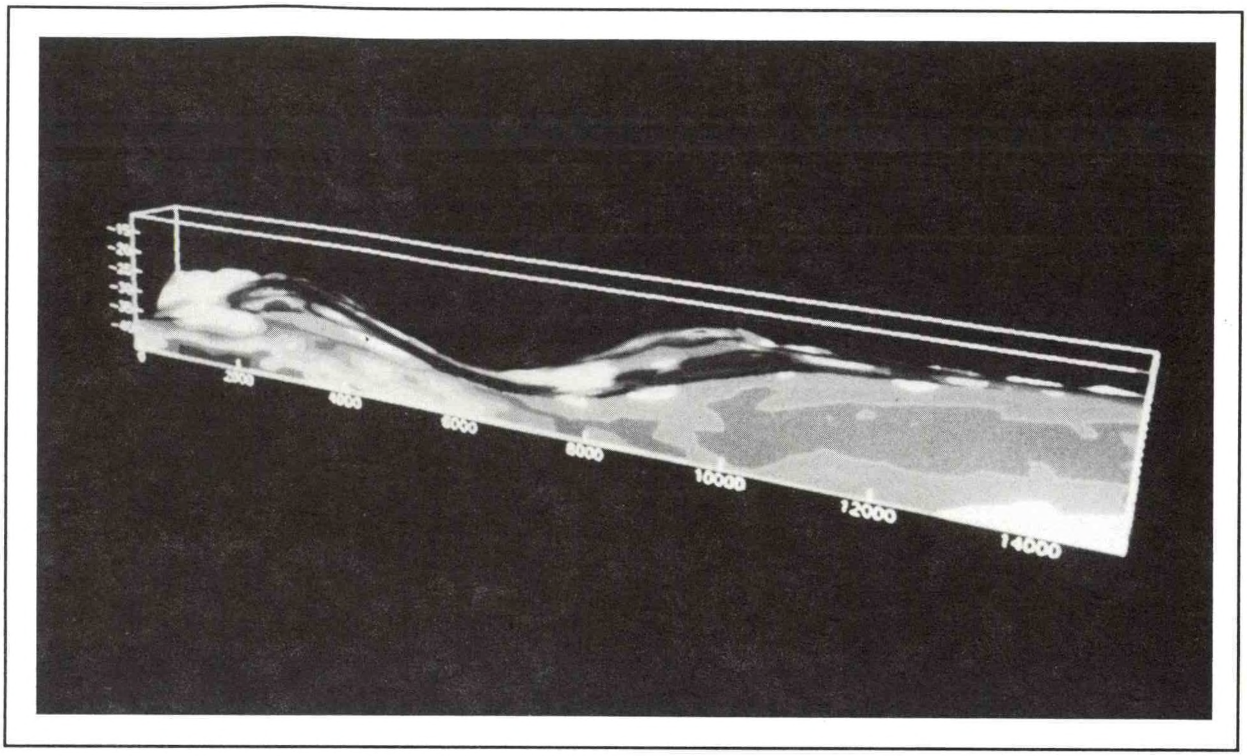

Figure 7. 3-D View of a Section of Gulfport Ship Channel

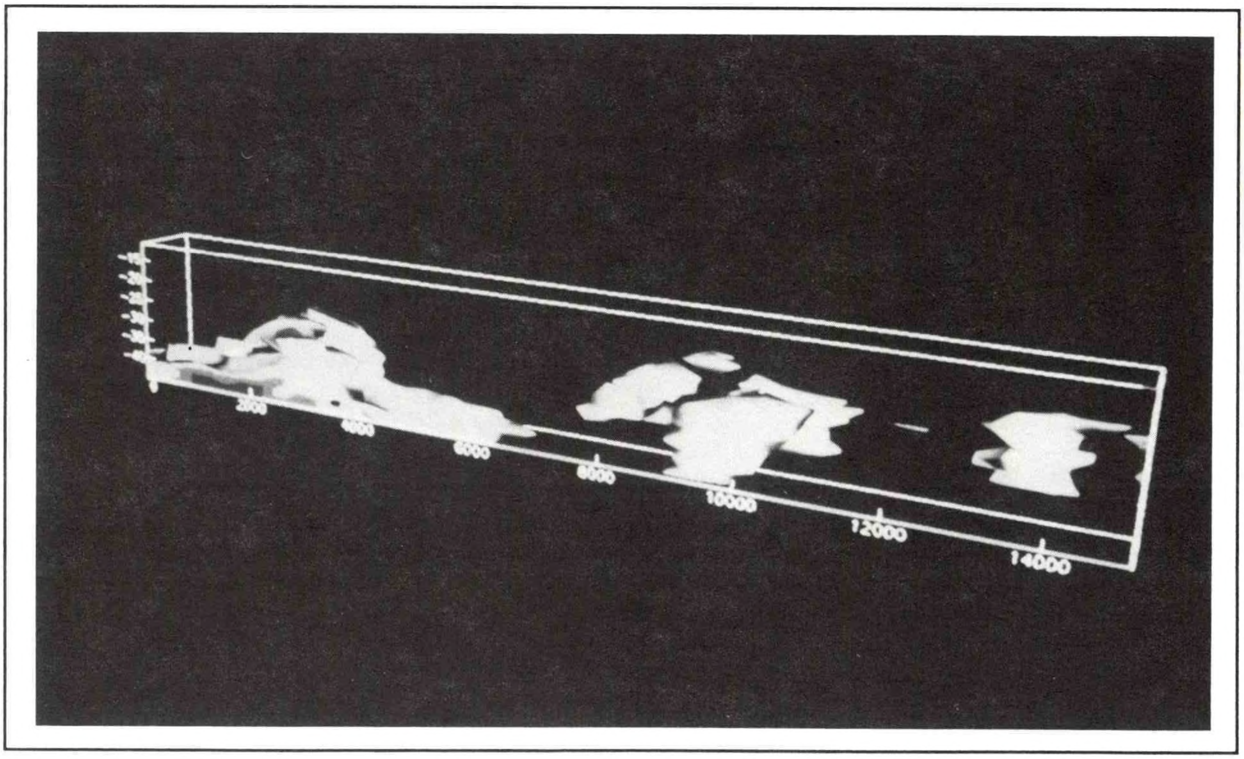

Figure 8. Volumetric Calculation for Sand in a Section of Gulfport Ship Channel

Other Applications

The acoustic impedance method is not limited to sediment characterization, but can also provide essential information on the:

1) location of marine sand deposits for beach replenishment,
2) long-term monitoring of dredged material disposal areas,
3) delineation of submarine geologic formations,
4) detection of submarine features such as pipelines or other dredging hazards, and
5) identification of fluid mud in navigable waterways.

Conclusions

In its present state of development, acoustic impedance processing of seismic reflection data provides an accurate, continuous description of bottom and subbottom marine sediment characteristics in a rapid, cost-effective manner. Results from properly calibrated surveys have been used to provide Corps' Districts and dredging contractors with:

1) density estimates of marine sediments,
2) continuous subbottom information for planning and designing dredging and sampling programs,
3) estimates of the volume and type of material to be removed through dredging, and
4) a detailed and continuous geologic database for aiding long-term planning of future work.

Acoustic impedance information—if properly implemented in the project planning stages—provides valuable data on the distribution and extent of differing marine sediments, aids in locating optimal placements of sampling cores, and supplements previously obtained soil borings by providing continuous profile coverage of sediment characteristics between sample locations.

Epilogue

During preparation of this paper, plans were formulated to perform high-resolution acoustic impedance surveys prior to dredging operations in Boston Harbor, Baltimore Harbor, Galveston Ship Channel, Houston Ship Channel and Pascagoula Ship Channel. Additionally, two beach replenishment surveys to acoustically locate and calculate the volume of suitable sands were in the planning stages.

Possibly for the first time in Corps of Engineers history, Mobile District advertised site conditions for dredging at Gulfport Ship Channel using density predictions determined by geophysical acoustic impedance surveying in addition to traditional borehole information. True site conditions resulting from dredging operations beginning in May 1992 will be closely monitored and compared to predictions.

Lastly, procurement of a waterborne integrated geophysical exploration system capable of rapid bottom and subbottom site characterization was begun. Such a system will include a support vessel housing an integrated navigation and data management computer with appurtenances necessary for acquiring and processing a wide variety of geophysical data. Emphasis is being placed upon procurement of equipment capable of acquiring high-resolution reflection seismic information compatible with acoustic impedance processing algorithms. This capability will be supplemented with side-scan sonar, magnetometer, electrical, and electromagnetic devices to form a complete hydrographic survey system meeting long-range needs of the Corps of Engineers.

Acknowledgments

Tests described and resulting data presented herein were obtained from research conducted under the WES DRP (Program Manager Mr. Clark McNair) and from site surveys sponsored by the U.S. Army Engineer District, Mobile. It should be noted that any degree of success achieved in this project can largely be attributed to the talents of those individuals working with the authors in this interlaboratory team effort: Darla McVan, Hydraulics Laboratory; and Keith Sjostrom, Tom Harmon, Rodney Leist, and Tina Grau of the Geotechnical Laboratory. Permission was granted by the Chief of Engineers to publish this information.

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"KAIKO" — 10,000m class deep sea research ROV

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(JAMSTEC)

As was already presented in previous MFP meetings, JAMSTEC is now developing a 10,000m class deep sea research ROV. The ROV is now named as "KAIKO" meaning ocean trench, and will be completed next summer.
This is to report the latest construction progress of "KAIKO".

1. General Discription

① Principal dimension of the vehicle is 3.1m long, 2m wide and 2.3m high with 5.1tons in air but 10kg buoyant in water. Delivered power is 45kw. It has also a high grade color TV camera, a monochrome TV camera and a pair of manipulators.

② Operation depth is over 10,000m, tow speed is 1.5kts and vehicle speed is 2.0kts. The data transmission rate is very high, amounting to 1.26 Giga bits per second, because the vehicle has several TV cameras and these data rate amounts to 840 Mega bits per second. This goes up to the support vessel via the lancher. The launcher has a TV camera and several sonars and these data rates amount to 420 Mega bits per second. There are another control signals but they are relatively low data rate.

2. Construction Schedule

Construction schedule will be explained.

3. Overall conception of the system

General view of the launcher and vehicle will be shown.

4. Main componets

Pictures of fabricated main componets will be shown, including manipulators, frame of the vehicle, pressure vessel of the launcher, cable, heave compensator, traction winch, cable store winch, etc.

5. Coming Schedule

The fabrication of all the parts will be finished this summer, and the assembling work will be finished this autumn. The test operation will continue until the middle of next year. The modification work of the support vessel will also be accordingly carried out.

The sea trial will start on May beginning from 1,000m deep. Final sea trial of 11,000m depth is foreseen at Mariana trench in the end of July 1993.

"KAIKO" will be delivered to JAMSTEC in the end of August 1993.

Marine science and technology requires international cooperation, and JAMSTEC is making efforts to widen the mutual cooperation. I hope you to join the survey cruise by this "KAIKO".

TRANSFORMATION OF NOSC INTO NCCOSC/NRaD AND ITS EFFECT ON OCEAN PROGRAMS

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Introduction

Many of you have been wondering what an NRaD is, and what became of the Naval Ocean Systems Center (NOSC) and several other U.S. Navy Laboratories you have contacted in the past or that you are visiting during this 18th UJNR Marine Facilities Panel technical program and tour. There has been a major reorganization of the Navy's research, development, test and evaluation activities involving seven research and development centers and 29 engineering and fleet support groups. They have been consolidated into a streamlined corporate laboratory and four warfare centers.

Background

The consolidation concept is designed to strengthen management of the RDT&E structure by taking advantage of efficiencies, eliminating unwarranted duplication, and considering performance of some functions under tri-service management. The consolidation plan is aimed at preserving the Navy's core mission capability to perform research, development, test and evaluation, and in-service engineering in the face of possible budget and personnel reductions.

Simultaneously with the consolidation, the Navy will purify the missions of its warfare centers. This will result in the transfer of two of NOSC's past functions—(1) surface ship antisubmarine warfare control systems and torpedoes, and (2) submarine arctic warfare—to the new surface and undersea warfare centers. The Navy reorganization plan calls for closure of the NOSC Hawaii Laboratory by October 1993. Mission purification will result in the transfer of command, control and communications functions from several existing laboratories to what was formerly called NOSC.

Reorganization

Under the reorganization, NOSC became part of the Naval Command, Control and Ocean Surveillance Center (NCCOSC), joining seven electronic systems engineering activities on the East and West Coasts; the Fleet Combat Direction Systems Support Activity (FCDSSA) on Pt. Loma, site of NCCOSC's headquarters; and the Naval Space Systems Activity (NSSA) in Los Angeles. A technical department specializing in navigation and communication work at what was the Naval Air Development Center (NADC) in Warminster, PA, is also included in the new organization.

NCCOSC is organized into three geographical/functional elements—the Research, Development, Test and Evaluation (RDT&E) Division; the West Coast In-Service Engineering Division (or NISE West); and the four East Coast In-Service Engineering Activities (or NISE East).

The former NOSC organization is now the RDT&E Division, a subordinate command of NCCOSC. The division's informal title, derived from using the letter "N" to designate "NCCOSC" and deleting the "T&E" for the sake of brevity, is "NRaD."

NCCOSC's mission is to serve as the Navy's full spectrum research, development, test and evaluation, engineering and fleet support center for command, control and communication systems and ocean surveillance and the integration of those systems which overarch multi-platfoms. NCCOSC reports to the Commander, Space and Naval Warfare Systems Command.

The new Naval Air Warfare Center (NAWC), reporting to the Commander, Naval Air Systems Command, includes two former R&D Centers—the Naval Weapons Center at China Lake, CA, and the Naval Air Development Center, Warminster, PA—and five other activities, including the Naval Air Test Center at Patuxent River, MD, and the Pacific Missile Test Center at Pt. Mugu, CA.

The new Naval Surface Warfare Center (NSWC) includes three former R&D centers: the Naval Surface Warfare Center with laboratories in Dahlgren, VA, and White Oak, MD; the David Taylor Research Center (DTRC) at Carderock and Annapolis, MD; and the Naval Coastal Systems Center (NCSC) in Panama City, FL.

The new Naval Undersea Warfare Center (NUWC) includes the Naval Underwater Systems Center (NUSC), New London, CT, and Newport, RI; and two engineering stations, the Naval Sea Combat Systems Engineering Station, Norfolk, VA, and the Naval Undersea Warfare Engineering Station, Keyport, WA.

Both the Naval Surface Warfare Center and the Naval Undersea Warfare Center report to the Commander, Naval Sea Systems Command.

In addition to creation of the four new centers, the Navy has streamlined its corporate laboratory structure. The Naval Research Laboratory (NRL) in Washington, D.C., and the Naval Oceanographic and Atmospheric Research Laboratory (NOARL) at Bay St. Louis, MS, have been joined.

The Naval Civil Engineering Laboratory (NCEL) remains a naval facilities command laboratory with its original mission.

Effects on Programs

The ocean engineering programs that have been of great interest to this panel remain with the people that you know. The programs are now at NRaD (NOSC), NSWC (DTRC and NCSC), NUWC (NUSC), and NCEL. The primary thrusts in ocean sciences and oceanography continue to be at NRL (NOARL) with specialized oceanographic tasks supporting undersea surveillance at NRaD, undersea warfare at NUWC, and undersea facilities at NCEL. The Fleet Weather Facility at Monterey now reports to NRL, along with NOARL.

So, you see, there are a lot of new organizational titles; but, the work continues by the same people in the same locations in the types of tasks of most interest to this panel. The one exception is the closure of the NRaD (NOSC) Hawaii Laboratory and the relocation of the effected programs and personnel to NRaD's San Diego headquarters. The movement necessitated by the "purification" of weapon systems tasks is not of prime interest to this panel.

Recent Activity/Advances
In Remotely Operated Vehicles

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Annapolis, Maryland

Early ROV development began in the late 1950's, with the need in the U.S. Navy for search and recovery activity on weapon (torpedo) test ranges. The 1960's and 1970's saw development of the Naval Ocean System Center's CURVE and SNOOPY class of vehicles and the development of a small civilian ROV industry with several companies developing underwater TV observation vehicles.

In the late 1970's the need for "real" observation and underwater work associated with growing offshore oil development activity resulted in a rapid increase in the number of ROV's, an increase in their size and capabilities and the creation of ROV's as an industry.

During the 1980's most ROV development and activity was focused on this expanding use of ROV's for offshore oil support operations.

Typical of modern day offshore oil support vehicles would be the Perry Tritech TRITON (Figure 1), SCORPION (Figure 2) and RECON VIPER (Figure 3). These three vehicles sort of represent the large size, midsize and moderate size vehicles currently doing offshore oil work.

A short Summary of their specifications is found in the following Table.

SPECIFICATIONS	TRITON	SCORPION	RECON VIPER
Depth	1000 m	1000 m	1000 m
Size Height Width Length Air Weight	 152 cm 150 cm 254 cm 2500 kg	 144 cm 114 cm 203 cm 1367 kg	 100 cm 114 cm 206 cm 700 kg
Through Frame Lift	3000 kg	454 kg	NA
Power System @ 2,4000 VAC 3Q60 Hz	(2) 50 HP Electrohydraulic	75 HP Electrohydraulic	20 HP Electrohydraulic
Propulsion Thrusters	3 Vertical and 3 Horizontal	3 Vertical and 3 Horizontal	1 Vertical and 3 Horizontal
Automatic Controls	Heading Pitch & Roll Depth	Heading Pitch & Roll Depth	NA
Sonar - Lighting - TV Cameras - and Manipulator Work Systems are included with each vehicle as appropriate to its size and mission function.			

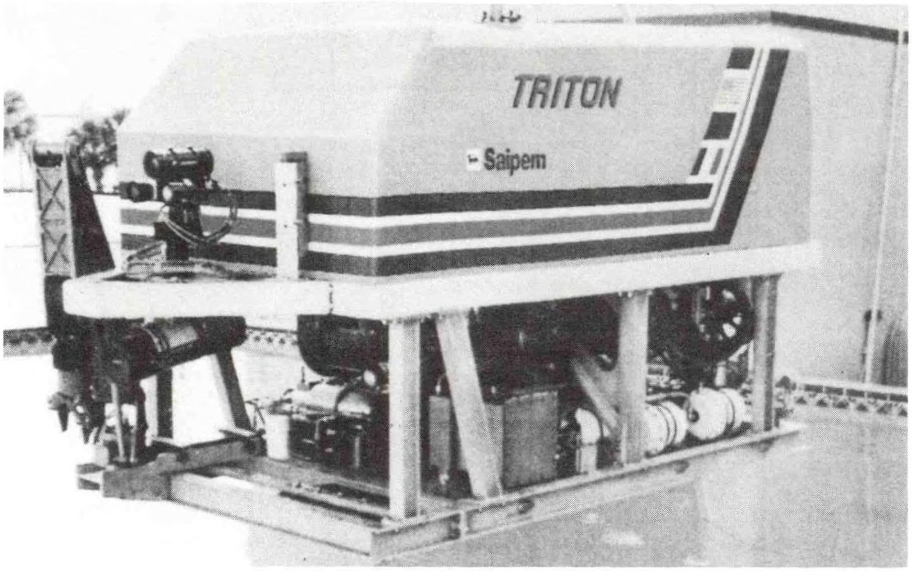


FIGURE 1
PERRY TRITECH
TRITON VEHICLE

FIGURE 2
PERRY TRITECH
SCORPION VEHICLE

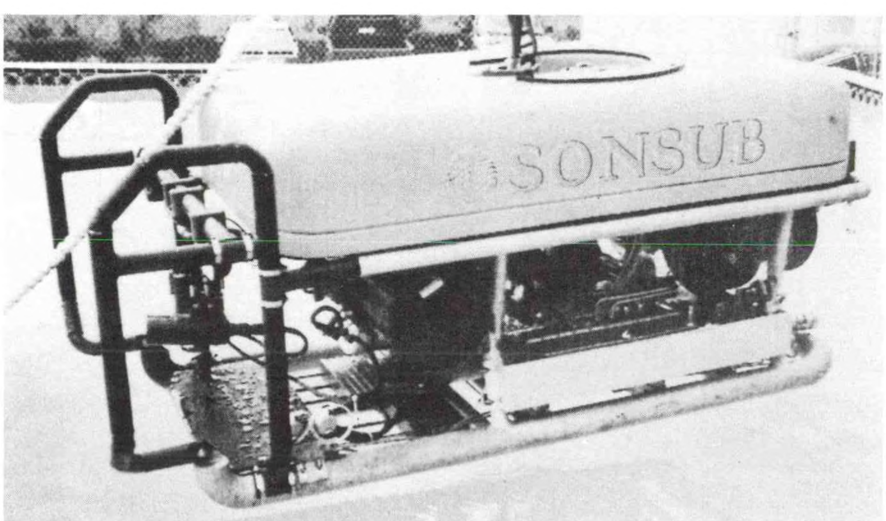


FIGURE 3
PERRY TRITECH
RECON VIPER VEHICLE

As we get into the 1990's several new and different uses of ROV's are emerging. The ever increasing depth requirements for offshore oil activity has forced the need for the development of deeper and deeper ROV capabilities.

With this deep capability came the realization that there were many areas and objects that could be explored, examined and if needed, recovered.

Aircraft accidents at sea are now able to be more fully investigated through the recovery of the flight recorders and aircraft structure. Examples include the location and recovery of wreckage from the 1985 Air India 747 crash in the Atlantic and the 1988 South African Airways 747 crash off Mauritius in the Indian Ocean. A current (1991-1992) investigation and recovery activity off Italy is centered on the recovery of the flight recorder and wreckage of an USTICA (Italian) DC9 that crashed at sea under mysterious circumstances.

Vehicles and systems that are being used for this type of deep ocean investigation include the Eastport International towed search sonar vehicle EXPLORER 6000 (Figure 4) and deep observation and recovery vehicle MAGELLAN 725 (Figure 5).

These systems were used to resolve the S.S. LUCONA affair. During the winter of 1990-91 the wreckage of the ship was located in 14,800 feet of water off of the Maldive Islands in the East Arabian Sea. The TV and Photo documentation from MAGELLAN 725 proved for the Austrian Courts that the ship had been sunk by an internal explosion and that it was not carrying a high value Uranium Processing Mill as had been claimed to obtain a large insurance settlement.

In August 1991, the U.S. Navy lost a UH 46D twin rotor helicopter in 17,250 feet of water some 440 miles off Wake Island in the Pacific. Recovery of the helicopter for accident investigation was initiated by the U.S. Navy's Naval Sea System Command - through the Supervisor of Salvage (SUPSALV).

This SUPSALV Navy office has an on-going contract with Oceaneering International which involved the design, construction, maintenance and operational use of the ORION (Figure 6) towed acoustic search system. The recovery operations contractor for SUPSALV is Eastport International which designed, built, maintains and operates the CURV III system (Figure 7). Both these assets were used to recover the helicopter during February 1992. This recovery of major wreckage from a depth of 17,250 feet points to the fact that with modern day ROV's; items can be located, examined and recovered from almost any ocean depth.

Another technology area where ROV's are seeing more and more use is that of trans-ocean cable burial, inspection and repair. Two new cable maintenance ROV's have been obtained by AT&T, Transpacific Communications, Inc. and are operated under a multi cable owner's agreement. These two SCARAB (Submersible Craft Assisting Repair and Burial) ROV's are SCARAB IV (Figure 8) and Pacific SCARAB ONE (Figure 9). Both of these large ROV's were designed and built by International Submarine Engineering of Port Coquitlam, B.C., Canada. The cable trenching, jet sled work systems mounted below the vehicles were designed and built by Oceaneering International of Houston, Texas. Technical details of Pacific SCARAB ONE are as follows:

Operating Depth	2500 ft
Vehicle Weight	7000 lbs
Size	L-14', W-6', H-10'
Jetting Skid Weight	5000 lbs
Size	-14', W-6', H-5'

2 Seven Function Manipulators with Cable Gripper and Cable Cutter Tools
SIMRAD/MESOTECH Sonars
NAUTRONIX Positioning System
INOVATUM Cable Tracking System
Able to Excavate and Bury Cable - To Depths of 1.2 meters

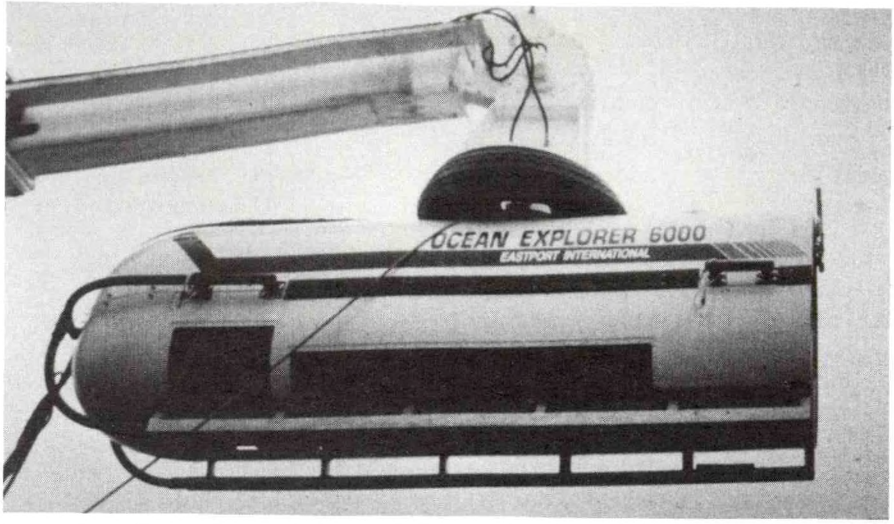


FIGURE 4
EASTPORT INTERNATIONAL
EXPLORER 6000
TOWED SONAR SEARCH
VEHICLE

FIGURE 5
EASTPORT INTERNATIONAL
MAGELLAN 725
DEEP OBSERVATION
AND RECOVERY VEHICLE

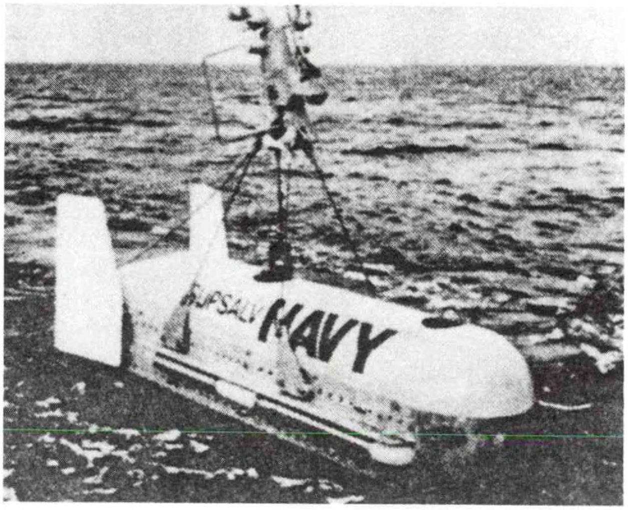


FIGURE 6
USN-SUPSALV (OCEANEERING INTERNATIONAL)
ORION TOWED SONAR SEARCH VEHICLE

FIGURE 7
USN-SUPSALV (EASTPORT INTERNATIONAL)
CURV III DEEP OBSERVATION AND RECOVERY VEHICLE

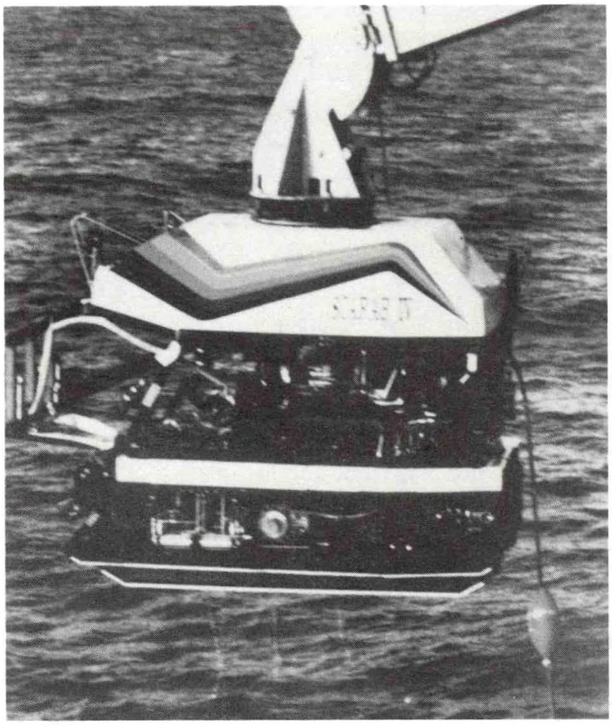


FIGURE 8
SCARAB IV

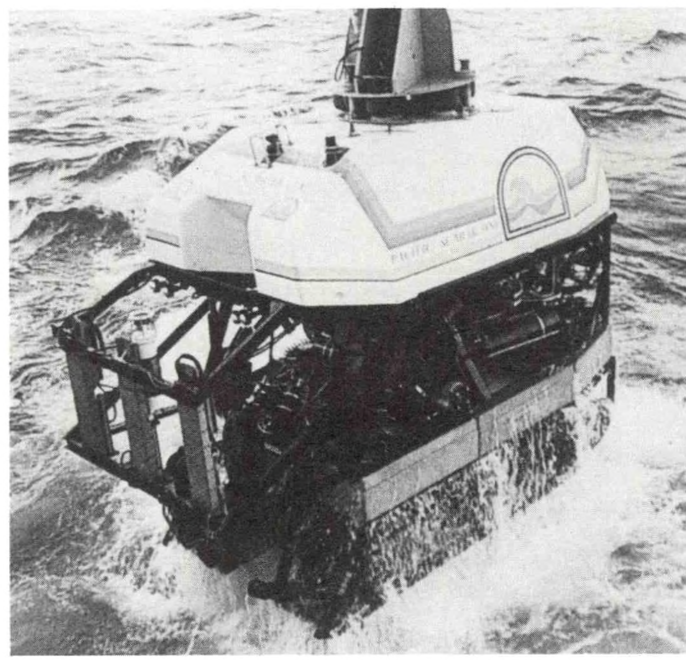


FIGURE 9
PACIFIC SCARAB ONE

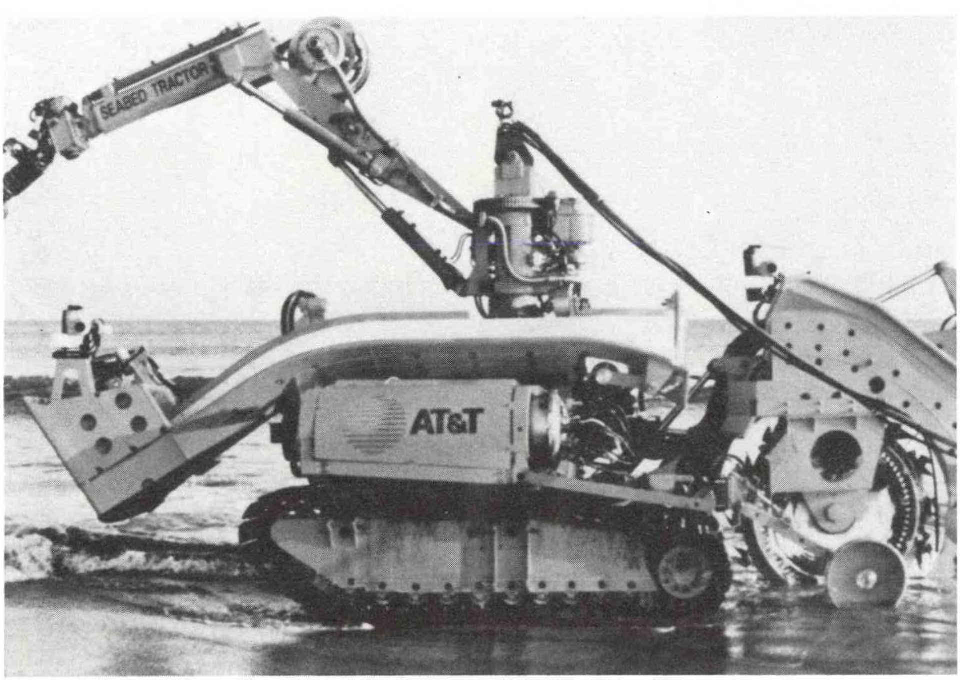


FIGURE 10
AT&T SEABED TRACTOR

For more difficult and specific on bottom cable maintenance activity AT&T, Transpacific Communications has developed a SEABED TRACTOR (Figure 10). This bottom crawling ROV can work to depths of 1400 meters. It's normal function is to bury cables and repeaters in the continental shelf areas using a variety of digging/trenching tool packages depending on the type of bottom. These interchangeable tool packages include:

1. Hydraulic high pressure water jetting sled.
2. Mechanical chain (saw) trencher.
3. Rock wheel cutter.

A separate cable stowage reel can be carried for deployment and burial of short cable runs. A crane mounted manipulator/grabber system is also available for specific cable handling functions and a portable dredger can also be used for local excavation.

The basic tractor is 4.0 m long, 3.0 m wide, 2.8 m high and weighs 8 metric tons. It has a payload of 4 metric tons, a tractive force of 4 metric tons and a variable speed capability of from 0 to 6 Km per hour. The tractor has a power, control and handling umbilical cable 48.5 mm in diameter. It's breaking strength is over 80 metric tons. A dedicated launch and recovery A frame, 2400 meter cable drum and a standard 20 ft. ISO container control cabin make up the shipboard support equipment. The entire system can be deck mounted on any appropriate sized ship of opportunity. A frame L&R operations can be conducted from the stern or side in up to sea state 5 weather conditions.

From the very large cable maintenance vehicles just discussed, we turn to another new ROV field that uses very small vehicles. The Benthos MICROVER (Figure 11) is used for internal pipeline and plant inspection. This ROV is 5.5" in diameter, 25" long and weighs 14 lbs. Operating to depths of 100 feet, it uses a forward looking pan and tilt mounted TV system. Three thrusters provide forward/back, twist and vertical maneuverability.

Specifically designed and radiation hardened for internal nuclear plant inspection is the DeepOcean Engineering "FIRE FLY" vehicle (Figure 12). It is 12.5" high, 7" long and 5.5" high and weighs 10 lbs. It has a test depth of 150 feet.

In another approach to pipe inspection, Inuktun Services of Nanaimo, B.C., Canada has developed a standard MINITRACK (Figure 13) crawler assembly that can be used in a number of configurations to provide internal inspection of pipes from 6" to 26" in diameter (Figure 14).

In summary, while the major uses of ROV's are found in the offshore oil industry, new and different applications are being developed and implemented. Successful deep ocean search and recovery operations show that the oceans are no longer inaccessible. Cable burial and repair activities are being done with large sophisticated ROV's while ultra small single purpose vehicles are being used to inspect pipes and power plant equipment in areas that have also been thought to be inaccessible.

In the words of the Star Treck TV series "ROV's" are now able to go where no man has gone before.

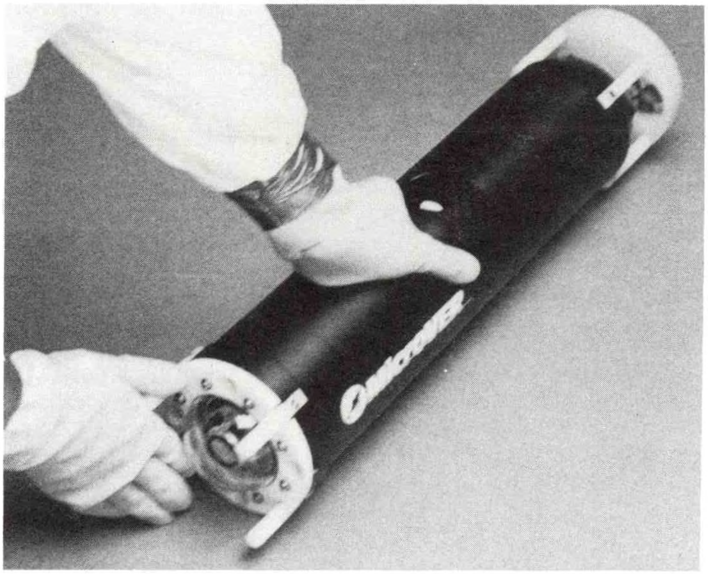


FIGURE 11
BENTHOS MICROVER

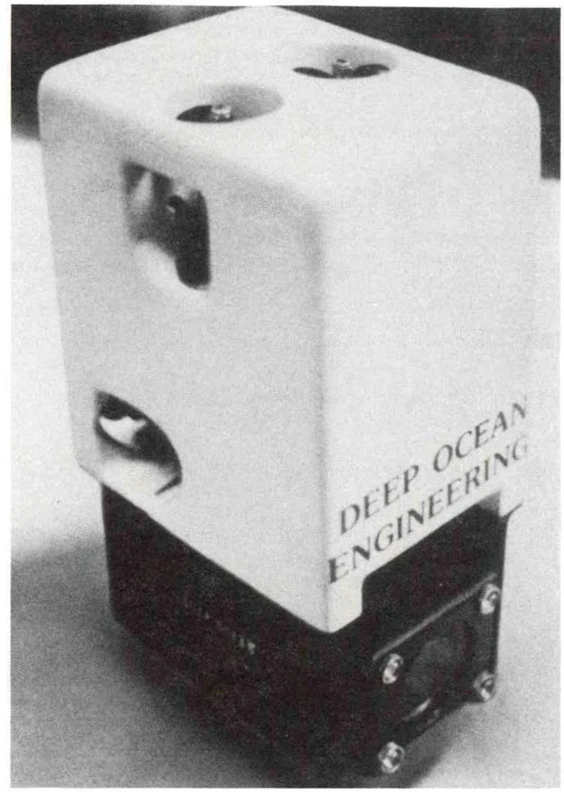


FIGURE 12
DEEP OCEAN ENGINEERING
FIRE FLY

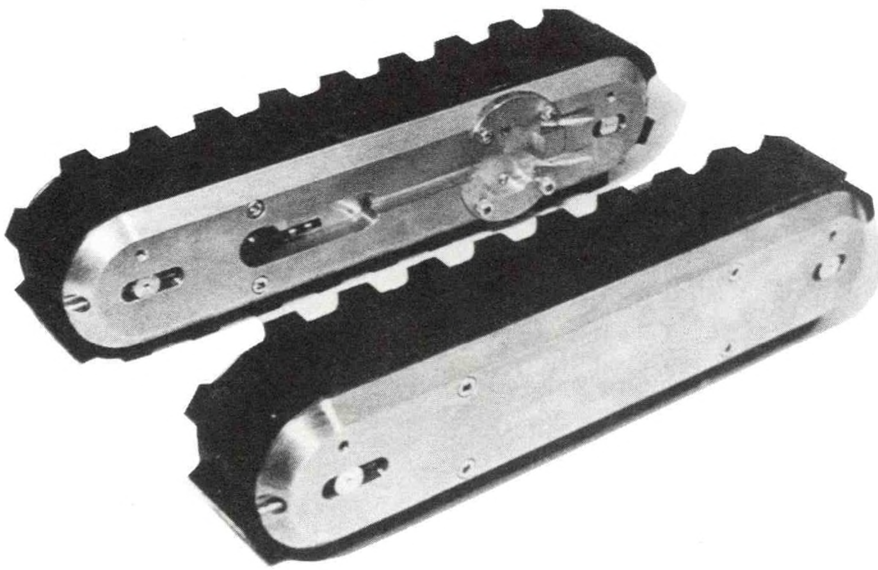
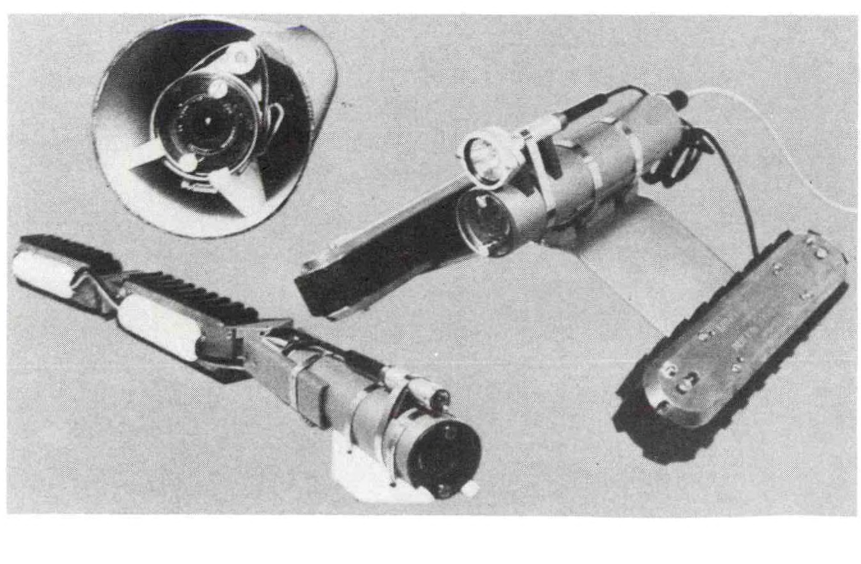


FIGURE 13
INUKTUN MINITRACK
CRAWLER UNITS

FIGURE 14
INUKTUN - PIPE INSPECTION
VEHICLE CONFIGURATIONS



DEVELOPMENT OF COLLECTION, ISOLATION AND CULTIVATION SYSTEM FOR DEEP-SEA MICROBES STUDY

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1. INTRODUCTION

JAMSTEC(Japan Marine Science and Technology Center) has developed the manned submersible survey vessels, "SHINKAI 6500" and "SHINKAI 2000", and the remote controlled unmanned exploration system, "DOLPHIN 3K"(ROV). In addition, 10,000m class remote controlled unmanned survey system is now under construction.

Deep sea surveys by using these manned and unmanned submersibles have revealed the existence of deep sea biological communities, composed of organisms scarcely known in the past, at deep sea hydrothermal vent and cold seep areas. The study of microbes living in the deep sea environment has been the focus of recent marine microbiological research.

JAMSTEC has started building a system to collect, isolate and culture deep-sea microbes that maintaining its deep-sea ambient environmental conditions from 1990. This system is now under construction and expected to be complete in the middle of 1993.

2. OUTLINE

This system consists of 4 subsystems, that is, Sediment sampler, Dilution device, Isolation device and Culture vessel.

The basic operation of this system is to use a submersible to collect sediment from the deep-sea bottom and bring it to the surface while retaining its ambient pressure and temperature. After diluting it to the certain concentration by sterilized sea-water in Dilution device on land, it is isolated by transfer dilution to 36 pieces of Pyrex glass cells and culture at the deep-sea conditions up to 680kgf/cm^2(6,500m water column) and 300 ℃ in Isolation device. Culture medium in cell, which is confirmed to be isolated, is finally transferred to Culture vessel for mass cultivation. The control of temperature and pressure conditions, the dilution works and the monitor of microbes' growth are all done in a control room remotely.

General view of this system is shown in Fig.1. Table 1 shows the pressure and temperature conditions of each subsystems.

3. SEDIMENT SAMPLER

Sediment sampler, schematic diagram shown in Fig.2(1), consists of isobaric collection vessel which contains accumulator, isobaric section and measurement section, outer container and adiafatic materials.

At the sea bottom(Fig.2(1)), container is opened. Sediment on sea bottom is scooped by submersible's manipulator and is filled through guide hopper into measurement section, where exact quantity of 5ml is retained by turning hopper to drop the excess of sample. After sediment is transferred into isobaric section for retaining the pressure by moving rod, container is closed for retaining the temperature(Fig.2(3)).

4. DILUTION DEVICE

Dilution device, system diagram shown in Fig.3, mainly consists of 4 isobaric cylinders and sterilized sea water tank with many high pressure parts(tubes, valves and connections), and the whole are placed in isothermic room.

Isobaric section of Sediment sampler is connected with inlet port and sediment sample is isobaricly transferred to dilution cylinder. In measurement cylinder sediment sample is mixed and diluted with sterilized sea water to the required concentration. Diluted sample is transferred to Isolation device through an outlet port while retaining its deep-sea ambient pressure.

Although Dilution device has so many valves, as shown in Fig.3, a remote operation and a programmable control for these valves sequence permit easier handling.

5. ISOLATION DEVICE

As shown in Fig.4, Isolation device consists of 36 pieces of cells(20ml each) made of Pyrex glass, an isobaric vessel, a heater/cooler jacket, an agitator, a microbes density measuring system and its rotator.

Heater/cooler jacket consists of electric heater, cooling tube and glass wool as insulation materials.

After sterilized, the vessel is filled with pure water as pressure transfer media, and each cell is filled with broth. Samples diluted at the former step are isobaric transferred into each cell and mixed with broth together. The pressure inside cell is balanced with silicon bellow.

36 pieces of high pressure tube coming from each cell is integrated at a valve unit and fixed with high pressure connections of Dilution device. Works of isobaric transfer are easily and remotely operated from control room.

6. CULTURE VESSEL

Culture vessel has only one Pyrex glass cell of 1,000ml, although its construction is very similar to Isolation device. We are planning.to have two sets of Culture vessels which can work individually.

Isolated sample, certified at the former step, is isobaric transferred to the cell, where broth is already filled, for mass cultivating.

The other purpose is to observe deep-sea microbes growth characteristics against pressure and temperature more precisely.

7. MICROBES DENSITY MEASURING SYSTEM

Fig.5 shows the principle of this measuring method.

Two beams of semiconductor laser are transmitted to a lens unit through fiber optic glass, after being generated by a laser source and separated at a beam splitter. These beams are crossed at one point inside cell to increase its optical power density.

Microbes, as seemed to be small suspended particles in the water, generate scattered light due to laser irradiation. The higher the microbes density, the higher the intensity of scattered light. Using this, we can measure the microbes density by detecting the intensity of scattered light.

8. PROSPECT

Elemental tests of each system are now being carried out. Actual operation of this system for the purpose of microbiology study is scheduled to start from September, 1993.

This system is expected to give us various and fruitful results in the study of deep-sea microbiology. This system is not only for Japanese, but also researchers of all over the world, and we hope that international cooperation in this field will be encouraged with this new tool.

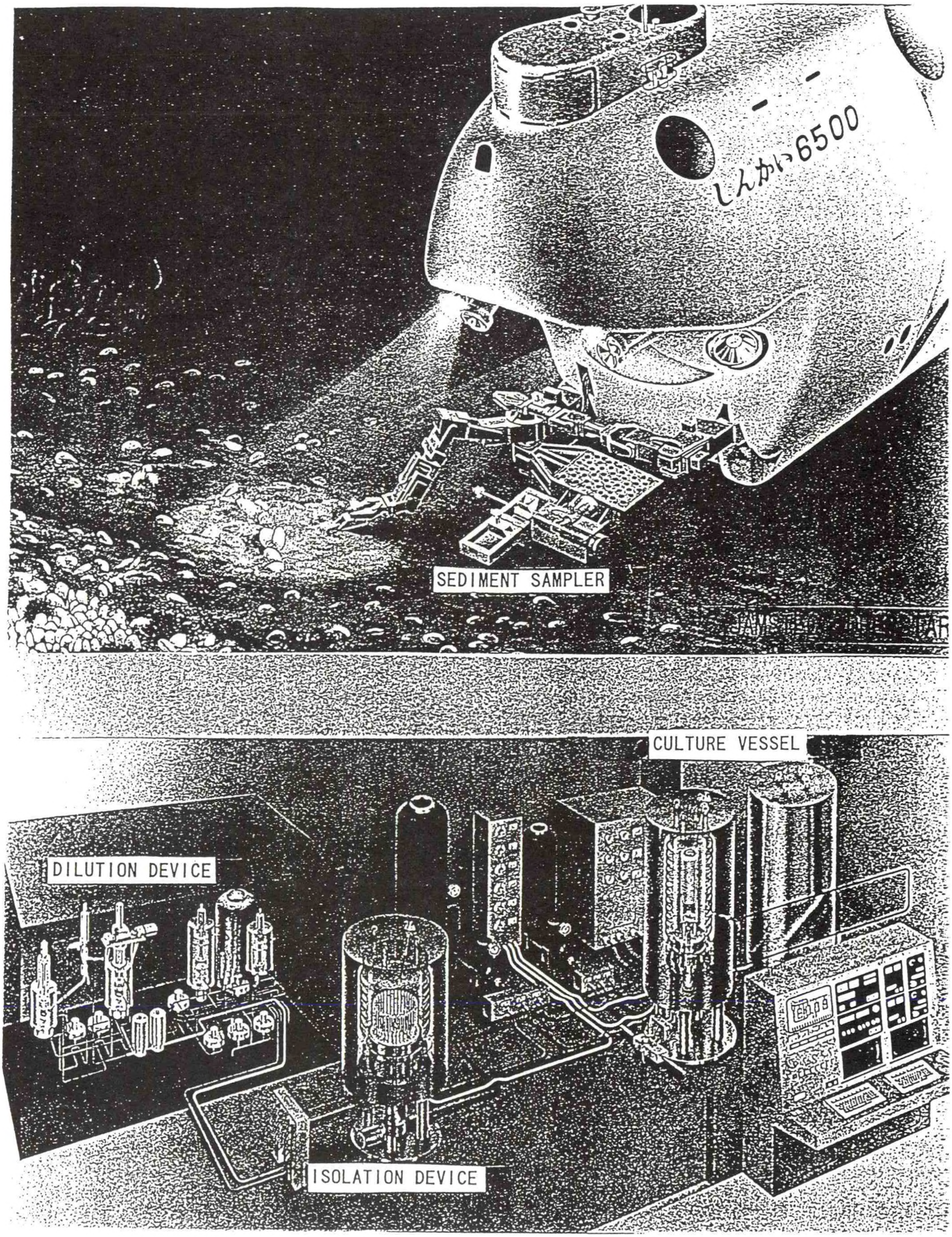

Fig.1 General View of the System

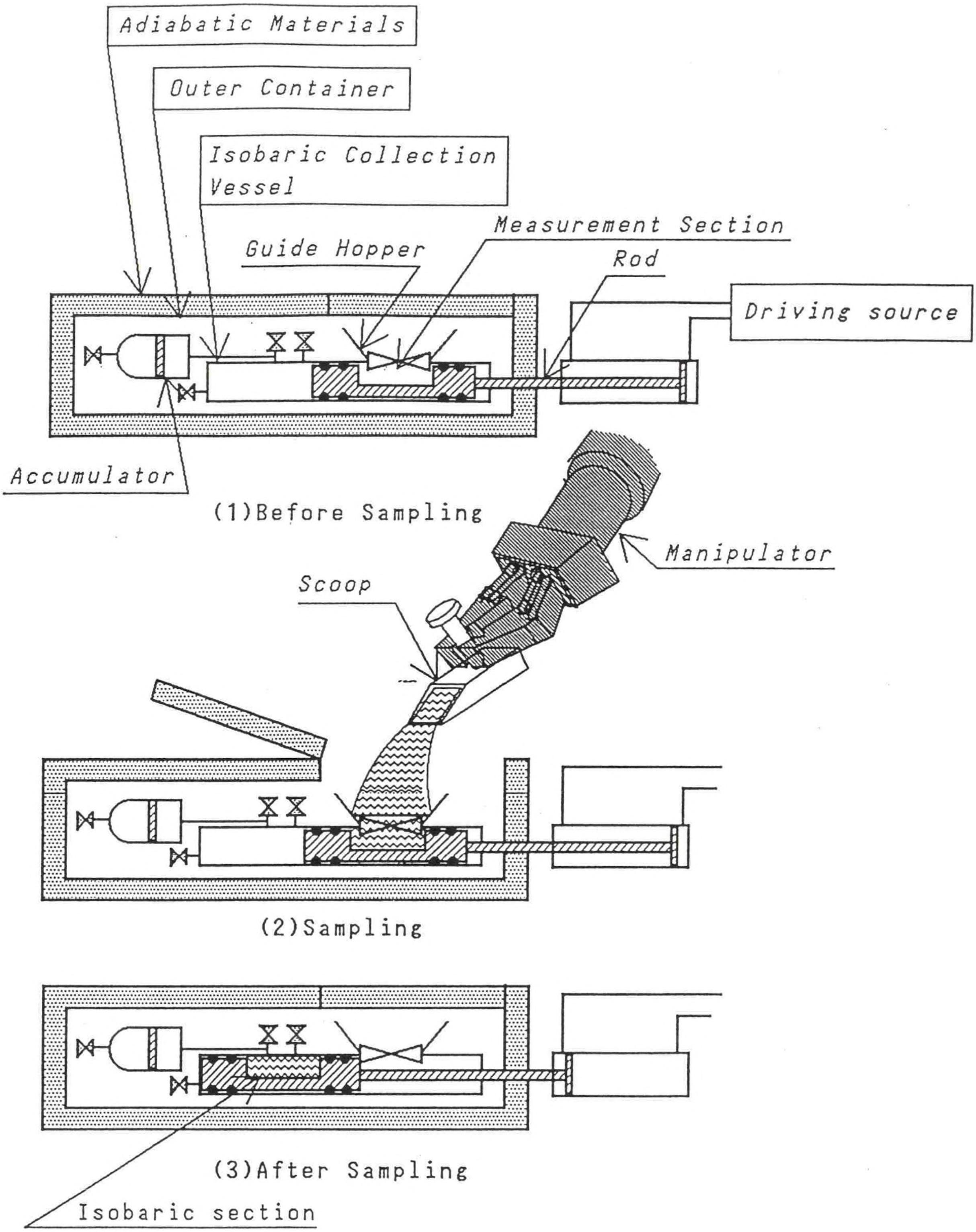

Fig.2. Schematic Diagram of Sediment Sampling.

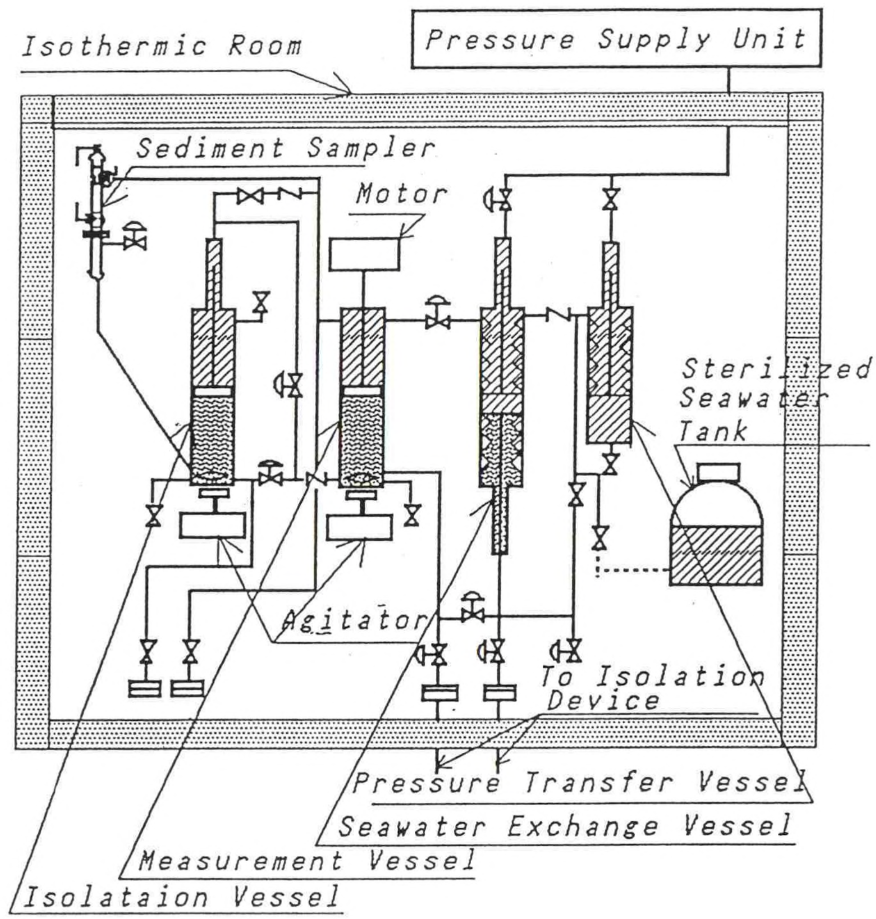

Fig.3. Schematic Diagram of Dilution Device.

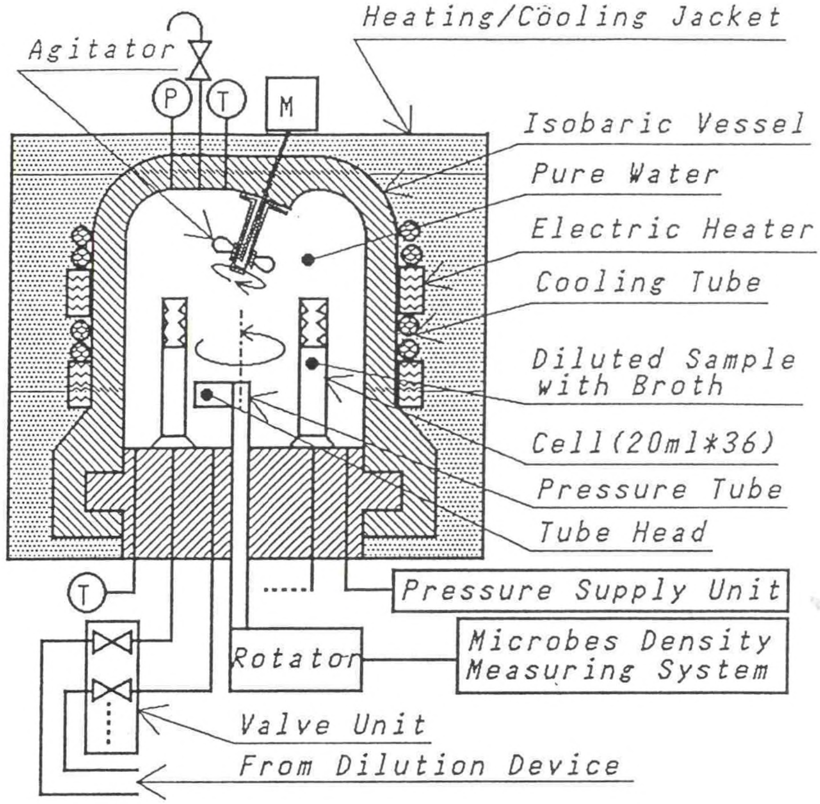

Fig.4. Schematic Diagram of Isolation Device.

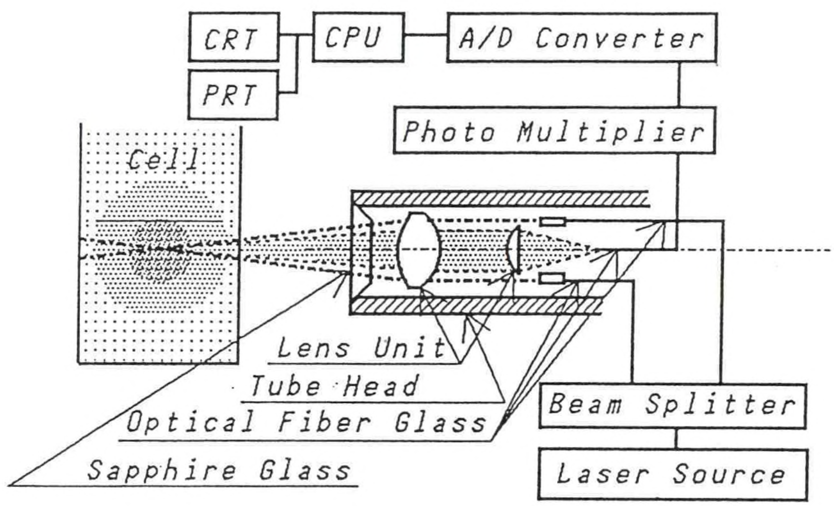

Fig.5. Schematic Diagram of
Microbes Density Measuring System.

OCEAN VOYAGER: An unmanned underwater vehicle

Prepared by Dr. Barry Steer on behalf of
S. Dunn, J. Cuschieri, K. Ganesan, J. Kloske, L. LeBlanc,
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July 13, 1992

ABSTRACT

Currently, freely swimming robot-submarines are severely limited in scope. They have an impoverished ability to sense and reason. They require environments which are strictly controlled. They are incapable of taking anything other than the simplest actions when confronted with a problem. Other key issues of navigation, range capability, endurance, high density low volume energy systems, graceful recovery from failure conditions, all remain outstanding and substantial research issues.

An underwater robotic-system endowed with algorithms that utilise both state and sensor information, able to build a modifiable map of its marine environment, and able to utilise this learned map to operate efficiently while carrying out its preset goals and tasks in some optimal (or satisficing) manner is an ambitious goal.

This document describes the efforts currently underway in the Advanced Marine Systems Group, at Florida Atlantic University (FAU) whose aim is to develop one particular robotic-system. The effort is aimed at developing a freely swimming robot-submarine.[1] The goal is to develop technology for AUVs that will support Ocean Science.

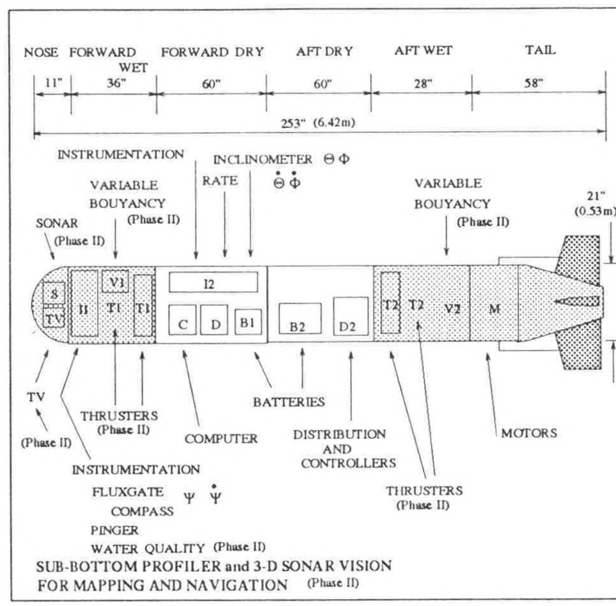

Figure 1: Schematic of FAU vehicle the Ocean Voyager.

INTRODUCTION

To fully develop an intelligent robot-submarine to operate in the way envisioned above a multi-disciplinary, multi-institution, multi-national approach will be essential.[2]

From a "robotics" perspective it is convenient to group the issues and problems under a number of different headings. These include such aspects as (1) sensors and sensor technology, (2) navigation,[3] (3) maps and map management based both on pre-mission input and information sensed during the task, (4) mission management, (5) command and control, (6) systems issues, (7) through water communications,[4] (8) propulsion systems, (9) energy storage systems, and (10) low power sub-systems.

Many missions can be envisioned for an AUV,[5] and they

[1] Other terms in use are, for example, Unmanned Untethered Underwater Vehicle or Autonomous Underwater Vehicle (AUV)

[2] The following partial list of subject areas gives some indication of the range of topics and subjects involved. These include (1) naval architecture, (2) hydromechanics, (3) control, (4) image processing, (5) robotics, (6) materials, (7) structural principles, (8) aeronautics, (9) acoustics, and (10) the effects of the sea-water environment itself.

[3] By navigation we mean a process which establishes ("fixes") the position and attitude of the robot-system relative to some frame of reference. The frame of reference may be its own positional history or the position of objects in its environment observed by the robot-system. Or if semi-autonomous by an external observer informing the robot-system where it is located.

[4] We note recent work by Josko Catipovic at the Woods Hole Oceanographics Instititution using incoherent modulation resulting in shallow water 1-10-km implementations with data rates up to 20kb/s.

[5] Examples include; vent mapping (science applications), oil rig monitoring, and tracking of pipe lines, (development of support technology for oil exploration) weather front following or under-ice operations (meteorological and climatic applications), biological assay in the euphotic zone, (climate change and husbandry of the oceans), submarine sentry duty, (mili-

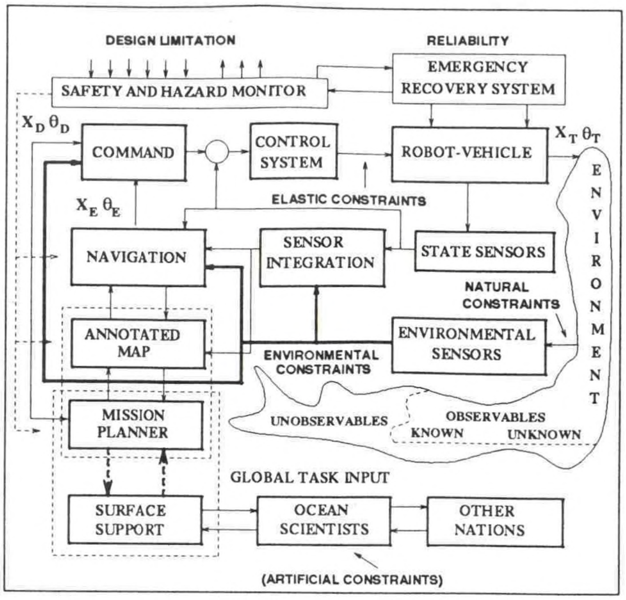

Figure 2: A possible black box wiring diagram showing the inter-connection of sub-systems for an underwater robot-submarine. The topology of these interconnections is only partially complete and accurate. For example, in other robot-system implementations the navigation subsystem is used to provide environmental sensors with positional information. This is done because when sensors make measurements the global location of the vehicle is used to "coordinate" them.

are likely to be highly complex. This complexity will warrant careful attention to tasks like resource optimization, mission pre-planning, intelligent processing of information, and critical on-board decision making. There is a clear need to model the environment in which the vehicle must navigate. The problem of reliability and graceful recovery under failure and fault conditions is a major systems issue yet to be addressed. Further, capabilities, such as scene reconstruction and real-time sensory interpretation of the underwater environment, are also still in their infancy.

SYSTEMS OVERVIEW

In order to explicate the research issues we exhibit in figure 2 a black box wiring diagram of the sub-systems of a prototypical underwater robot-submarine. The subsystems as they relate to this figure and which are under study are summarised in the remainder of this paragraph. Following this summarising paragraph the remainder of this paper describes the individual contributions in more detail.

The FAU-Perry AUV, the "Ocean Voyager", is described. This is a robot submarine project started jointly by Dunn and Perry Technologies [6] in 1989. This is followed by a description of the organisation of the sub-sea computer systems. The 6 degree of freedom non-linear model of a submarine vessel is referenced and it is this model on which a simulation of the dynamics of both the Draper UUV and the Ocean Voyager have been programmed by Shein and Kloske. The numerical results of these simulations can be output and visualised on a Silicon Graphics workstation. We describe the navigation capability as developed by Kloske and Ryder. The ideas underlying Smith's work on fuzzy command and control are then described. An algorithm which embodies fuzzy principles is exhibited as a concrete example of some of the ideas outlined by Smith. The low-level control schemes, linear, neural, and fuzzy currently under development are described. The next section describes two recent and important developments in sensors and sensor technology. Cuschieri is developing a high resolution 3-D sonar imaging system for AUVs. While LeBlanc, Schock, and their co-workers have developed a calibrated wideband (2-10kHz), digital, FM sonar that provides high resolution ($\approx$ 10cm) , deep penetration, ($\approx$ 100m) low noise subbottom data. The next section discusses the need for a new paradigm for sensory interpretation for underwater robots. It notes that while algorithms developed to perform sensory interpretation for land based robot vehicles can assume that the cause of sensor motion is self generated, that underwater this assumption is, in general, no longer true. Plans are underway to use the chirp sonar sensor, in conjunction with established techniques from the field of machine vision, to automate the process of "scene" reconstruction of images it has acquired from beneath the sea-floor. This work builds on the work of LeBlanc, Schock, et al. Its output would be a data structure whose content could be incorporated into a map by an annotating process. Ganesan and Dunn's work on annotated maps is then described. The annotated map system will provide a framework to represent information which makes mission planning and guidance easy and fast. This work complements work at CMU also in annotated maps. Finally some ocean science tasks which a vehicle of this type could undertake are described. In particular measurements in the euphotic zone.

DEVELOPMENT OF THE FAU-AUV

It is well understood that building a real robot-vehicle forces those involved to solve more of the real problems than if only simulations are developed. Ocean Engineering and Perry Technologies chose to develop a torpedo shaped vehicle. A highly schematic version is shown in figure 1. Its overall length is 21ft (6.4m) and the outside diameter is 21in (0.53m). Its dry weight is 1800 lbs (about 800-kg). Its flank speed is 6 knots. The controllable speed range for the submersible is $1.69 \leq \| V \| \leq 10.13$ ft/sec, ($0.51 \leq \|V\| \leq 3.08$ m/sec). While the duration a submarine can cruise for is related to many factors, with the initially

tary applications), and autonomous laboratories to support science understanding of the physics, chemistry and biology of the oceans, (perhaps finding further evidence for the Gaian hypothesis (Gaia: A new look at life on Earth. James Lovelock, F.R.S. Oxford University Press, 1979.))

[6] Perry Technologies: A Martin Marietta Company, Riviera Beach, FL. USA

planned lead acid batteries, the cruise time is expected to be about 60 minutes. The CPU running time is estimated to be about 120-180 minutes. These times will increase as higher density energy systems become available. Hydrodynamic design will also improve these figures. Although for this vehicle this was not considered as a design option. Rather the emphasis was intended to be on developing experience throughout the whole design cycle, and in particular the intelligent vehicle control software. The CPU is a 68020 running at 25MHz. The organisation of the sub-sea computers for this vehicle is shown in figure 3. VxWorks is being used for code developement. This gives

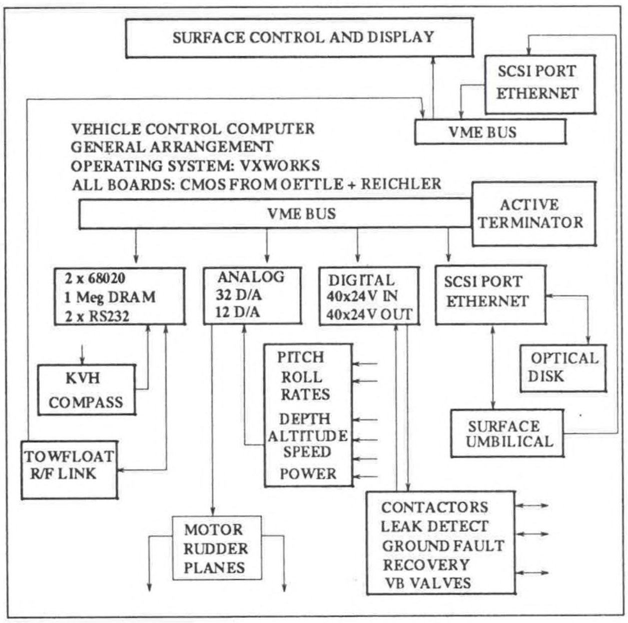

Figure 3: Actual organisation and components of sub-sea computer systems.

us compatability with a number of other institutions. The onboard memory is 1MByte in size. This clearly needs to increase in size. The power of the vehicle thruster is 3 hp. Initially this was designed to be 1hp but with uncertainty arising from the RF tether induced drag, its size was increased. For attitude control, two 24v 8A actuators will be used. To provide stabilization information, pitch and roll will be measured with clinometers. The rate of change of pitch roll and yaw will be measured with Watson rate sensors. Heading will be measured with a KVH ROV-1000. Altitude will be measured using a Mesotech 807 or 809. Depth will be measured using a Precise Sensors Inc. System sensor. The navigation system is a GPS system onboard a surface vessel with an 9600 baud RF link to a tow float attached to the vehicle. A variety of other sensors are planned to monitor the power and other critical systems. There is space available for a separate bouyancy control system and thruster for and aft. The dry payload is approximately $0.36 \times 0.34 \times 0.3\text{m}^3$. The vehicle is modular and an additional cylindrical section can be added.

HARDWARE IN THE LOOP SIMULATION

Shein and Kloske have developed a simulation based on a non-linear model of a submarines six degrees of freedom (6-DOF). [14]. The mathematical formulation is based on the David Taylor Naval Ship Research and Development Center report [3]. This simulation allows initial testing and debugging of the AUV software to take place in the laboratory rather than at sea. The simulation runs on a Silicon Graphics system. The simulation is being used to test linear, neural and fuzzy control algorithms. These are described elsewhere in this paper. It also allows us to develop and to test navigation and obstacle avoidance algorithms and to generally develop, test and debug the pre-flight and diagnostic software necessary for successful at-sea operations. As far as possible careful, attention will need to be paid to the software design to make it modular and reusable.

NAVIGATION

Kloske and Ryder have written software, which enables us to locate a vehicle using a combination of a Trackpoint II System[7], a Global Positioning System (GPS), and a ship's heading. Software has been written, tested and debugged using the Harbour Branch[8] vehicle, the Johnson Sea-Link. The location of the submersible has been automatically tracked to a horizonatal distance of about 700ft and a depth of about 2600ft. The system tracks and determines the location of the submersible relative to a boat and the GPS is used to determine the location of the ship in longitude and latitude. This all transforms to an uncertainty in Geodetic position of about $\pm$ 40ft. This figure will improve as we add new depth telemetry capabilities. The arrangement to determine position is shown schematically in figure 4. The location of the submersible is recorded automatically and will be available to other processes. Additionally, some dead reckoning capability will be available using the speed sensor in conjunction with the heading sensor. Clearly this will only be of use over very short ranges. Other possible navigation options are some combination of ring laser gyros, fibre optic gyros, doppler sonar, correlation velocity log sonar, or large scale deployment of either active or passive beacons.

COMMAND AND CONTROL SYSTEM

The Command and Control System is a heterogeneous group of hierarchical subsystems. Each subsystem operates as an EDACT Module with the capability of communicating with any other module. Because the AUV is a dynamic system operating in real time in a dynamic environment, the primary constraint on any task is the allowed completion time. The various time constants governing the

[7] The Trackpoint II System is a an Ultra-Short Baseline Acoustic tracking system from ORE International Inc. Falmouth, MA. USA

[8] Harbour Branch is an Oceanographic Institution in Fort Pierce, Florida.

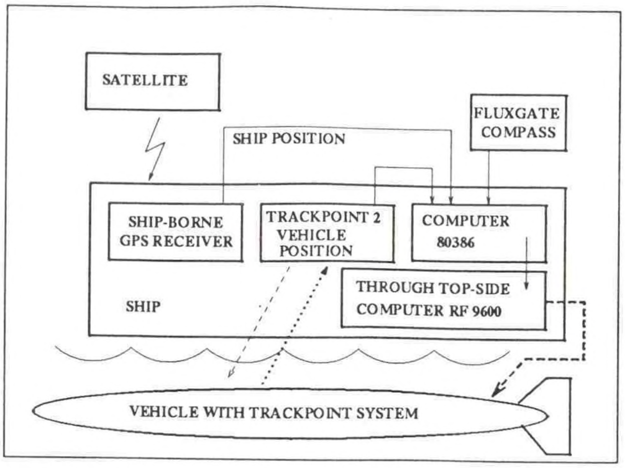

Figure 4: Development of Global Positioning System and Trackpoint to determine vehicle position.

various dynamic changes to the AUV/Environment system determine the rate at which decisions must be made. This forces a time ordered architecture on the overall system [7]. Decision making at a higher level of the hierarchy has more time for deliberation than at a lower level. Typically, the level of abstraction increases with the level of the hierarchy. Each subsystem hierarchy, however, need not be based strictly on the same time ordering as another subsystem. Each level of a time ordered hierarchy may itself be a hierarchical system ordered on some other basis such as abstraction or scope. The organization of the command and control system is also influenced by the size and complexity of the software needed for implementation. Consequently, the formation of different components may reflect function modularization or encapsulation.

Inherent in each task performed by the components of the command and control system is the satisfaction of time and event based constraints on the behavior of the system. Natural constraints are imposed by the environment and by design limitations on AUV performance. Artificial constraints are imposed by the goals and missions the AUV is given to perform. Communication between various components of the command and control system can be represented as the transmission of constraints. Crisp or Boolean constraints can create problems such as rapid switching between decisions. The system may be brittle to changes in constraint boundaries thereby making the specification of constraint boundaries critical. Moreover, the simultaneous satisfaction of multiple constraints may become problematic as the number of constraints increases due to contradictions. One solution to this problem is the use of elastic constraints [4], [24]. Elastic constraints allow partial satisfaction. The degree of satisfaction of an elastic constraint is an inverse function of how far the constraint must be stretched to accommodate the given situation. The simultaneous satisfaction of multiple elastic constraints becomes much less problematic, since all the constraints may be satisfied to some nonzero degree even though it may be impossible to satisfy all of them completely.

Decision making consists of rating and ordering different options based on their degree of constraint resolution. With elastic boundaries the system is more robust to parameter variations. Fuzzy logic provides convenient formalisms for representing and resolving multiple elastic constraints on system behavior [4], [24]. One goal of this research is to investigate the application of fuzzy decision making techniques to the command and control system.

The hazardous nature of the ocean environment requires that the control system operate reliably. The controller must specify an appropriate response to any event that could prevent the AUV from completing its mission. Robust solutions to complex problems often require generality. Because complexity makes it difficult to predict every situation precisely, specific solutions may not be feasible; whereas, general solutions are designed to work for many situations. Anticipating every possible hazardous situation and precisely specifying an appropriate response may not be feasible. A more robust approach is to specify general responses to a class of situations. Although a general response may not be as optimal as a specific response to a given situation, the general responses' increased reliability over a range of situations justifies the use of the general response. Fuzzy logic provides tools for approximate and general reasoning, thereby facilitating the expression of general solutions to complex situations. Development of the high level control system starts at a general or qualitative level. General solutions are constructed for as many situations as is possible. As expertise and computation power allows, more specific solutions replace the general solution in the specified situations. The high level controller switches between responses, general to specific to general, as conditions indicate. The control system maintains robustness while allowing for higher performance in special cases.

The representation of situations and responses is done with cascading levels of precision. The caveat is that precision is costly. At the highest level the lowest precision or greatest fuzziness is used. Only as much precision as necessary is used at each level. This approach reduces the memory and computation required to evaluate responses. For example, suppose the goal is to move the AUV to a target location. A high precision path planning algorithm would calculate the complete path from start to finish with the same degree of precision at each part of the path. A cascading precision algorithm starts with low precision far away from the target and then gets more precise as the AUV gets closer to the target. A specific solution might give the minimum energy or time path to the goal (at a potentially large computational cost); whereas a general solution is any path that moves toward the target and stays within a cone of acceptability, with the apex of the cone at the target location. The cone defines the degree to which precision must increase as the AUV nears the target. The general solution trades performance for robustness. An early example algorithm developed by Larcombe and

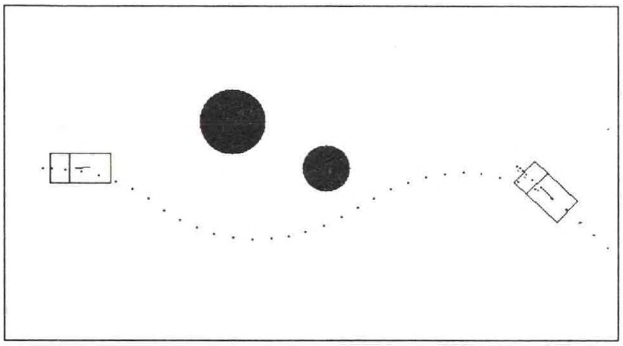

Figure 5: A fuzzy "style" algorithm that takes as its input the robot-vehicle's current position and heading and a goal position and heading and then "maps" the "difference" between them directly into actions for the controllers of motion and heading to act on. Unmapped objects are also avoided.

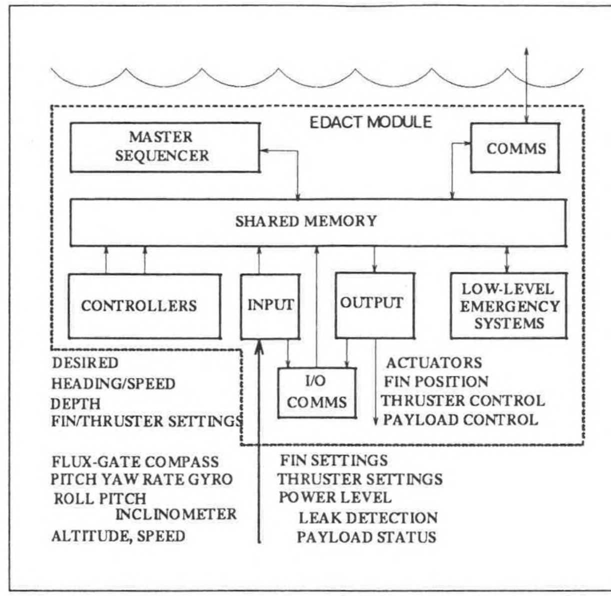

Figure 6: Communications layout for subsurface vehicle.

Steer [18] which embodies some of these characteristics is shown in figure 5. Although this is only a simulation[9] the control is carried out using some of the ideas and principles outlined in the preceeding paragraphs. The algorithm uses a blend of three constraints to guide the robot to its goal; the euclidian distance between the robot and the goal, the angular error between the desired goal posture and the current vehicle heading, and the perpendicular distance from a point on the robot-system to a line drawn through the desired posture axis at the goal location. The algorithm includes explicitly, and in a separate phase of the overall computation, the kinematic and dynamic constraints of a non-holonomic vehicle. We therefore maintain that such an algorithm could be applied to an underwater robot-vehicle. We also finesse issues concerned with producing planned paths that cannot be achieved in practise by a real vehicle. At each "moment" on its course to the desired goal the algorithm recomputes the next best move to enable it, ultimately, to reach its goal. The algorithm has also been designed to allow range and bearing information about unmapped obstacles to modify the actions of the robot-vehicle. Since the objects are unmapped they could be other moving vehicles. To overcome uncertainty in the actual movement the algorithm continually recomputes the control actions needed to achieve the goal. For this it needs navigational data. Although not implemented the algorithm has the potential to work in situations where the goal location, a constraint, changes. above.

LOW-LEVEL CONTROL SYSTEMS

The low level control system is contained in one EDACT module shown in figure 6. This low level control system operates at the fastest response time, (see figure 6 and controls the instantaneous state of the vehicle. Commands are passed to the low level system in the form of set points for posture, position, and velocity. The master sequencer coordinates the various low level control system components. For example the controllers block consists of controllers for all the various actuators on the AUV. The master sequencer is responsible for sequencing the desired controller at the appropriate time. For example, during testing the performance of a neural net heading controller might be compared to the performance of a fuzzy logic controller. A message sent to the master sequencer enables flexible selection of the particular controller to be used without recompiling the low level control system before each test. Part of this research will investigate and compare various low level control strategies including gain-scheduled PID, neural net, sliding mode, and fuzzy. We describe these in the following paragraphs.

Linear

A simulation has been built and tested using a gain scheduling PID controller. This simulation used a model of the Draper Laboratories unmanned untethered vehicle. Work is underway on validating a similar PID controller for the Ocean Voyager.

Neural

Venugopal has developed a neural network control scheme for the Draper Vehicle. The control scheme is on-line, that is, the controller adapts itself as along as the vehicle is under operation. A-priori knowledge of the vehicle dynamics, the environment or other characteristics which are necessary for the design of conventional controllers, are not needed in the present scheme [21], and [22]. The neural network learns the dynamics in very few learning cycles, taking the correct control action for an effective motion

[9] The vehicle simulated is actually a non-holonomic tricycle vehicle. However we maintain that the same fuzzy logic principles can be applied to an underwater vehicle.

through specified paths. The scheme has been tested on a linearized model of the vehicle dynamics as well as the nonlinear model, through simulations. Also the designed scheme is linked to the 6-DOF simulation of the vehicle. The neural network control scheme used in our studies is shown in figure 7 The overall mission planning, guidance and control setup is as shown in figure 2.

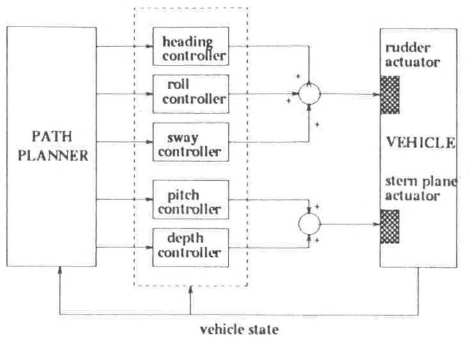

Figure 7: Neural network controller.

The path-planner sends the desired vehicle states, the (x, y, z) position and the pitch, heading and roll to the controller. The controller generates the correct control actions for the stern plane and rudder of the vehicle, while adapting itself to the dynamics, environment and the disturbances. Individual networks are used for the control of each state, and are updated using the corresponding error. The updating of the neural network weights are done based on the error between the desired states (generated by the planner) and the actual vehicle states, monitored by the sensors. We are able to control the vehicle using this scheme with zero tracking error for arbitrary commanded states. The present scheme uses a four layer network, with a maximum of 281 interconnections, which is computationally inexpensive for a real time implementation.

Three learning algorithms have been tried on the Draper Vehicle dynamics; the backpropagation algorithm, CMAC, and the ALOPEX. The relative merits and demerits of these algorithms for neurocontrollers are being compared. Currently we are also developing the ALOPEX algorithm with an architecture involving memory neurons. We expect that some of the problems associated with backpropagation and CMAC, when used in control applications, could be solved using this architecture. We propose to implement the control scheme on the vehicle, initially with a human operator. The operator would then be replaced by the neural network once it becomes trained. During the last stage of the project we would like to experiment with our algorithms and architectures on an actual AUV, which, so far, has been limited to simulations.

Fuzzy

The inherent nonlinear nature of submersible control response coupled with the variability of the ocean environment make robust controller design difficult. Fuzzy Logic Controllers (FLC) have shown promise in controlling complex, nonlinear, or poorly defined systems [19]. The nonlinear nature of fuzzy logic controllers coupled with their ability to reproduce qualitative and heuristic information about desired controller response make them a promising candidate for AUV control. Smith has shown that fuzzy logic controllers can be viewed as smooth variable structure controllers [15], [13]. Thus FLCs should perform at levels comparable or superior to conventional sliding mode variable structure controllers. Fuzzy logic techniques have been applied successfully to a six degree of freedom flight controller for a helicopter system [19]. An automated method for the design, calibration, and analysis of fuzzy logic controllers has been developed [15]. One goal of this research will be to investigate the application of this method to the control of an AUV.

ENVIRONMENTAL SENSORS

This section describes two recent sensor and sensor technology developments. Cuschieri is developing a high resolution 3-D sonar imaging system for AUVs. LeBlanc, Schock and their co-workers have been developing a chirp sonar system. Such technological development will extend the type of missions or tasks an underwater robot could deal with.

3-D Sonar Imaging

Results from a high resolution 3-D sonar imaging system being developed by Cuschieri [1] are shown in figure 8. The device consists of a forward looking sonar with a separate projector and receiver. The projector is a line source with an 80 degrees by 1 degree beampattern, which is electronically scanned within a 150 degree sector. The receiver is a multi-element array, where each transducer element has a directivity pattern which covers a full sector of view, one that is 150 degrees by 80 degrees. The purpose of this sonar system is to produce three (3-D) images which display the underwater topography within the sector of view up to a range of 200 metres, with an update rate of 6 seconds or less. The data received by the sonar system is processed using digital signal processing techniques which, after optimization of the system parameters can produce high resolution images. The size of the sonar system is sufficiently small that it can be mounted on an AUV. The generated images are of such quality that they can be used for AUV tasks such as obstacle avoidance, navigation, and object classification. The data processing is based on multiple cross-spectral analysis, which allows for the abstracting of the signal from the background noise. Significant data processing is required to generate the images; but through the use of modern Digital Signal Processing chips, it is possible to perform the processing in near real-time. The generation of the cross spectra is based on either classical estimation methods or on more modern spectral estimation techniques such as maximum entropy methods. Simulations have been carried out in order to explore the suitability of the different approaches for high resolution image reconstruction.

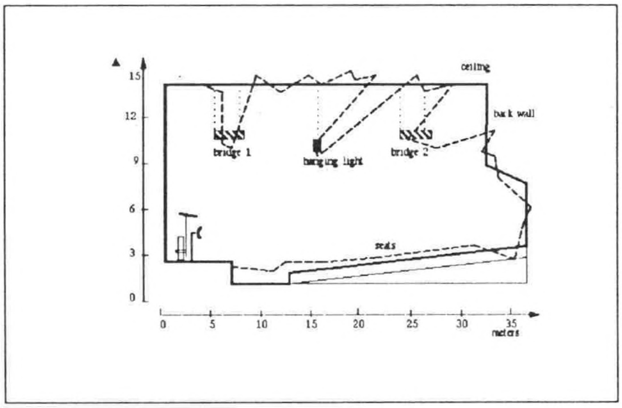

Figure 8: Experimental results using 3-D sonar system in-air.

Chirp Sonar

The data shown in figure 9 was obtained from the chirp sonar system developed by LeBlanc, Schock et al. [9], [10]. The figure shows the results from a geodetic survey off of the Florida coast near FAU in Boca Raton. The location of each data point was supplied from a Magnavox MX-200 GPS unit housed on-board our departmental vessel. The depths were obtained from the first return of the high resolution Chirp Sonar system. The distance between samples is of order 60 feet.

A description of the chirp sonar follows. The chirp sonar is a calibrated wideband (2-10kHz) digital FM sonar that provides quantitative, ($\approx$ 10cm) high resolution, deep penetration ($\approx$ 100m) low noise subbottom data. In addition, it generates an acoustic pulse with special frequency domain weighting which provides a nearly constant resolution with depth. The chirp sonar was developed with the objective of remote acoustic classification of seafloor sediments. In addition to producing high resolution images, the calibrated digitally recorded data are processed to estimate surficial coefficients as well as complete sediment impulse profiles. Surficial sediments from Narragansett Bay, in Rhode Island, (RI) have been used to provide a ground truth for an acoustic model. Quantitative acoustic returns from the chirp sonar have been used to estimate surficial acoustic impedance and to predict sediment properties. A robust acoustic classification model which uses core models to account for the local depositional environment have been developed. The model used an estimate of the acoustic impedance to predict surficial density, porosity, compressibility, and rigidity. The comparisons showed a high correlation between the core-determined sediment properties and the estimates obtained from acoustic measurements.

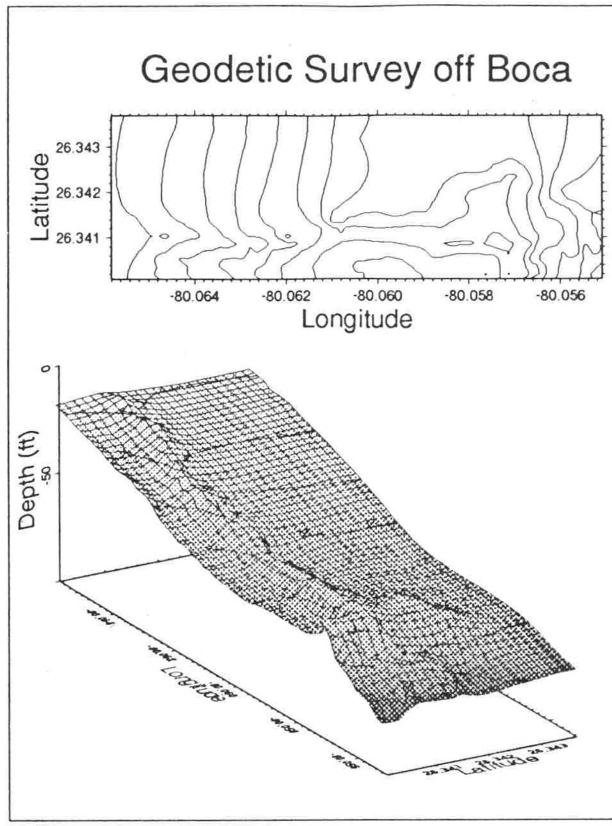

Figure 9: Geodetic survey off of Boca Raton Florida taken during March 1992. Location of each data point supplied from a Magnavox MX-200 GPS unit. Depths taken from output of the high resolution Chirp Sonar system. The distance between samples is 60 feet.

A relaxation time model has been developed that combines the various dissipative energy loss mechanisms of sound in marine sediments into a single parameter. Historical data were analysed by converting attenuation values reported in "dB/m@kHz" to a single relaxation time value. Analysis of previous attenuation measurements supported the use of a relaxation-time model. Based on a large collection of data, an empirical equation has been developed which relates relaxation time to grain size. Using this model, very little phase dispersion is observed for a correlated chirp pulse travelling through 40m of sand, silt, or clay. Yet, this is not so for a pulse in the ultrasonic frequency range (0.2-1.0 MHz) traveling through only 10cm of clay. Here significant dispersion is noted. Because of the unique Gaussian-like shape of the correlated chirp pulse power spectrum, pulse elongation owing to attenuation is minimized. Using the centre frequency shift in the power spectrum, a new "instantaneous frequency" method of attenuation estimation has been proposed which overcomes the problem of interfering reflections. Based on the relaxation-time model, the correlated chirp pulse is synthetically attenuated to establish a relation between relaxation time and centre frequency shift. '*In situ* sediment-type predictions from chirp sonar using the instantaneous frequency method and analyses of core samples taken in Narragansett Bay, RI, are in good agreement.

SENSORY INTERPRETATION FOR UNDERWATER ROBOTS

A new paradigm for sensory interpretation is required in the marine environment. Algorithms for sensory intepretation for land based mobile robot vehicles can assume, quite reasonably, that the cause of sensor motion is self generated. Underwater this assumption is, in general, no longer true. Random and systematic forces impose themselves on submersibles disturbing their position and velocity from that expected. Research is underway to develop algorithms that would implement an interpreter for sonar data.[10] Hallam [6] informally defines a sonar interpreter in terms of the task it performs.

> A sonar intepreter has the task of using acoustic data gathered by a physical sonar attached to an underwater freely mobile "platform" to construct detailed extero-centric three-dimensional computational models of the shape of the seabed and objects in the vehicle's environment. Its task is also to deduce the positions and velocities of those objects and the observer with respect to a fixed viewpoint independent frame of reference.

A sonar intepreter should take into account the following: (1) The description it produces should be view independent, (2) the system must be real-time[11], (3) objects will be visible irregularly and at random, (4) information concerning both diffuse and specular reflections should be used, (5) much of the time an object will be invisible (in this situation range shadows contain useful information), and, (6) as the information content of the input falls the quality of the information from the sonar interpreter ought to degrade gracefully.

An outline [6] of a sonar interpreter is shown in figure 10. While some sensory interpretation systems invoke *a-priori* models and attempt to instantiate them, the approach adopted here is based on the construction of *a-posteriori* models of the structure actually observed. The interpreter is data driven.[12] In this sense, its optical analog is the approach which first detects the "low-level" features and then attempts to build a computational description.

As part of this programme of work we intend to use the chirp sonar subbottom profiling system in conjunction with a well known and established technique from the field of scene reconstruction to automatically extract otherwise

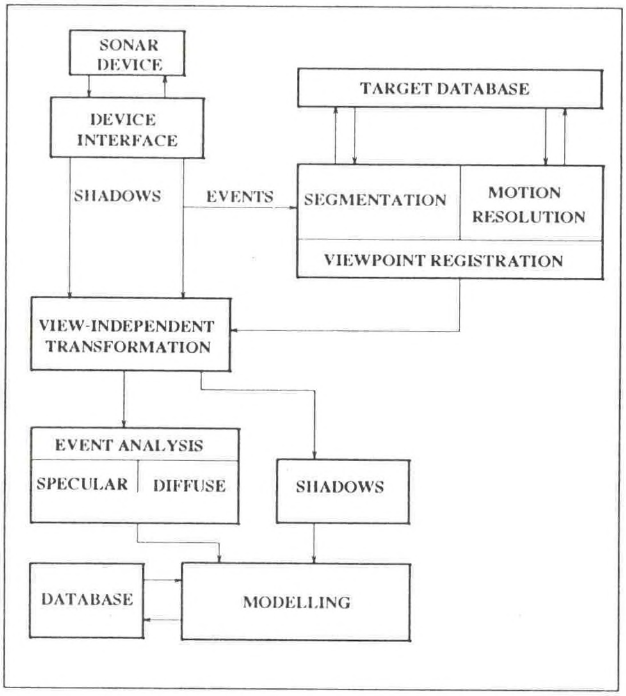

Figure 10: Organisation of a sonar interpreter for underwater robots.

unavailable information about the shape, structure, and composition of the subbottom of the sea-floor.

Use of specular reflections

As Hallam originally pointed out by judicious use of the information available in the specular reflections and the history of the motion of the vehicle, we can classify the specular echo sources and infer the local structure of the objects bearing them. The motivation for using this information is that the properties of the sources are important cues for the map making process. For example, are these observations the result of echoes from a cylinder or a sphere? Thus this information can be used to drive the object modelling activity and, almost certainly, will need to interact with the annotated map processes. Knowledge of the source properties is useful in two main ways, (1) the different source types reflect observer motion in different ways depending on the source topology, and this may be used to construct a correction term for the motion resolution system to account for the source behaviour, and (2) a partial knowledge of the properties of a given source may be used to suggest suitable observer motion strategies for elucidating the information necessary to complete the description of the source.

ANNOTATED MAP SYSTEM

The annotated map system is intended to provide a framework to represent the cartographic information that makes mission planning and guidance easy and fast. In addititon

[10] We are also exploring the conjoint use of geo-magnetic information to augment such a map.

[11] By real-time we mean producing output instructions at a rate sufficient for the task

[12] In later stages we would anticipate directing the attention of the interpreter in certain ways. This assertion is based on the accumulating evidence of the use of "reciprocity" in the perception processes of living sensory-motor systems.

to representing objects and terrain data, there are annotations attached to the objects which consist of descriptions of objects, hints for perception and control, and specifications of actions at particular situations. Tying knowledge in annotations to particular objects and locations in the map will make it possible to pre-plan difficult mission segments and to retrieve this information efficiently during execution. There are two types of access to information: queries and triggers. Queries allow a module to fetch all annotations of a specified type or all objects satisfying a criteria. Triggers are set up during mission pre-planning and, once activated at specific contexts, they deliver an appropriate pre-stored message to wake up a set of sleeping modules or to alert a running module to change its conditions. This framework of annotated maps will enable missions which would not otherwise be possible due to real-time constraints and limits in processing and algorithmic power. Maps also help in vehicle position correction during a mission.

The underwater environment poses new challenges to map representation and processing. Some of the issues are representations of objects in 3-D space, handling of uneven distribution of objects, efficient storage and retrieval of large maps, maintaining consistency during on-line updates of map data, and so on. In many of the missions envisaged the objects could be both physical (eg: rock, sunken barge, or pipe) as well as abstract (eg. salinity, temperature, electro-magnetic or acoustic signals). These could be either natural or man-made and need to be supported by appropriate annotations.

Mapping of a large area necessitates a variable resolution representation of information in order to conserve storage space and to reduce access time. As different modules have to share the map information, there is a need to have a distributed architecture supporting a point-to-point communication. Moreover, providing an interactive user interface to create and edit map knowledge base is an important design aspect.

The proposed design envisages a multiple-level resolution map representation, identification of a set of classes of objects with specific shapes and other related characteristics, and a distributed architecture to integrate the different functional modules. The map knowledge base consists of an object database, a depth information table, and a grid database. The map system supports spatial queries with the help of the grid database in which the positional information of objects is recorded.

OCEAN SCIENCE TASKS

Much has been written about the use of AUVs for science tasks. A torpedo shaped robot-submarine such as this first FAU vehicle, will have a role to play in monitoring the euphotic zone. Amongst the variables of interest are temperature, salinity, dissolved oxygen, flourescence, irradiance, beam transmission, dissolved organic and inorganic carbon, particulate organic carbon, nitrogen, nutrients, phytoplankton, primary production and particulate flux.

We plan to use existing sensors and instrumentation wherever possible. This effort is being pursued in conjunction with input from scientists at the University of South Florida and the University of Hawaii. To gain experience with a real vehicle while Dunn et al are developing the Ocean Voyager we are exploring the possibility of taking advantage of the upcoming availability of a robot-submarine developed at MIT. Our outline plan is to use this smaller, lightweight vehicle to experiment with and then to share algorithms and the lessons learned with the development vehicle, Ocean Voyager.

The seasonal boundary layer has been identified by Woods [23] as being one of the principal subjects for ocean monitoring.[13] The seasonal boundary layer of the ocean is the upper layer mixed vertically in winter by nocturnal convection forced by surface cooling or freezing. The depth of the seasonal boundary layer is less than one hundred metres in the tropics. It increases with latitude. The seasonal boundary layer and the thermocline ventilation must be accurately simulated by climate forecasting models and they must be accurately monitored by a Global Ocean Observing System (GOOS) [23]. The plan is to use the either the Ocean Voyager and/or the MIT Sea Grant vehicle "Odyssey" to measure regions and zones of this thermal boundary. A small scale characterisation of aspects of the gulf stream temperature variations off the Florida coast could be undertaken, for example.

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OCEAN ENGINEERING AT FAU

Ocean Enginering at FAU offered their first course, "An introduction to Oceanography" in 1964. By the Fall of 1965 35 students had registered and in doing so became the first Ocean Engineering department in the world. Moving forward in time to 1986 the Naval Systems Warfare Centre funded a study jointly carried out by FAU (S. Dunn) and CMU (C. Thorpe). A Florida High Technology Industry Council initiative resulted in support of $110,000/yr between 1987-1989. In 1989 Cuschieri in conjunction with Herbert from CMU were awarded an N.S.F grant totalling some $200,000 for work on sonar vision. The Advanced Marine Systems Center in which the AUV development effort takes place was started and is directed by Professor Stanley Dunn. This centre is funded by the State of Florida. This support is over $300,000/yr. This funding started in 1989. Again in 1989 and to complement this support from the State Perry Technologies agreed to jointly fund a programme of development in AUVs. The total amount of that funding was $100,000 from each partner. During the same year FAU and Perry jointly initiated the 1st International Human Powered Submarine Race. This competition held again last year (1991) and attracted 36 entries of which 34 actually competed. The total amount of funding needed for this effort was of order $500,000 much of which was recouped from sponsers. In 1991 Dunn and Ganesan were funded by the N.S.F to investigate annotated maps. This programme is funded to about $100,000/yr. This award "complements" an N.S.F. funded programme into annotated maps awarded to Thorpe at CMU. The chirp sonar programme is currently funded to about $250,000 by the Office of Naval Research.

Annotated Maps for Autonomous Underwater Vehicles *

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Abstract

A futuristic view of the missions that may be accomplished by autonomous underwater vehicles includes oil field monitoring, vent mapping, weather front following, submarine sentry duty, monitoring geological experiments, tracking pipe lines, and so on. These missions are complex and need specific attention to tasks like resource optimization, mission preplanning, intelligent processing of information, and critical on-board decision making. A map-based representation of objects, landmarks, terrain and other features would serve to define the vehicle's environment and provide important information for navigation. Annotated map system is a framework for attaching annotations such as descriptions of objects, hints for perception and control, and commands for various actions. Tying knowledge in annotations to particular objects and locations in the map will make it possible to pre-plan difficult mission segments and to retrieve information efficiently during a mission. The underwater environment poses new challenges to map representation, map creation, and map manipulation. The map system should be able to handle objects in 3-D space and large areas of navigation. This paper describes some complex missions envisaged for AUVs, the need for map-based navigation, and a design approach for a proposed map system.

1 Introduction

Oceans play an important role in various facets of life with its immensely potential resources. Underwater mineral and oil exploration, biological and geological studies in the deep sea, crucial military operations are some of the applications which need an effective navigational system. There is a growing need for higher levels of performance in teleoperated systems with greater degrees of intelligence and for development of autonomous underwater vehicles (AUVs) capable of independent reasoning and action under uncertain conditions. Unsupervised navigation through cluttered environments is a challenging problem for many applications not only in undersea, but also in space, transportation systems, automated manufacturing, and in hazardous environments.

Realization of robust autonomous navigational systems is faced with a number of constraints such as critical response times, non-availability of highly accurate sensors, limited energy resources, and so on. As the vehicle has to act in real-time relative to the task environment, there is only limited time available to assimilate the data collected by sensors or search a complex map before taking desired actions. Highly accurate observations may require more computing resources, more favorable conditions of observation, and prohibitively high costs. In spite of these limitations, navigational aids could be made more effective with the use of added knowledge about the environment. Pre-computed mission-specific information would greatly help in compensating the resource limitations of the vehicles. One promising solution for efficient autonomous navigation is to use annotated maps with descriptions of objects, annotations, and other information.

Usage of maps for navigation is not unconventional. Mobile robots are often supplied with a model of the environment. Annotated maps were

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first used in several mobile robot systems on board the CMU Navlab [TG90]. This system features a distributed database and a single grid database to support geometric queries. Annotations which tie specific information to particular objects and locations in the map is the central design concept. It is also possible to specify activation of triggers at predetermined locations in the map. Different classes of objects include point, line, road, intersection, etc. Maps are built by first driving the robots by hand, recording the location of roads and the location and description of objects along the way.

A schema-based approach to capture patterns in the environment has been reported from University of New Hampshire [TT91]. Schemas are packets of actions that should be performed together in some specified situations. These schemas are aimed at helping an AUV to accomplish its goals and to respond to unpredictable environment during a mission. Hebert [Heb89] has presented algorithms for building maps of road scenes using active sensors and for using the maps to traverse through the roads. Faster and more reliable navigation as well as simpler perception are explained as the major advantages of using maps for navigation.

In this paper we discuss the issues involved in the design of annotated maps for use in AUVs. The underwater environment is very different from the land environment and hence requires specific attention in many aspects of map system design. Also, we describe typical AUV missions that can make use of annotated maps for navigation and related task execution. Development of annotated map system for AUVs was taken up by Advanced Marine Systems Group at Florida Atlantic University in 1991. This effort is part of an integrated scheme for development of hardware and software for intelligent autonomous underwater vehicles [DCG+92].

2 Scenario of AUV Missions

AUVs have long been a vehicle in search of a purpose, partly due to their relatively recent appearance and partly due to a lack of awareness on the part of potential user communities. In the following section we will discuss several missions suitable for existing AUVs. The technology required for these missions is presently available, but few such missions have been carried out. The missions described are in general order of complexity, with the simplest missions first. Although the missions described here are all very different, the architecture proposed in this paper will easily handle their varying measures of complexity, data storage and data handling needs.

2.1 Reconnaissance Surveys

This is the simplest mission in terms of required intelligence. The AUV is expected to travel to a site, perform some form of search pattern, recording the location of discovered objects. Three forms of this mission are possible. 1) The environment is unknown and is to be mapped 2) The environment is known and an object is to be found 3) The environment is unknown and an object is to be found. Data stored will consist of a database containing the sea-floor information, and a collection of objects with attached descriptions. Some of these objects may be abstract, such as way points and hazardous area warnings.

2.2 Submarine Sentry Duty

The AUV is expected to act as a long range convoy picket. As a convoy moves across the ocean, the AUV will alternately sprint ahead, then stop and listen for threats to the convoy. Objects in the database will consist of the separate members of the convoy, and possibly other AUVs also acting as sentries. Data concerning possible targets will need to be quickly analyzed for threat content and transmitted to the surface fleet. Navigation need not be particularly accurate on a global scale but must be accurate on a local scale. The surface fleet will be maneuvering quickly and in close formation, and the AUV must maintain its position relative to them.

2.3 Weather Front Following

While weather fronts in the atmosphere have been studied in great depth, little information has been gathered on their effect on the oceans. Generally, data has only been collected from static monitoring sites. This allows a very brief insight into the structure of the front as it passes the site. More information about the front could be gathered if the monitoring station were able to track the front as it moved across the ocean, gathering both spatial and temporal history data. Gathered data would include salinity and temperature and their gradients. This is necessary to generate a model of the front in order to produce a suitable vehicle track. Waypoints will have to be generated as the vehicle moves and gathers information, these way points can then be inserted in the map, allowing the vehicle to constantly update its planned path.

2.4 Vent Mapping

The AUV will be required to map the chemical and thermal qualities of the water around a deep sea hydrothermal vent . The AUV will be operating for short periods of time between long periods of submerged inactivity. The environment will be particularly hostile, including overhanging obstacles, a non stationary terrain, seismic activity, corrosive chemicals and extreme high temperatures. Navigational data will be received from pre-placed sonar markers. This will be highly accurate and rapidly updated. Sensor data will include information received from a comprehensive science package, and sonar and visual sensors. The map system will store information about vent data, position, activity, threat level and shape.

2.5 Deep Sea Oil Field Monitoring

This mission will be described in some detail, and an example database of object types will be given in Appendix A. Consider an oil field landscape containing a network of pipes, risers and oil rigs (fixed and floating). Water quality and sonar conditions are poor, hence pipe detection is best carried out using magnetic means. Currents will be high and shearing may be present (different velocities and headings of currents at different depths). All these factors mean that position sensing will be very poor and that navigation is best carried out by comparing the vehicles position with positions of known, fixed objects - an ideal mission for map-based navigation. A typical mission will be a general survey of pipelines and seabed installations and the determination of the location of leaking oil or gas. A concurrent mission is monitoring the chemical content of the water. The discovery of a chemical plume would trigger the AUV into a homing routine up the plume to the site of the leak, overriding any current commands. Some of the problems involved with pipe following that must be addressed by the annotated map system, are as follows : pipes can be partly buried, pipelines may cross and pipes will meet and diverge at seabed installations. Another major danger to the AUV are mooring lines for floating structures. These may be very small but pose a significant threat to the vehicle. It is thus important that these are carefully designated in the map and the AUV warned to avoid them, or at least traverse areas containing them with caution.

3 Map-based Vs Sensor-based Navigation

In unknown environments, the only choice is to use sensor-based navigation. Sensors help the vehicle to adapt easily to changing environments. However, there are a number of limitations with sensor-based navigation. First, the limited visibility of sensors puts an upper limit to its range of observation. Computational resources needed to interpret sensor data on-line is another concern. On-board resources of a vehicle may be minimal and it may not be practical to have very accurate, long range sensors. Moreover, there may be many local misleading information which could lead to dead ends or inefficient routes. In some situations, local information collected by the sensors may not be sufficient to take appropriate decisions.

An alternative approach is to use global map and mission-specific data for pre-planning the routes and for supplementing sensor data. Models of environment in the form of maps may provide relevant information to help take critical decisions such as which route to take at a fork in the path without making a costly mistake. Uncertainty associated with sensor data can be lessened to a great extent with the use of maps. Map-based navigation, hence, may be more accurate and reliable. Maps also make the perception simpler by giving hints about possible location or shapes of objects. Position correction of AUVs is extremely complex because of the difficulties in communicating with external agencies like satellites and other stations on land. Maps can aid in estimating the vehicle position by referencing to objects in maps in the context of the observations collected by the sensors.

As information about complete navigational space is available in the maps, it is possible to perform long range path planning and to incorporate task-specific actions much ahead in time. On-line computations can be reduced to a great extent, thus saving precious resources of the vehicles. However, the need for a model of the environment is influenced by the sensor capabilities as well as the nature of the tasks. Accurate knowledge of position and location of obstacles may not be of much importance in an open terrain with simple straight cruising. When the environment becomes cluttered, obstacle salience assumes greater importance in terms of both position estimation as well as safety of the vehicle.

In some situations, knowledge about the environment may be limited or uncertain. Sensors may supply vague information because of hostile surroundings. Annotations help the autonomous vehicle to reason in such situations by matching the map database contents and taking leads from the instructions in the knowledge base. This framework in which sensory data is supplemented with map-based information maximizes the confidence with which navigational decisions can be made and allows complex missions that would not otherwise be possible due to real-time constraints and limits in processing and algorithmic power.

4 System Architecture

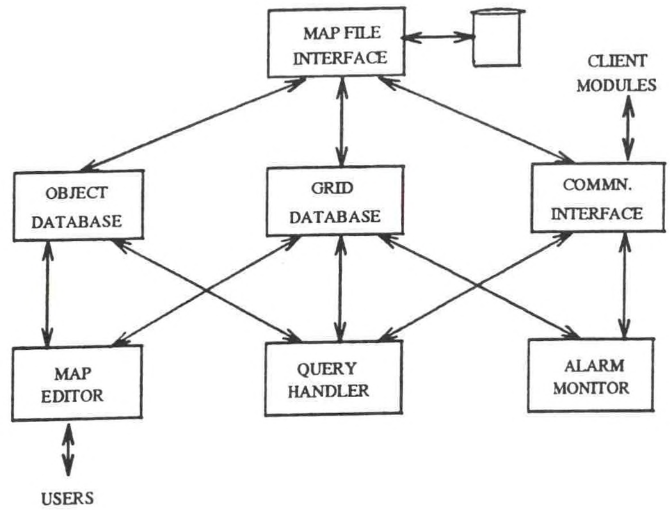

Figure 1: Annotated Maps - System Architecture

The annotated map system is a framework to represent information regarding the environment such as objects, obstacles, and terrain data. In addition to geometrical details of objects, the map knowledge base consists of annotations which may include navigational commands, information to perform other mission tasks such as object recognition or parameter measurement. The information in the packets of annotations facilitate pre-planning of missions reducing time-consuming and costly on-line computations. The idea is analogous to the mental framework we humans normally possess when we drive through familiar roads and surroundings.

In general, annotations can be used to describe objects, provide hints for perception and control, or specify particular actions at specific situations. There are two types of access to information: queries and triggers. Queries allow a module to fetch information on demand returning annotations of the requested type or objects satisfying a criteria. Triggers are set up during mission pre-planning and are activated when a specified condition is met. They deliver an appropriate pre-stored message to wake up a set of sleeping modules or to alert a running module to change its conditions. A block schematics of the architecture of the proposed annotated map system for autonomous underwater vehicles is shown in figure 1.

Object Database which is the heart of the system holds descriptions of objects along with annotations. Grid Database is a mapping of the same information, but organized in geometric-reference fashion typical to conventional geographical maps. Query Handler supports data access queries from the client modules like planner, controller, perceptory modules, and so on. Alarm Monitor constantly keeps track of the vehicle position and checks whether any alarms are crossed and if so, sends triggers to appropriate modules. Details of database structure, queries, and triggers are in the following sections.

Map File Interface handles the read/write operations of map data between main memory and disk. Communication Interface takes care of message formatting and other communication protocols. Map Editor supports creation and modification of map database.

4.1 Object Database

Object Database supports a structure to represent map objects and mechanisms to respond to feature-referenced queries. Detailed descriptions of objects such as shape, physical dimensions, annotation details, and alarm trigger details are held in the object database. Each of the entries in object database may be identified by a unique object ID and an object name. The object description may include a set of annotations related to the particular object. The annotations are treated by the map system as a packet of messages without concern about what they contain or how to interpret them. The map system is intended to just hold the relevant information and to convey the requested details to the client modules.

Annotations can be of various types: commands to initiate certain actions such as "Reduce Speed" or "Turn on Forward Looking Sonar", details on how to read the data, how to perform certain computations on the data, and so on. The client modules are expected decipher the annotations they receive along with other details of the object.

One important consideration in the design of object database is standardization of objects, their shapes and other attributes. In the case of land navigation, road segments, intersections, buildings, trees, etc., may form the set of objects of interest. Since most of these are man-made, it may be relatively easy to enumerate, classify, and standardize. Objects in underwater may be sunken barges, pipe lines, coral fields, reefs, or other artificial objects like transponders, sonar beacons, etc. The sample database given in Appendix A illustrates the set of objects in a typical mission. Some missions such as weather front following or vent mapping may require representation of abstract objects like temperature, salinity, chemical contamination, and so on. A precise definition of such objects is possible only in the context of mission objectives and the specific tasks to be performed.

After careful consideration of underwater navigation, we have identified a set of standard shapes for physical objects such as point, line, rectangular and circular planes, rectangular box, and cylinder which can approximate the actual shapes of most of the underwater objects. The proposed design also supports data structures to represent abstract objects like temperature or salinity. It has been facilitated to store and process various types of object attributes like numeric figures or descriptive texts.

Three generic classes of objects are alarm objects, reference objects, and composite objects. The objects could be in active or passive state and only those objects in the active state participate in queries and triggers. Reference objects are attached with geometric information like shape and location as well as an optional set of annotations. Alarm objects additionally have trigger messages addressed to different modules. Alarms are of two types: one-time triggerable or multiple triggerable. Composite objects describe a collection of component objects. Specifying a composite object is an efficient way to group objects and manipulate them. For example, an oil rig may be described as a collection of a number of parts with different shapes, dimensions, and functions. It can be represented as a composite object while each of its parts may be separately represented in the database. Another example is a pipe line network which is composed of many segments of pipes, T-sections, intersections, meters, and valves.

Organization of the database should take into consideration of the set of operations as well as search and storage space efficiencies. Hierarchical organization of different classes of objects is one desirable approach in terms of improving the data access time. An efficient hashing function to index to the desired entry is another approach. Hashing is a good example of time-space tradeoff which can directly reference to the records in a database by doing arithmetic transformation on keys to generate the address. The database operations like add, delete, modify and retrieve objects can be efficiently supported using a hash table storage organization.

In addition to the notion of free/occupied space, there is an extra dimension of maximum depth in underwater environment. Information about the underwater terrain has to be recorded in order to aid damage-free navigation of AUVs. Our design of map database incorporates a depth information table which would hold depths of water column at discrete points in the navigational space.

4.2 Grid Database

A Grid Database is a mapping of objects into a grid format to facilitate geometric queries. Depending on the desired resolution, the space is divided into discrete blocks and the objects are stored based on their corresponding locations. This is the typical cartographic representation of information used in conventional geographical maps. Objective of this mapping is to support direct access of position-referenced queries eliminating complex computations.

Unlike the situations on land, underwater navigation is in 3-D space and geometric mapping and representation of objects are more complex. While the size of object database is determined by the number of objects it holds, storage requirements of grid database is related to the size of space to be mapped and the desired grid resolution. For example, for an area of 100 * 100 miles and 10 miles deep and if the resolution needed is 0.1 mile, the number of grid blocks required is 1,000,000. It is very obvious to notice that marginal increase in the above dimensions or improvement in resolution raises the storage requirements enormously.

We have to consider two facts about the underwater environment while designing the grid database structure. First, the objects are sparsely distributed and it may be acceptable in many situations to have a $2\frac{1}{2}$-D representation of objects in which objects are positioned in 2-D X-Y plane with an additional depth and object height information. Although, it leads to extra computational time to decide whether space is free or occupied as well as to estimate the location of objects, it is an acceptable alternative especially for underwater environment. Second, the AUVs often need to know in greater detail only about the area in its immediate vicinity. Hence, the notion of a global map having low resolution and local maps with finer resolution is an attractive proposition. The price we pay is the computational resources needed to zoom the area of interest as the vehicle moves. Folding and unfolding of local maps may be carried out in the background and for all practical considerations, the response time will not be affected. Also it should be noted that when the AUV requires finer resolution, it will probably be traveling at lower speeds allowing slower response times

The proposed design envisages a multiple level resolution mapping strategy. The resolution of the global map and the number of levels of finer resolution mapping would depend on the area to be covered, the desired resolution of target site and the available memory. Based on the preliminary studies, we presume that two or three different levels of resolution would suffice for reasonably large areas with good resolution.

4.3 Queries and Triggers

Queries allow a module to fetch information on demand. There are three types of queries: to access object descriptors such as annotations, to get depth information at specific points, or to focus on objects in vicinity. Some typical examples are "give depth at 100, 345" , "give points where depth is 100 feet", " give ids of line objects within a radius of 100 feet", "supply description of object with id 453", and "give id of composite object having a name oil rig".

The above queries require only simple search and match operations. Any query involving complicated computations or multi-level filtering need not be supported as it involves specialized query language. Moreover, such queries may be map-dependent or mission-dependent which may be programmed external to map module. This helps in meeting the design requirements such as simple map operations and query language.

Triggers are special forms of annotations monitored by the map system. These help the vehicle to send specified messages to a set of designated modules. Triggers may be set up during mission preplanning and used to wake up sleeping processes at specified locations or to alert a running module to change its conditions. Triggers eliminate the need for continuous polling of vehicle position. In this way, position tracking is centralized and all needy modules are alerted when a trigger position is reached. If each module were to continuously poll the navigator and controller for current position, the controller could become overloaded. Active polling by all modules consumes a great deal of computing power too.

Trigger messages are often commands to initiate certain actions. A plane alarm near the shore could be used to alert the vehicle to go up when the specified plane is crossed. When a sharp turn is expected, another alarm object placed in appropriate location in the map could alert the controller to reduce the speed of the vehicle. Usage of precious on-board power can be minimized by placing alarms at various points where the sensors like sonars to be turned on and turned off. Alarms can be in active or passive state and the current state of an alarm may be toggled by trigger messages of another set of alarms. Trigger messages for a typical mission can be found in the sample database in Appendix A.

4.4 Communication Interface

There are a number of functional building blocks in autonomous vehicles such as planner, navigator, controller, perceptory control modules, and so on. Many of these modules may be holding the map knowledge base either fully or partially. The intelligence of the system resides to large extent in its ability to provide effective communication between these different modules. The inter-module communication messages may include queries and responses, trigger messages, map data, updates on objects, and so on. Communication between various modules should be based on some standard protocols and message formats. The interface should ideally support asynchronous operation, flexible message formats, and higher level command interface. We plan to use the Efficient Distributed Architectural Tool Kit (EDAT) [JG91] developed at Advanced Marine Systems Group to meet the inter-module communication needs of annotated map system. EDAT is built around the IPC mechanism called sockets in the TCP/IP environment and can be used in heterogeneous hardware and operating system platforms. The tool kit handles higher level queries, commands, and data formats. As the order and timing of arrival of messages from various modules to other modules is non-deterministic in nature, an asynchronous message passing protocol is supported. The inherent reliability of IPC mechanism guarantees that no messages are lost or corrupted. EDAT is expandable in a dynamic fashion to include additional modules as well as to cope with abnormal termination of modules.

4.5 Map Building

Sources of information for building annotated maps include technical publications, human experts. and the on-line data collected during previous missions of the vehicle. If the terrain is unknown or only partially known which is often the case of underwater environments, on-line data gathered by the sensors is the main source of information. Depending on the availability and usage of data, map building can be either off-line or on-line. Maps may be built off-line using unambiguous information from publications, reports, direct human experience and judgement. An interactive interface is required to create and modify descriptions of objects and terrain. We propose to develop a graphical user interface based on X-window system to facilitate user-friendly map creation and editing.

When the map data is input or modified on-line, the data collected by the sensors like sonar or laser are to be analyzed and meaningful interpretations are to be extracted before feeding into the map database. Computational resources needed to perform the data analysis on-line may be prohibitively enormous. One practical alternative is to conduct a couple of exploratory missions to gather data using on-board sensors and process the raw data after the completion of each of the missions. The information thus derived would be useful in navigation and further data collection during subsequent missions.

5 Conclusion

We have justified the need of annotated maps for navigation of AUVs by illustrating specific example missions. The system architecture of the proposed annotated map system was discussed. A sample database for one of the AUV missions is given in Appendix A. Development of annotated map system for AUVs is in progress. We are in the process of identifying the set of objects, annotations, and triggers for specific AUV missions. The annotated map system, once completed, will be integrated into our AUV- OCEAN VOYAGER developed at Advanced Marine Systems Group.

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Appendix A: Sample Database

In this appendix, we describe an imaginary environment based on a typical North Sea field, such as the Argyle field (see Figure 2).

Map Objects

The map objects associated with this layout are :

Wells Wells are complex structures resting on the seabed, they can be approximated by 20 ft. cubes.

Rigs The Rig is the single major structure, floating at the center of the field, it is approximately 300 ft square and extends some 40 ft into the water.

SSM The Subsea Manifold rests on the seabed directly below the rig. It is approximately 40ft across and 20 ft high. It has several bundled pipes extending to the surface.

SBM The Seabed manifold is a smaller version of the SSM, it allows oil to rise to the surface. It is approximately 30 ft across and 20 ft high. It also has a pipeline running to the surface.

Anchors Anchors are large concrete blocks resting on the seabed, they are 20 ft across and rise 10ft from the sea-floor.

Pipelines and Cables Pipelines are defined by a bounding cylinder around them. In the case of cables, a virtual object containing a warning encloses the cable, this will be considerably larger than the cable and indicates a hazardous region.

Virtual Objects Several abstract objects are included in the map, these are used to guide the vehicle around the sea-floor, and can be considered 'signposts' indicating upcoming hazards or actions. These actions could be requests to turn on specific control modules in the vehicle such as pipe following or well locating. Warning lines or planes can specify regions in the environment that are either impassable or to be crossed with caution. The warning lines in the following example are of the latter type, and indicate that the vehicle is about to enter a region containing a cable. This would trigger the AUV into a creeping mode with extra attention being paid to forward looking obstacle avoidance.

Mission Tasks

There are various types of tasks that can be useful for the execution of this particular mission. They are:

Dead Reckon This a fundamental navigation tool. It allows the AUV to execute simple movement commands such as goto(x,y), depth(z), speed(v) etc. In the following mission it is used to traverse a section of open seabed where object following is not possible. Dead Reckoning assumes that the vehicle has accurate position sensing abilities, particularly at the start of the run.

Pipe Following The AUV is assumed to have the pipe within sensor range. This module will determine the direction of the pipeline being followed and issue control commands accordingly. Events such as crossing or buried pipelines will be handled by the insertion of dead reckoning alarms into the map to allow the vehicle to cross problem areas.

Well Location The AUV is required to locate a large metallic object on the sea-floor. Search patterns are not required as the alarms should trigger the AUV into this mode when the wellhead or similar structure is within the sensor range of the vehicle.

Home The AUV heads for its dock. This might include a complex docking algorithm allowing the AUV to autonomously reach the mother ship or rig, or it may surface and then hand over control of the vehicle to a human operator.

Mission description

A vehicle mission is shown in figure 2. Objective of this mission is to travel up to the upper right section of the field, surveying two pipelines. The desired vehicle track (the dotted line) is intersected by several objects. These could be either physical or abstract. The vehicle starts the mission the rig (1) and follows a pipe upto well 24-5. It then navigates across the sea-floor, locates wells 24-3 and 24-13 and then returns to the oil rig. The actions of the vehicle triggered by various alarms placed in the map are given in table A.1.

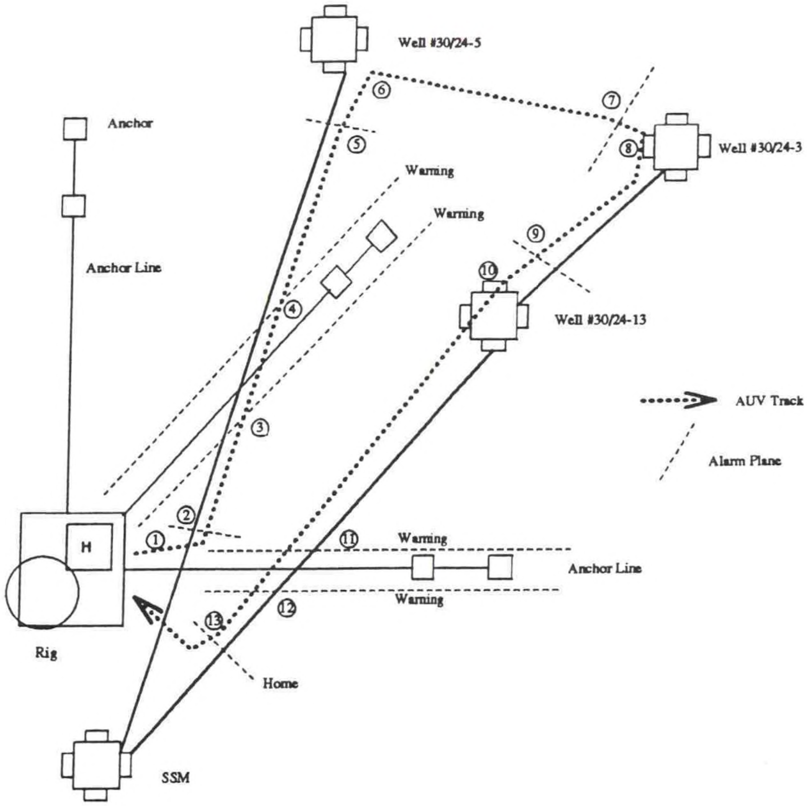

Figure 2: Sample Mission

Number	Alarm Name	Message	Destination	Action
1	Plane Alarm	Goto(start)	Navigator	Dead Reckon to First Waypoint
2	Plane Alarm	Pipe Follow	Navigator	Follow the Pipe
3	Warning Plane	Avoid Cable	Perception	Drive around the Cable
4	Warning Line	Normal Mode	Navigator and Perception	Return to Pipe Following
5	Plane Alarm	Locate Well	Perception	When Well located, actuate Dead Reckoning Alarm
6	Dead Reckoning Alarm	Goto(well 30/24-3)	Navigator	Dead Reckon to next target well
7	Plane Alarm	Locate Well	Perception	When Well located, actuate Pipe Following Alarm
8	Pipe Following Alarm	Pipe Follow	Navigator	Follow the Pipe
9	Plane Alarm	Locate Well	Perception	When Well Located, actuate Pipe Following Alarm
10	Pipe Following Alarm	Pipe Follow	Navigator	Follow the Pipe
11	Cable Alarm	Avoid Cable	Navigator and Perception	Avoid the cable
12	Safe Alarm	Normal Mode	Navigator	Follow the Pipe
13	Home Alarm	Goto(home)	Navigator	Return to the Rig

Table A.1 Alarm Details

Development of an Autonomous Vehicle with a Closed Cycle Diesel Engine

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1. INTRODUCTION

Ocean ridges where lithospheric plates are being produced, fascinate geologists, biologists and engineers. While dynamic structures in seafloor are being investigated successfully by utilizing manned submersibles and remotely operated vehicles, an unmanned and long endurance system is expected for scientific and marine engineering survey of the wide area of seafloor. Many projects are currently promoted to construct prototypes of vehicles which can dive freely in a deep sea[Ref.1]. In 1990, the University of Tokyo and Mitsui Engineering & Shipbuilding Co.Ltd. jointly started a project for "Development of autonomous underwater robots for survey of mid-ocean ridges", in short the "R1 Project" [Ref.14]. This paper introduces the outline of the R1 project and details of an Air Independent Power (AIP) system for the robot.

2. R1 PROJECT

The target of the R1 Project is to build an autonomous underwater free swimming vehicle called the "R1 robot", which can survey a wide area of ridges by measuring seawater temperature and other characteristics in the vicinity of the seafloor. It is expected to make detailed research when abnormalities in temperature etc. are detected. To perform this mission, the robot must swim freely for many hours without restriction of a troublesome umbilical cable. Accordingly, high autonomy and a high density power source are required.

The schedule of the project is divided into two stages. During the first stage, which is a 6-year plan and started in 1990, the possibility of operating a vehicle equipped with a closed cycle engine is emphasized. The target is to construct a prototype R1 robot(which will be called the R1 in the following), whose operating depth is 400m with 24-hour duration. The R1 will be launched in 1995.

In the second stage of a 3-year plan, a practical R1 robot which dives to the depth of 3,000m and surveys the mid-ocean ridges, will be constructed on the basis of the technology from the first stage.

3. ROBOT DESIGN

The conceptual drawing of the R1 is shown in Fig.3-1 and the principal particulars are as follows:

Overall Length	: 7 m	Hull Diameter	: 1 m
Weight in Air	: 5.6 ton	Operating Depth	: 400 m
Max. Cruising Speed	: 3.6 knots	Duration	: 24 hours

The internal part of the hull is divided into a closed cycle engine power section and a control section. A payload for the mission is included in the latter. Two vertical thrusters are fitted in the fore and aft part.

4. POWER SYSTEM

4.1 Requirements for underwater power system

General requirements for AIP as an underwater power generation systems are as follows.

1) Safety, and reliability
2) Compactness, light weight
3) Easy operation, i.e. simplicity
4) Good response to load change
5) Low noise and vibration
6) Cost-efficiency

No power system can, however, satisfy these requirements perfectly. It is necessary to find a suitable point of compromise according to the purpose of application. Therefore, the resultant options may vary according to the terms which should be emphasized.

The essential features of the R1 robot are deep diving depth, autonomy and 24-hour endurance. When endurance is long, 2) and 3) of the above requirements are not achievable with conventional batteries due to their fundamental limitations of energy storage, power density, and cost as shown in Fig.4-1. The most likely AIP candidates, at present, appear to be thermal engines based on fuel cells, the Stirling and the diesel.

While fuel cells offer high thermal efficiency in excess of 50% and possibly up to 75% including waste heat recovery, they regrettably require more research and development to be used as AIPs, especially with respect to fuel and safety[Ref.2].

A few types of Stirling engine are now under development by Kockums Marine AB as AIPs[Refs.3,4], and are appealing as far as noise reduction is concerned. The present status of Stirling engines, however, is that they need more development to overcome lack of reliability .

From the point of view of noise performance, diesel engines may be considered as relatively inferior to the other systems. It was shown, however, noise can be reduced to an acceptable level by using flexible mounts and acoustic enclosures. On the other hand, reliability, controllability and thermal efficiency of diesel engines are superior than the other systems. Especially, the diesel engine has acquired high reliability through long history, which is essential for the power system of AUVs. It was concluded that the Closed Cycle Diesel Engine (CCDE) is the most suitable and the shortest way to a practical AIP system for the R1, which should be constructed in few years.

4.2 Design requirement for CCDE as an AIP for the R1

4.2.1 Basic principle of the CCDE

Fig.4-2 shows the basic principle of the CCDE system. For underwater operation, the exhaust outlet is connected to the inlet of the engine passing through exhaust gas processing units, in which exhaust gas is cooled down and combustion products are removed. Then the remainder is recirculated to the engine as synthetic atmosphere after mixing with replenishment oxygen.

The combustion products of hydrocarbon fuel are mainly carbon dioxide(CO_2), water vapor, and soot. The water vapor in the exhaust can be removed easily by condensing with the cooler, and the soot also can be considerably reduced by slight increase of the oxygen concentration in recirculated gas at the engine inlet. Since disposal of the remaining carbon dioxide is more complicated, the CCDE system is mainly characterized by what kind of disposal method of carbon dioxide is adopted[Refs.5-9].

4.2.2 Selection of the closed cycle system

As the R1 robot aims for 3000m in diving depth and 24 hours endurance, the CCDE system must meet the following requirements.

1) Depth independence
2) Compactness
3) No buoyancy control i.e. no change of weight nor the center of gravity
4) High overall efficiency i.e. high power density

The "CO_2 absorption by chemical solution with the non-regenerative absorbent" exhaust gas processing method was chosen on thorough theoretical and practical investigation including glass apparatus test. Potassium hydroxide (KOH) was employed as absorbent, because of its superiority in absorptive capacity and its high absorption rate.

Introducing this closed cycle system, a diesel engine can operate fully independently of its surroundings. Then the diving depth is only dependent on the strength of the pressure hull and no weight change occurs through operation. Moreover, as the absorbent removes CO_2 which deteriorates the engine performance due to its lower gas index value[Ref.9] selectively, the working fluid for the engine can be almost the same constituent as of atmospheric air (nitrogen/oxygen). It should be emphasized that the commercially available engine can run according to the original design conditions and maintain its performance at the same levels as per usual in an air aspirated operation.

4.3 CCDE test plant [Ref.13]

4.3.1 Configuration

Fig.4-3 shows a schematic diagram of the CCDE system for the R1. The exhaust gas from the engine is cooled down with an indirect cooler in which the water vapor resulting from the combustion is condensed and drained by a neighboring mist separator. The cooled gas, then, flows into an absorber where CO_2 is removed by direct contact with the absorbent. The effluent exhaust gas, of which the temperature is raised by the heat of chemical reaction, is cooled down again and the condensed water is returned to the absorber. Then, the gas is recirculated to the engine after mixing with oxygen replenished at an appropriate rate to sustain the combustion.

A YANMAR AG20s-2 diesel generator set of 16kW/1800rpm nominal output with a 4TN84L-RDG direct injection engine was selected for a test plant. The power output of the engine is about twice the estimated value for the R1. The test plant is composed of four major units, namely a power generation unit, an exhaust gas cooling unit, a CO_2 absorbing unit and a liquefied oxygen tank. These units are integrated into circular frames with a diameter of 900 mm as shown in Fig.4-4. A conventional small cryogenic liquefied oxygen tank is placed outside. Normal diesel oil is used as fuel.

4.3.2 CO_2 absorption system

The main feature of the absorption system is the adoption of a simple bubbling method with a specific bubbler which is installed in an absorbent tank. Since this system does not include any active control of both the exhaust gas and the absorbent condition in order to follow the load change, auxiliary power and space saving, and constructional and operational simplicity can be achieved.

4.3.3 Oxygen control system

Considering the storage density and cost, liquefied oxygen (LOX) has been chosen as oxidant. After vaporized in a heat exchanger with ambient gas in the engine capsule, oxygen gas is supplied to the recirculated exhaust gas. The oxygen replenishment control loop involves an oxygen sensor, an electronic flow-control valve and a one-loop programmable digital controller as shown in Fig.4-5. The oxygen replenishment for the recirculation gas is regulated to keep the oxygen concentration constant at the engine inlet. This is a very simple loop and easy to control. The same system had been examined and confirmed its usefulness and reliability with a larger type of CCDE system[Ref.9].

The oxygen sensor is a newly developed zirconium oxide cell type (time constant 1 sec). Since this sensor adopts both the voltage generating cell method and the electrochemical pumping method, it is not necessary to use reference air, which is indispensable to the former types of oxygen sensor [Ref.10].

4.4 Test results

The closed cycle tests were conducted at constant speed of 1800 rpm with maximum electric output of 14kw (100% load). KOH solution, at 48% concentration by mass, was chosen as the absorbent based on the glass apparatus test result.

4.4.1 Steady state performance

Fig.4-6 shows the engine performance of open cycle (i.e. air aspiration) and closed cycle modes. The closed cycle mode test was conducted with oxygen concentration of 27 vol% at engine inlet in order to reduce the soot in exhaust gas. Concentration of CO_2 at engine inlet was a little less than 1 vol% in each load. At engine outlet, it was about 1 vol% higher than that of open cycle mode. These values gradually increased as the accumulative reaction proceeded, keeping the balance between the value at engine inlet and outlet. Fuel consumption was maintained at the same value of the open cycle mode, while CO_2 concentration at engine inlet was permitted to increase to 10 vol%. Total absorptive capacity of stowage absorbent was about 97% of theoretical reaction to carbonate. Consequently, it was confirmed that the absorbing unit of this type performed adequately.

Since pressure, temperature and flowrate conditions of the engine intake gas were maintained approximately at the same levels of the open cycle mode, the engine in closed cycle mode can be operated almost in the same manner as in the air aspiration mode. It can be concluded, therefore, that reliability and durability of the engine is satisfactory as in the open cycle mode.

The exhaust gas cooling system and the water separation system worked satisfactorily under all operating conditions.

4.4.2 Transient performance

(1) Load change

A commercially available natural aspiration engine was adopted. The engine speed is regulated by an electronic governor with quick and precise response, then it hardly changes even during large load swing. This means that flowrate of the recirculation gas is almost constant under all loading conditions ranging from 0 to 100%. In addition, as mentioned above, the CO_2 absorber of this CCDE system absorbs all the incoming CO_2 without control at any load. Consequently, the transient performance of the CCDE is dependent mainly on the response of the oxygen control system.

In the most severe load change from 0% to 100% in a period of approximately 5 sec, the change of oxygen concentration at engine inlet begins about 6 sec after the initiation of the load change. This delay corresponds exactly to the time required for the exhaust gas to recirculate to the oxygen sensor. The maximum transient deviation in oxygen concentration is less than 3 vol% down, and of intake gas pressure is about 25 mmHg down. Within 50 sec, they are restored to the demanded value of 27 vol% and normal pressure level respectively. The engine speed falls within 1.5% and restores to the rated speed at the end of load change. In a reverse load change test from 100% to 0%, almost the same transient behavior of reverse deviation is observed.

(2) Start-up sequence

The start-up sequence is fully controlled by a main computer using the control loop shown in Fig.4-5. The oxygen is not supplied until the engine is cranked and runs up to 200 rpm by a starting motor. Then, diesel fuel is injected after the oxygen concentration becomes the set point (22 vol%) under the usual P+I control. When the fuel ignites and the engine runs up to 1200 rpm, the engine is regarded as having established start-up. Then, the starting motor is cut off and the engine speed is automatically controlled to the rated speed of 1800 rpm when the engine state meets the conditions i.e. the lubrication oil temperature rose to a set value or 1 minute passed. Here, the start-up sequence is completed. After that time, the CCDE system is controlled under the normal operation control mode.

Fig.4-7 shows an example of the auto start-up sequence in closed cycle mode. Oxygen concentration falls initially following the cranking since the remaining exhaust gas in the pipeline of the last operation is aspirated at first, and the oxygen replenishment is insufficient when the control valve begins to open. Therefore, the oxygen concentration at this period changes in various ways according to the conditions of the last operation. After that, the oxygen concentration increases quickly up to 30 vol%, then settles down to the demand value of 27 vol% taking about 30sec. The engine speed overshoots to about 2000 rpm after the fuel ignites, then quickly settles down to 1200 rpm. It should be noted that 30 vol% in oxygen concentration is never critical in such a short period.

On the basis of these results, it is concluded that neither precise timing in start-up sequence nor strict control of oxygen concentration level are necessary in transient and steady state operations.

4.4.3 Vibration and noise isolation

While the diesel is relatively noisy compared with other thermal engines, it is said that the noise level of air conditioning compressors in common use on board a normal submarine have a source level of about 10 dB less than a small diesel engine[Ref.11].

The engine noise falls about 10 dB simply by switching over the open mode to the closed cycle mode. It mainly depends on that the emitted noise created by air aspiration and exhaust disappears. This kind of air-borne noise can be attenuated by using acoustic enclosures including the use of a pressure hull. This measure is easy for the CCDE because the system is originally independent of its environment. Solid-borne noise, due to vibration, which transmits low frequency sound to the hull, can be decreased by about 40 dB by fitting an air spring support system. On the basis of vibro and noise isolation test, it is concluded that noise emission can be reduced to an acceptable level by using flexible mounts and acoustic enclosures with appropriate design.

4.5 Prototype CCDE for the R1

The design and construction of a prototype CCDE system has been started based on the test results from the test plant, and the submerged test is scheduled in 1992.

Fig.4-8 shows a engine and exhaust gas cooling unit for the R1, a diesel generator with 7kW rating is employed. A general arrangement plan of the system which is installed in a capsule of 0.9m in diameter and 3m in length is shown in Fig.4-9.

5. Conclusion

A test plant of the Closed Cycle Diesel Engine system was constructed equipped with a chemical absorber for CO_2 removal from exhaust gas using non-regenerative absorbent. Through various kind of tests, it was confirmed that the CCDE is a suitable air independent power source for autonomous underwater vehicle. The R1, which is a cruising type AUV installed with a 7 kW diesel generator, will be launched in 1995.

Acknowledgment

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Prof. Hisashi Ishitani's Lab: Faculty of Engineering, Univ. of Tokyo,
Prof. Keiji Kawachi's Lab: Faculty of Engineering, Univ. of Tokyo,
Prof. Tomoyoshi Takeuchi's Lab: University of Electrico-Communications,
Prof. Hiromi Fujimoto's Lab: Ocean Research Institute, Univ. of Tokyo,
Prof. Tsuneo Yoshiki's Lab: Institute of Industrial Science, Univ. of Tokyo

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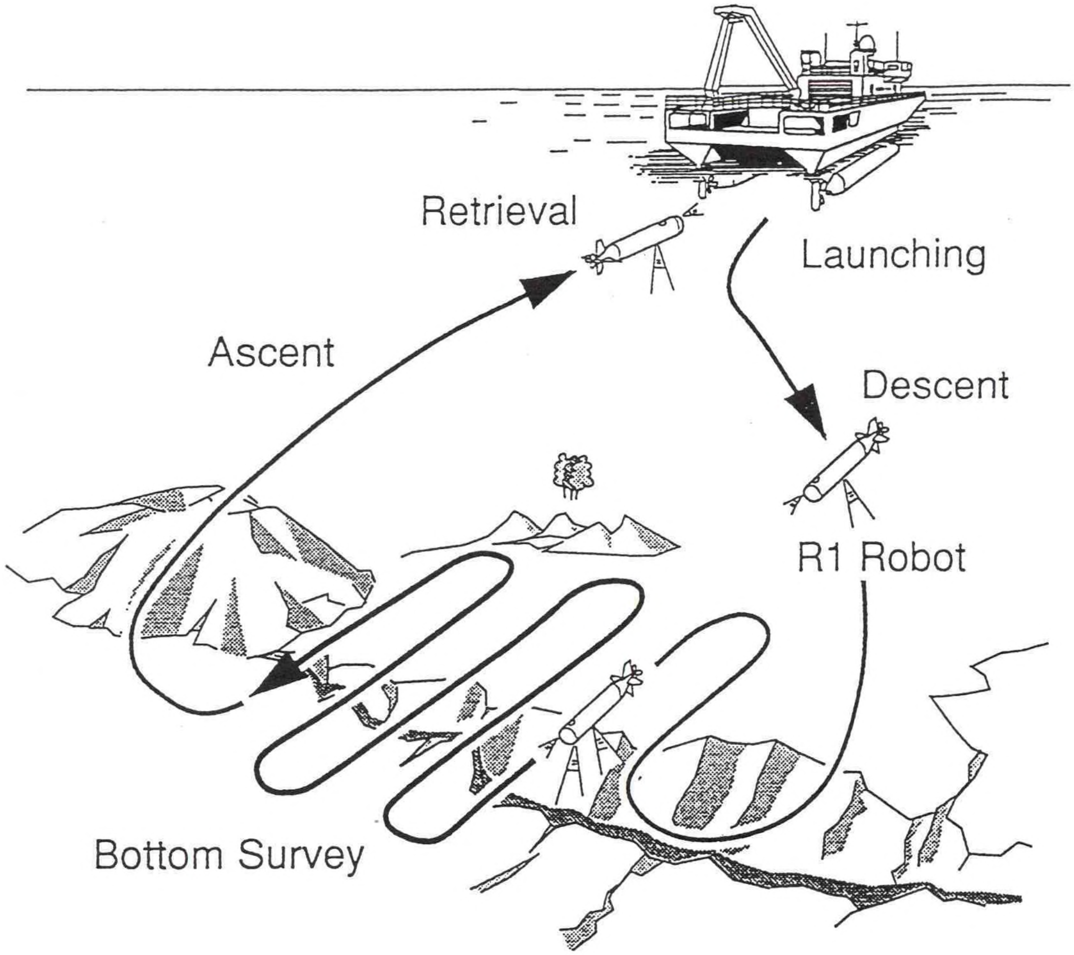

Fig.2-1 R1 in mission

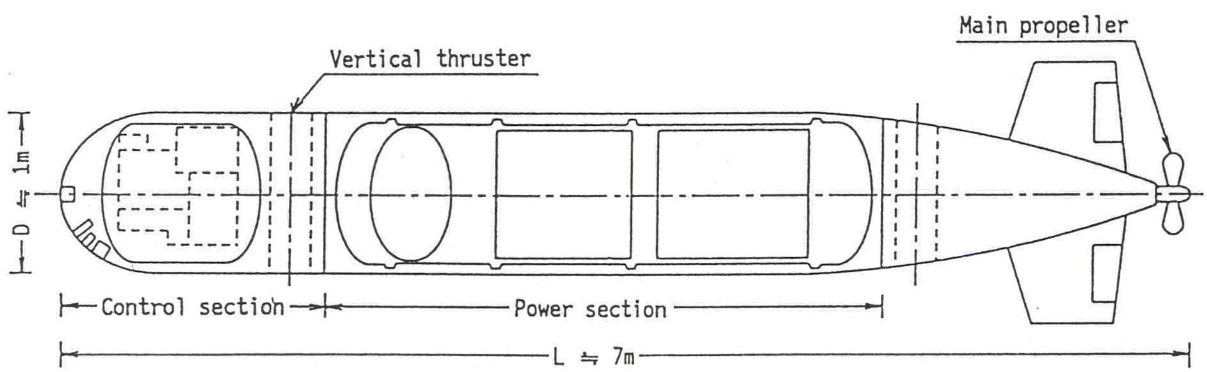

Fig.3-1 Conceptual drawing of the R1 robot

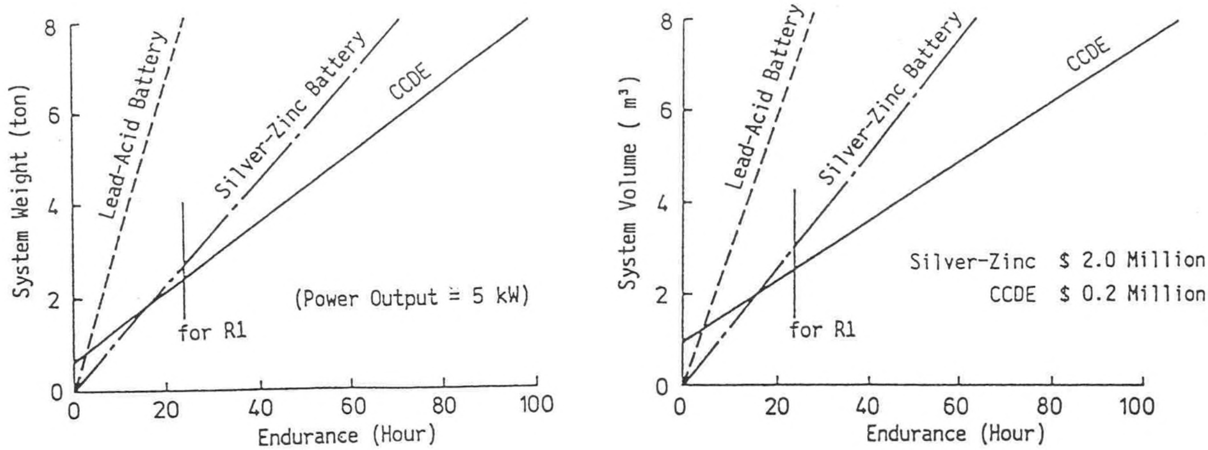

Fig.4-1 Comparison of Batteries and the CCDE

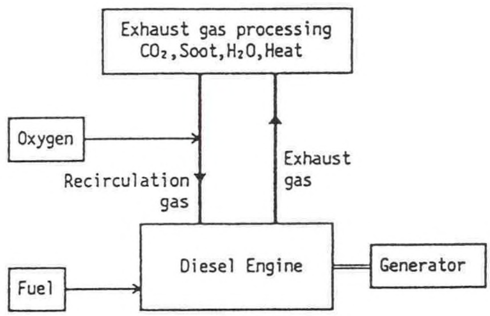

Fig.4-2 Principle of the CCDE

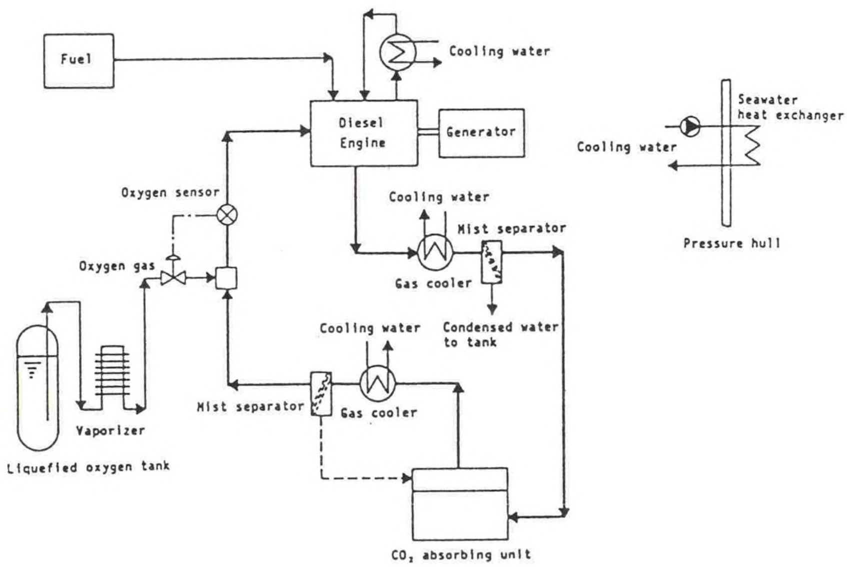

Fig.4-3 Schematic diagram of constructed CCDE

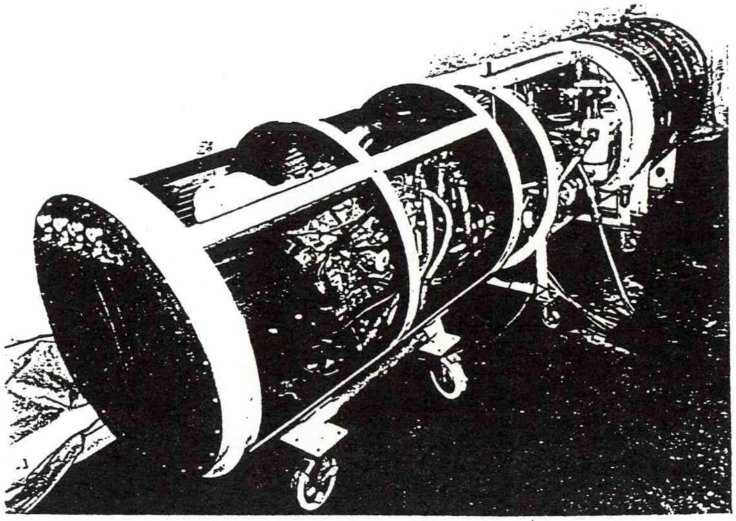

Fig.4-4 CCDE test plant

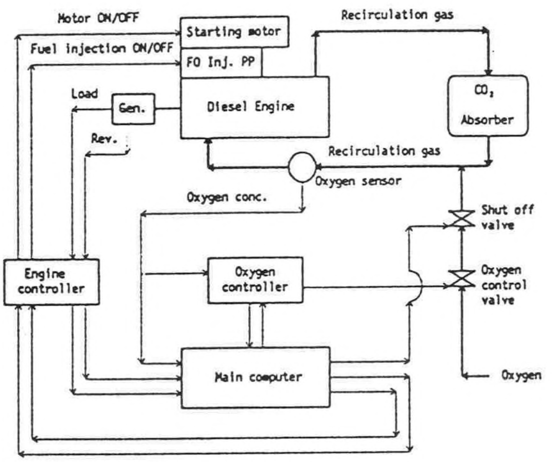

Fig.4-5 CCDE control system

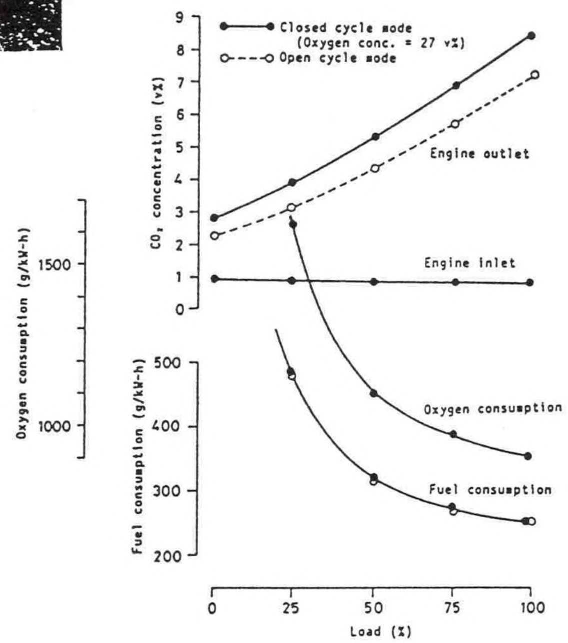

Fig.4-6 Engine performance of the CCDE

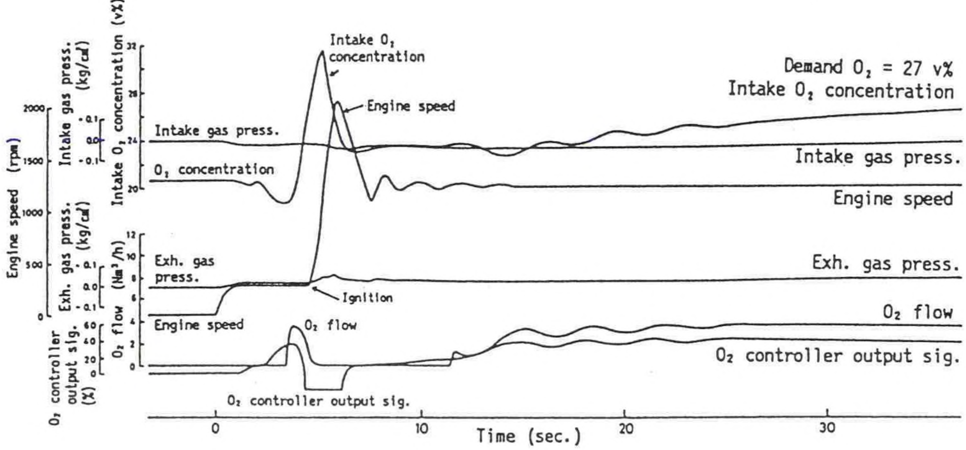

Fig.4-7 Start-up sequence in closed cycle mode

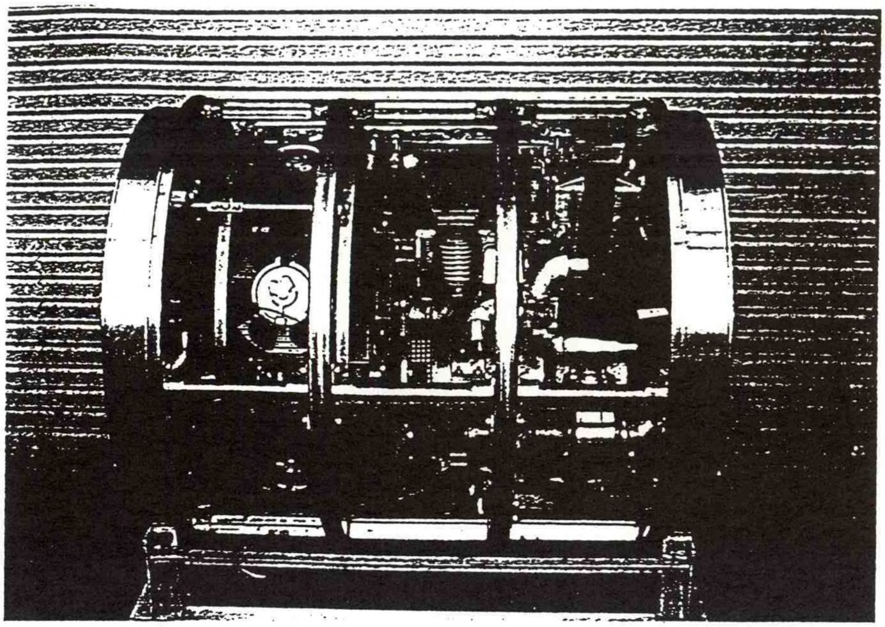

Fig.4-8 Prototype engine and cooling unit for R1

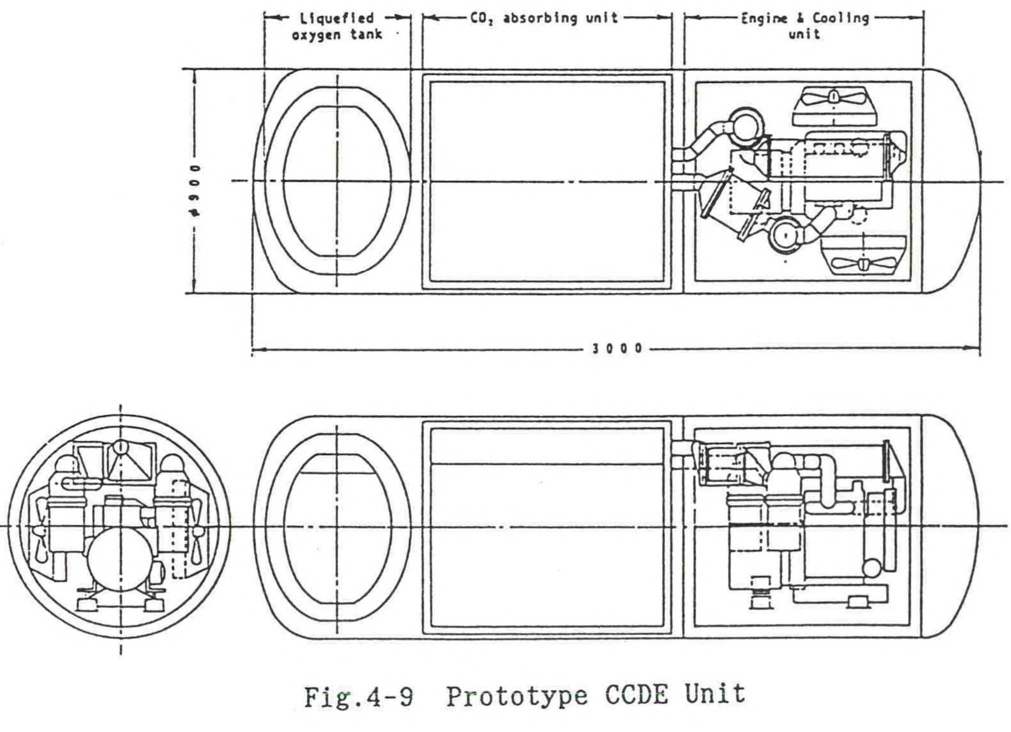

Fig.4-9 Prototype CCDE Unit

DEVELOPMENT OF DEXTROUS MANIPULATORS WITH TELEPRESENCE AT NRaD

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ABSTRACT

The efforts of the NAVAL COMMAND, CONTROL AND OCEAN SURVEILLANCE CENTER, RDT&E DIVISION (NRaD), [formerly NAVAL OCEAN SYSTEMS CENTER (NOSC)] over the past twenty-five years to define, develop, test, and evaluate dextrous manipulator systems with telepresence are summarized. The accomplishments, lessons learned, and recommendations for future manipulator systems are presented.

INTRODUCTION

The Advanced Systems Division of NRaD's Hawaii Detachment has had a long-standing commitment to the development of dextrous manipulators with telepresence. The long-term objective is to develop the technologies required to build remote work systems that can function equivalently as a human diver in performing unstructured undersea tasks. Such a system would not be constrained by the operational limitations of divers in hazardous areas, great ocean depths, cold temperatures, and operating time while submerged. While providing such dextrous manipulative capability, the system would also provide a high degree of telepresence, the feeling by the operator that he/she is at the remote site performing the task.

A major step has been taken toward the development of a dextrous manipulator with telepresence with the Concept Verification Model (CVM) developed under the TeleOperator/telePresence System (TOPS) program (Figure 1). The emphasis of the project is on developing the capability for remotely performing tasks that require the dextrous, adaptive, and judgmental capabilities of man rather than on performing precise, well-defined tasks that can be addressed by purely robotic systems or specialized tools.

BACKGROUND

Over a span of two and a half decades, the Advanced Systems Division has developed manned undersea vehicles; unmanned, undersea remotely operated vehicles (ROVs); remotely operated, unmanned ground vehicles (UGVs); and teleoperated manipulator systems.[1,2,3]

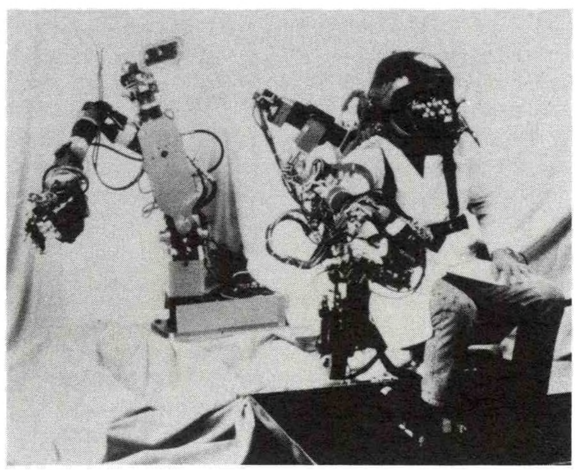

Figure 1. TOPS CVM

During its development of the manned submersibles, NRaD laid the groundwork for its basic philosophy for telerobotic systems; i.e., the telerobotic system should allow full, natural perception of the environment and work space. In developing an acrylic, transparent hull submersible that placed the operator within a "bubble" offering panoramic viewing, NRaD departed from the typical manned submersible porthole viewing configuration. This system provided its operators with an excellent view of the work tasks and the environment, which allowed them to perform undersea tasks such as search, observation, inspection, and manipulation more effectively. However, size, safety, operating time, operational costs, and other operational issues led NRaD to pursue unmanned, remotely operated undersea vehicle systems as replacements for manned submersibles.

Teleoperator Systems Development at NRaD

The Remote Unmanned Work System (RUWS) was developed at the Hawaii Laboratory in the early '70s as a 20,000-foot operating depth, remotely operated undersea work system (Figure 2). The RUWS remote vehicle was equipped with a 7 degree of freedom (DOF) manipulator, a 4-DOF grabber, and a basic set of hydraulic tools for use by the manipulator.

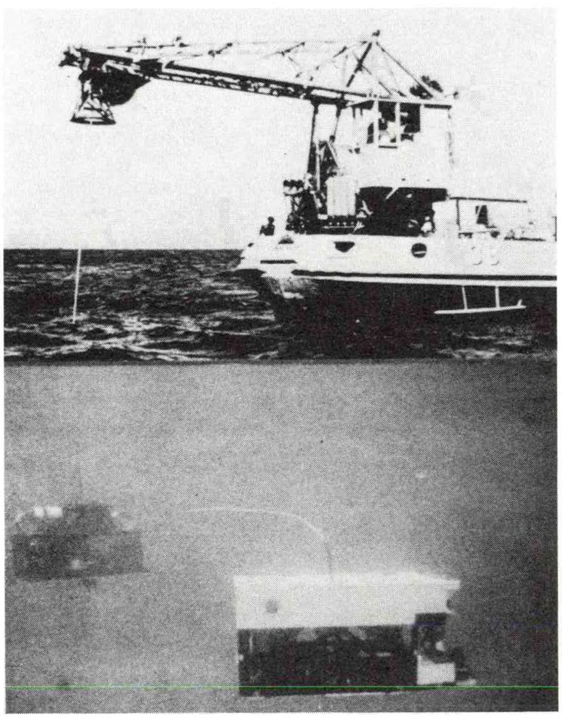

Figure 2. RUWS.

During the development of RUWS and several other ROVs, test operations were conducted in recovery, inspection, and emplacement tasks (Figure 3). The "lessons learned" from those operations provided impetus to the TOPS program. Although hydraulic tools were available for use by the RUWS manipulator, additional special tools were often required (Figure 4) to allow for limitations in the manipulator. During several operations, the tools had to be modified or new tools fabricated because the task was not as anticipated. Although pre-operations planning had been done and special configurations were implemented for the vehicle, few missions were completed without difficulty because of limited work system mobility at the work site and limitations in manipulator capability.

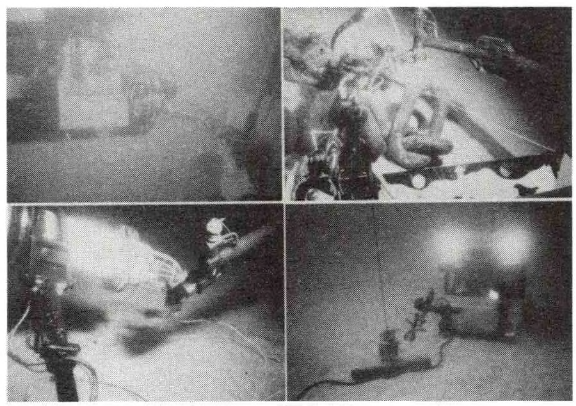

Figure 3. Manipulator work.

Tasks that are simple for a diver, such as putting a snap hook onto a shackle, proved to be difficult because of limitations in manipulator dexterity and vehicle mobility. For example, if currents were present, the object to be worked on had to be approached with the vehicle heading into the current. This frequently resulted in a task orientation that was less than ideal for the manipulator. Maneuvering the vehicle for proper positioning usually resulted in agitation of the bottom sediment, which greatly reduced the remote operator's visibility. Conditions such as those for each mission seemed to provide unique challenges to the operators even when the missions consisted of fairly simple tasks. The operators were often more frustrated than fatigued in attempting to complete the tasks for a successful mission. Tasks that could easily be performed by divers were not at all trivial for the ROV work system. In order to provide the work capability needed for many undersea missions, a work system should have equivalent capabilities to a diver.

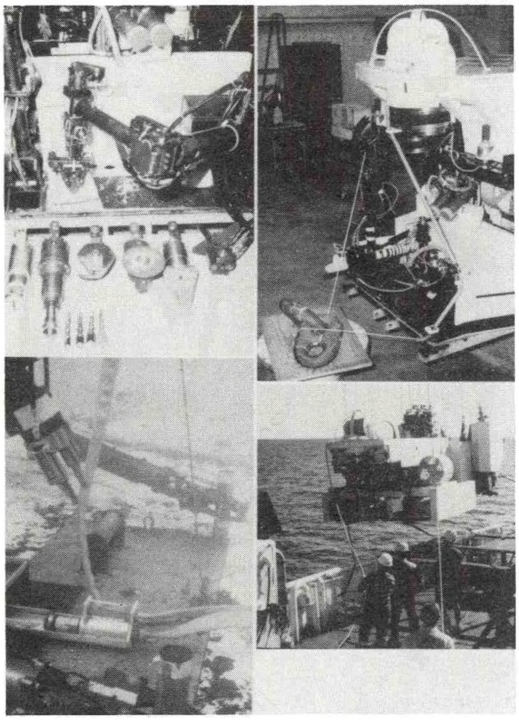

Figure 4. Vehicle configuration.

Diver Tasks

An assessment of tasks performed by Navy and civilian divers determined: (1) the importance of various tasks within dive missions, e.g., threading lines through structures and mating fasteners; (2) the manipulative and sensing capabilities used by divers to perform various missions; and (3) the key design parameters for the development of a diver-equivalent manipulator system.

In determining the importance of various tasks within dive missions, it became clear that the major differences between what divers could do and what could be done with manipulators were that divers could perform a series of complex functions and adapt to differing situations to successfully complete a mission. Maneuverability, dexterity, and full sensory capability were key to the adaptability and versatility required to successfully complete the variety of tasks within the missions.

In determining the key design parameters for a diver-equivalent manipulator system, it became evident that the configuration that would best allow the operator/manipulator system to approach diver capability would be an anthropomorphically-configured, master slave manipulator with bilateral force feedback. A manipulator system with joints and links that match those of the operator (kinematic equivalent) and with all manipulative appendages and sensory systems in the same relative positioning (spatial correspondence) as the operator's appendages and sensory systems would allow the operator to perform the tasks as if he/she were present at the work site.

A system having spatial correspondence between the slave and the operator allows the operator to draw on his/her experiences and reflexes. If spatial correspondence is lost, operators can adjust, but performance is reduced. The loss in performance shows up in objective measures such as additional training required to attain proficiency, higher error rates, longer times to complete tasks, as well as increased mental and muscular fatigue by operators.[4]

Anthropomorphic Manipulator Development

The first anthropomorphic (having a human-like configuration) manipulator developed at NRaD was the Remote Presence Demonstration System[1,2] (nicknamed "Greenman") (Figure 5). It was assembled in 1983 using MB Associates arms and an NRaD-developed torso and head. It had an exoskeletal master controller having kinematic equivalency and spatial correspondence in the torso, arms, and head. Its vision system consisted of two 525-line video cameras each having a 35° field of view and video camera eyepiece monitors mounted in an aviator's helmet.

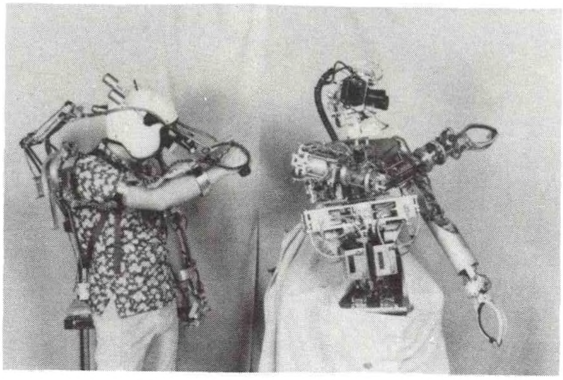

Figure 5. Remote Presence Demonstration System.

Greenman provided NRaD with valuable experience in teleoperation and telepresence issues and designs. Even though it had simple claw hands and no force or tactile feedback, novice operators could readily use it without training to perform manipulative tasks. However, it clearly showed that dextrous hands, force feedback, and high-resolution vision were necessary to achieve diver-equivalent work capability. Also, the Greenman was not designed for in-water use, and demonstrations of in-water operations were deemed necessary to fully demonstrate the diver-equivalent concept.

TOPS PROGRAM DEVELOPMENT

TOPS Long-Term Concept

The long-term concept for a diver-equivalent manipulator system is shown in Figure 6. The master controller "fits" the operator like a business suit and senses his/her hand, body, and head motions. The slave manipulator mimics the operator's motions, senses its interaction with the environment, and provides sensory feedback to the operator via the master controller in a manner natural to him/her.

Figure 6. TOPS Concept.

An assessment was conducted of available, near-term, and long-term technologies in planning for the development of the first TOPS model to verify the concept. Because the first model was to be a 3-year project only, long-term technologies were not included in the project scope.

Long-term technologies identified for future TOPS systems were: (1) tactile telepresence systems, (2) high-definition TV (HDTV), (3) human equivalent dextrous hands, (4) the integration of virtual reality with the vision system, (5) advanced manipulator controllers, and (6) passive sonar for underwater directional hearing .

TOPS CVM

The first model of TOPS was called the Concept Verification Model (CVM). This model incorporated available and near-term teleoperation and telepresence technologies including (1) a dextrous hand, (2) high-fidelity force feedback, (3) high-resolution, head-coupled vision, and (4) an integrated, natural master controller with spatial correspondence. The primary technological thrust was in the development of the two major subsystems: (1) the manipulator and (2) the vision system.

TOPS CVM Manipulator Development

The development of the TOPS CVM manipulator was contracted to Sarcos, Inc. and the Center for Engineering Design at the University of Utah. The manipulator was developed in three phases. The hand was developed in the first phase; the arm was developed and then integrated with a revised hand in the second phase; and the torso and head were developed and integrated in the third phase. The supporting control system was developed throughout all phases.

In the first phase, the hand development consisted of finger, hand, and wrist design concepts; tendon, actuator, and valve evaluation and development; sensor and supporting structure development; and antagonistic (pull-pull) servo control system development. A brassboard, 9-degree-of-freedom (DOF) hand was developed incorporating a 4-DOF thumb, a 3-DOF index finger, and a 2-DOF middle finger (Figure 7). The hand was attached to a 3-DOF wrist incorporating coincidental axes. The exoskeletal hand master represented a major design breakthrough where the structure fit on the backside of the hand but had virtual joints with pivot centers coincident with the operator's finger joints. The brassboard hand was demonstrated at the end of the first phase (1 year). Demonstrations showed that the hand had the capability to perform standard hand grasps and manipulate various objects (such as threading a #10 nut onto a stud, and grasping and using standard hand tools), and showed high-sensitivity force feedback with high intersystem stiffness.

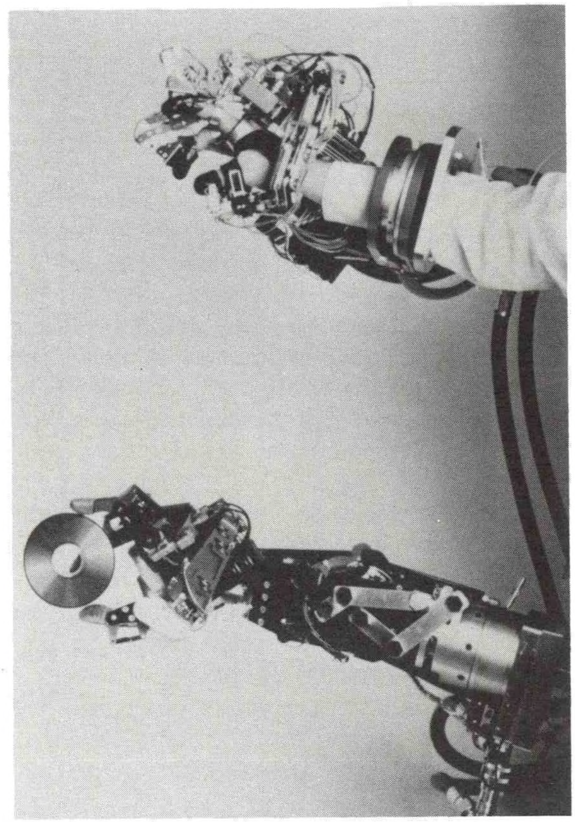

Figure 7. TOPS CVM brassboard hand.

In the second phase, the hand was revised while the arm was developed, then the arm and hand were integrated; low-friction rotary actuators were developed; and development of high-performance servo system components and controllers was continued. The arm was designed with a 3-DOF shoulder and 1-DOF elbow. The 3-DOF shoulder was designed to allow forearm/elbow orientations for various work task requirements. The exoskeletal arm master allowed full, natural operator control of the slave manipulator.

In the third phase, the torso and head were developed; and subsystem and component development of valves, actuators, tendons, sensors, and hand designs were continued. All subsystems were then integrated and the system was tested in water. The 3-DOF torso was developed to provide a natural, short-range mobility and repositioning capability for the arm and head. The 3-DOF head was developed to provide natural, spatially correspondent visual positioning capability. Force feedback was not incorporated in either the torso or the head.

TOPS CVM Vision

The development of the vision system capitalized on efforts by Armstrong Aerospace Medical Research Laboratory (AAMRL) on developing helmet mounted display (HMD) systems for the US Army's Light Helicopter, Experimental (LHX) program. After evaluating prototype HMDs developed for the LHX, a "pancake window" HMD configuration was selected for TOPS. A contract was awarded for an HMD to Technology Innovations Group (TIG) of New York. The HMD included a pair of 1023-line, monochrome CRTs with 68° field of view optics (approximately the same view as from a diver's mask); air cooling for comfort; and a "clamshell" rear-hinged section to make it easy to put the helmet on and take it off (Figure 8).

The remote portion of the vision system consisted of a pair of 1023-line monochrome cameras with fixed-focus lens mounted in an underwater housing.

The display electronics package developed for the LHX program was acquired from AAMRL. The display electronics allows precise distortion correction for each channel, video signal, and CRT display. Correction parameters for each item can be stored on disk to allow rapid component changeout and reconfiguration.

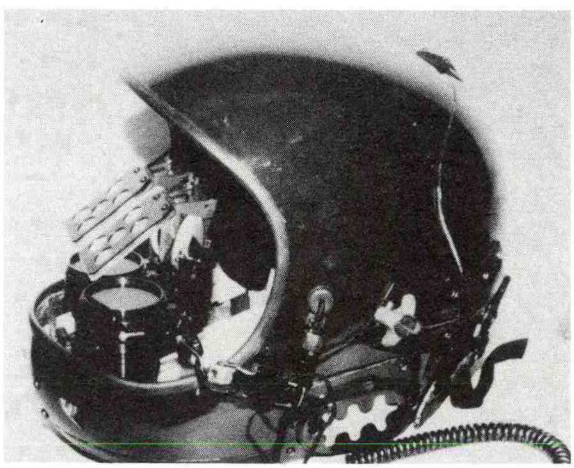

Figure 8. TOPS CVM Helmet Mounted Display.

TOPS CVM Overall Objectives Met

The overall TOPS CVM technical objectives were met in the development of an advanced manipulator system that begins to approach diver work capability. A high dexterity (22 DOF) manipulator with high-fidelity force feedback and a high-resolution, head-coupled, stereo vision system was achieved. The combination of high dexterity, kinematic equivalency, good force reflection, and a spatially correspondent 3-D vision system contributes to a high level of telepresence, i.e., the perception that the system is transparent to the operator. Because the operator feels that he/she is at the work site performing the task, he/she can concentrate on the task and not on operating the system.

Lessons Learned

Very valuable lessons were learned during the development and testing of the TOPS CVM.[5] The manipulator demonstrated great potential for performing a variety of manipulative tasks. The force-reflecting exoskeletal system was natural and easy to use. However, subtle differences in kinematics and materials had major impacts on system performance. When link lengths and joint axes of the master controller did not properly match the operator's links and joints, and when grasping and positioning were not replicated exactly, the operator worked with significantly more caution and at a reduced speed. The fingertip configuration and materials of the slave hand also impacted the ability to securely grasp objects, and hence affected the operator's confidence and the speed of task performance. The compensation for gravity in the hand and arm for all areas of the workspace is very important to overall system performance and in the minimization of operator fatigue. Also, the capability to "freeze" operator-selected joints would be very valuable for fine positioning tasks.

The tendon system proved too delicate, bulky, and complex for an operational underwater system. Tendon technologies that more closely replicate the human tendon system need to be developed.

The torso proved very useful in extending the manipulator's work volume and capability, in changing the viewing perspective, and in providing a "natural zoom" capability (the ability to position the cameras closer to the work task simply by leaning toward the object).

CONCLUSIONS/RECOMMENDATIONS

Telerobotic systems will continue to be important for environments and tasks that are hostile to humans, but where man's cognitive and manipulative capabilities are needed. This is particularly true for situations where the environment would expose humans to great danger. The undersea salvage sites are typically chaotic and require the knowledge and skill of an experienced operator to complete specified missions.

Unstructured tasks usually require that full manipulative, sensory, and cognitive capabilities be employed. Any manipulative or sensory capability that a manipulator system does not provide is a "handicap" to the operator. The TOPS CVM represents a step toward minimizing the "handicaps" an operator typically inherits with a manipulator system.

Continued refinements are needed in the TOPS CVM design to improved operator machine interfaces and produce a ruggedized, smaller hand for operational use.

The next development phase requires continued development in component technologies for increasing hand dexterity, providing underwater directional hearing capability, enhancing vision, and providing tactile telepresence.

Component developments required for increased hand dexterity include reliable, low-stiction tendons; biological-like lubricants; compact, tendon-routing technologies; small, responsive, lightweight, muscle-like actuators; finger- and palm-padding type materials; and tough skin-type materials.

The development of small, high-definition TV cameras and monitors are needed for 20/20 color vision systems.

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Precise Navigation and Control of an ROV at 2200 Meters Depth

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ABSTRACT

This paper describes the navigation and control techniques used to perform a survey with centimeter precision at an ocean depth of 2200 meters. The scientific objective of the survey was to map the conductivity and temperature above an active "hot smoker" hydrothermal vent. Using two broadband, 300 kHz transponders and a precision depth sensor, the position of the *Jason* ROV could be fixed nearly three times a second. *Jason's* control system used this information to hover and fly precise tracklines over a twelve hour period. The paper describes the operation, shows trackline and hover data, and concludes with a summary of future planned work.

INTRODUCTION

The *Jason* ROV recently made precise measurements of a hydrothermal plume at a depth of 2200 meters as part of the CREST Project. The setting was the Endeavour Hydrothermal Vent Field, an area of intense hydrothermal activity and rough volcanic terrain about 150 miles off the coast of Washington State. During the experiment, *Jason* mapped temperature and conductivity in three dimensions above an active "black smoker" vent with unprecedented precision and control.

The EXACT system, based on broadband high frequency acoustic transponders, provided high-update navigation with positioning resolution on the order of 1 cm. This information provided feedback to automatic control loops that regulated *Jason*'s position to hover and follow tracklines with a precision of about 20 cm. The precise navigation and control permitted the scientists to locate and carefully measure anomalies of temperature and conductivity, and to observe their change with time.

JASON AND ITS CONTROL SYSTEM

Figure 1 shows the *Jason* ROV. Jason [1] performs scientific survey and sampling to depths of 6000 meters. *Jason* operates from a dynamically positioned ship and is connected to its companion vehicle *Medea* via a neutrally buoyant cable. *Medea* is connected to the surface by a 0.68" steel-armored fiber optic cable. *Medea* serves to stabilize the long cable and to isolate *Jason* from the heave of the ship. Cameras on *Medea* provide a high-altitude view of *Jason* operations.

Jason is equipped with an automatic control system that allows its heading, depth, and horizontal position to be controlled. Previously, this control system has been demonstrated off the WHOI dock [2], and on scientific operations in shallow water [3].

The pilot can command *Jason's* automatic control system in several ways. Tracklines can be specified numerically. The most common technique used is called "joystick auto", where the pilot commands the speed and direction of the position setpoint with the same joystick used for manual control.

We used the control system during a survey of two War of 1812 shipwrecks, the Hamilton and the Scourge [3]. *Jason's* ability to fly along well

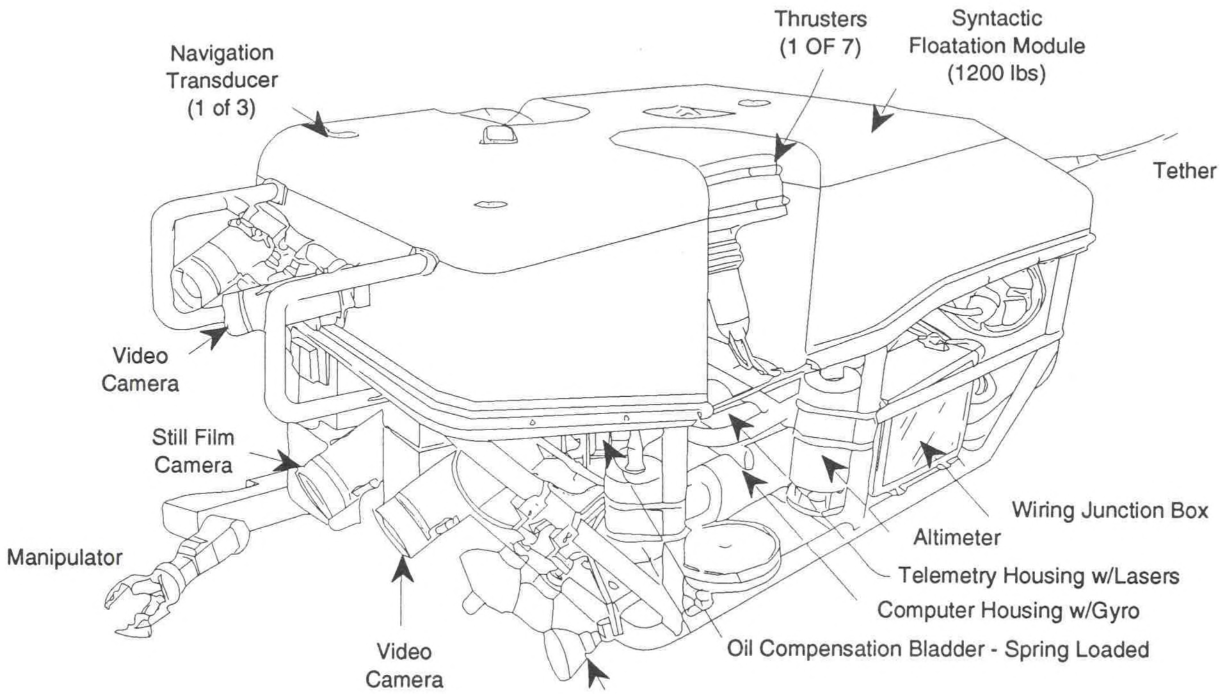


Figure 1. The *Jason* ROV performs scientific survey and sampling to depths of 6000 meters

controlled tracklines proved useful for making sonar runs on the ships, allowing the sonar look angle to be precisely and continuously controlled. Automatic control was also useful while making a high-altitude photomosaic when the pilot could not see the ship with the continuous video system. The control system also helped students linked to the expedition via satellite to control *Jason* remotely.

In all previous closed-loop control work with *Jason*, the hardwired SHARPS navigation system was used as a position reference [4]. With SHARPS, each net transceiver is connected to the control computer with a high bandwidth cable. This hardwired configuration utilizes one-way travel times between the transceivers on the vehicle and those in the net. This technique permits very high update rates (up to 10 fixes/second), minimum latency, and high immunity to multipath. Resolution exceeds 1 cm., and the maximum range is about 100 meters. However, the cables impose operational constraints.

Navigation for the precise deepwater survey used the EXACT system [5]. Like traditional long baseline systems, EXACT uses two-way travel times between the vehicle and fixed transponders to determine position. EXACT has range and resolution performance similar to SHARPS and distinguishes individual transponders through the use of coded, broadband pulses. Unlike the SHARPS system, the net elements for EXACT require no connections, and the master unit on the vehicle communicates to the surface computer through a low-bandwidth serial link.

PRECISE SURVEY IN DEEP WATER

The high-resolution *Jason* survey required continuous operation of a nested set of navigation systems and control loops, as shown in Figure 2. A low-frequency long baseline system, surveyed using P-code GPS, provided position fixes for the ship and one of the vehicles every 5 seconds. A commercial dynamic positioning used the long baseline information to automatically control the support ship (DSVSS *Laney Chouest*). The navigator was responsible for adjusting the commanded ship position in order to keep *Medea* appropriately positioned above *Jason*. Control of *Medea* was so sufficiently precise that we could view *Jason* most of the time by *Medea's* video cameras.

During an extended *Jason* lowering, we sent four EXACT transponders to the seafloor in a free-fall elevator. The EXACT units were housed in 10" glass spheres, and were powered by alkaline battery packs. Due to a rough

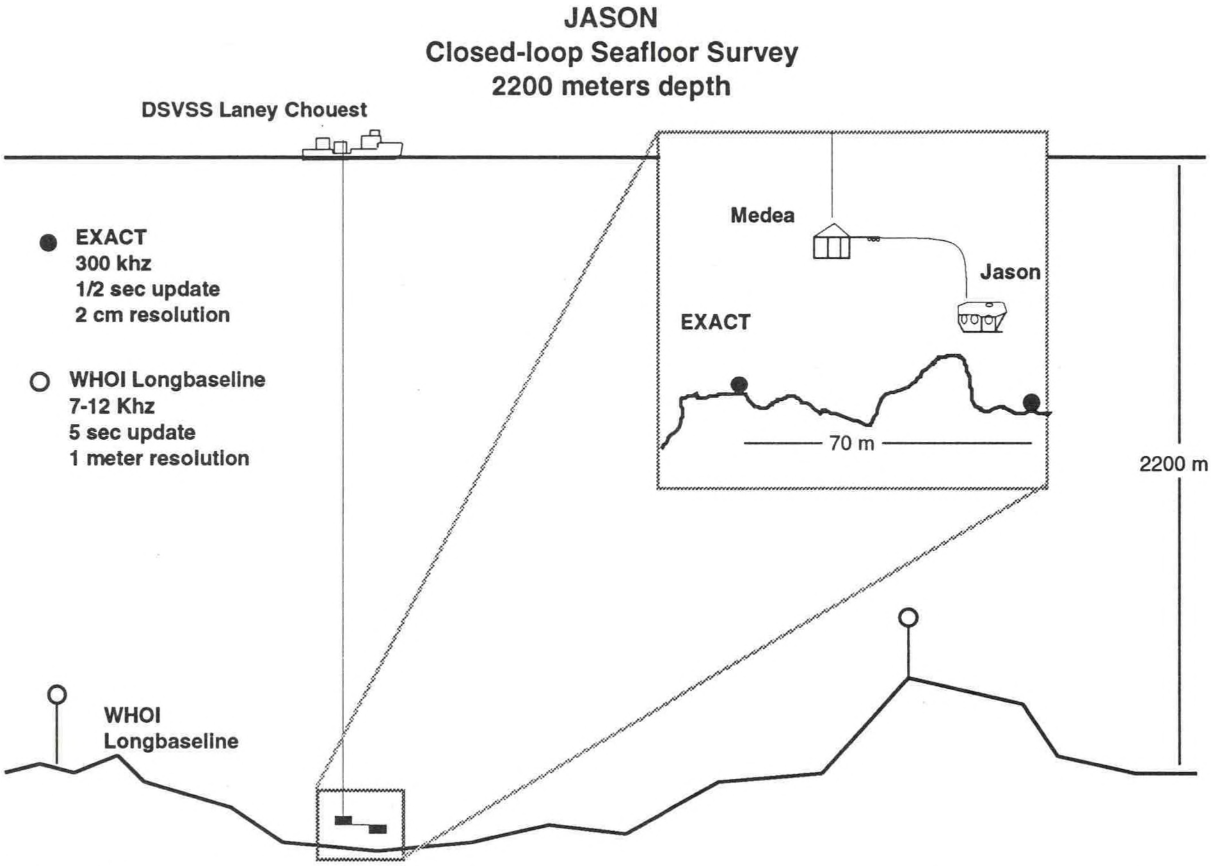


Figure 2. The precision survey required coordination of the dynamically positioned ship, the *Medea* vehicle and *Jason*. All vehicles were tracked with conventional long baseline navigation.

landing in rugged volcanic talus, two transponders imploded on landing. The remaining two transponders were extracted from the overturned elevator, and these units functioned satisfactorily during the rest of the deployment, routinely providing ranges up to 100 meters. After the survey, *Jason* returned the transponders to the elevator for recovery.

The transponders were placed about 70 meters apart approximately 40 meters to the west of a vigorous hydrothermal structure called "S&M" (Smoke and Mirrors). The EXACT net was registered by performing a least-squares fit between corresponding EXACT and long baseline fixes. After first placing the transponders, we found that the net was not centered over the plume, so the it was rotated by moving one transponder. The EXACT net was registered again with the long baseline fixes. When using the EXACT navigation, *Jason's* position was fixed by combining two ranges with the vehicle depth, as measured by a Paroscientific Digiquartz pressure transducer. Following adjustment of a range gating algorithm, tracking was very reliable.

Occasional dropouts were caused mostly by a software problem rather than difficulty with the navigation equipment. After establishing the EXACT net, *Jason* hovered and flew precise tracklines through the plume for 12 hours. Sensors aboard *Jason* used during the experiment included temperature, conductivity, and downlooking scanning sonar.

Figure 3 shows representative tracklines for a one hour period, including a closeup that shows the control precision. As in all other examples of ROV position control, the data shows a characteristic steady oscillation or limit cycle. In previous analysis and experiment [6], the nonlinear, sluggish response of *Jason's* thrusters has been shown as the source of this behavior. The performance shown in this plot is consistent with earlier results obtained with

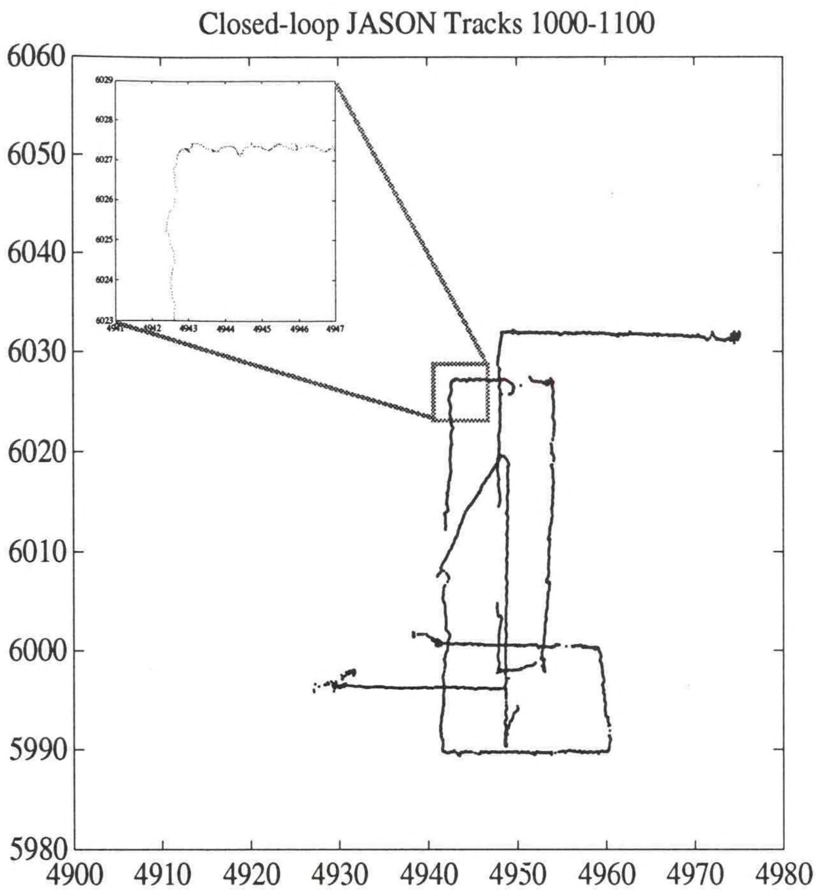


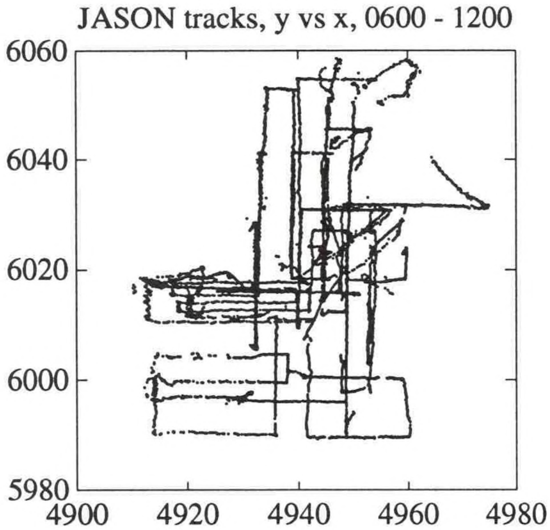
Figure 3. This plot shows *Jason* tracklines over a one hour period. The inset shows the control precision.

Jason using the hardwired SHARPS navigation system [2,3].

Figure 4 shows the tracklines for a 6 hour period as viewed from the top and from the side. These plots illustrate the use of an ROV like *Jason* as a quantitative scientific instrument. While logging temperature and conductivity data, the ROV could hold depth and heading while translating slowly along carefully controlled tracklines. This allowed the hydrothermal plume to be mapped, as the scientist specified the commanded depth and track direction. *Jason* could also hold position while the changes in survey data were recorded.

CONCLUSION

This experiment demonstrated precise control of an underwater vehicle, and showed that the technique is practical in virtually any water depth. In this example, we mapped the temperature and conductivity of a "hot smoker" plume. Other potential applications include high-resolution bottom mapping, structural inspection, and coordinated vehicle-manipulator control.



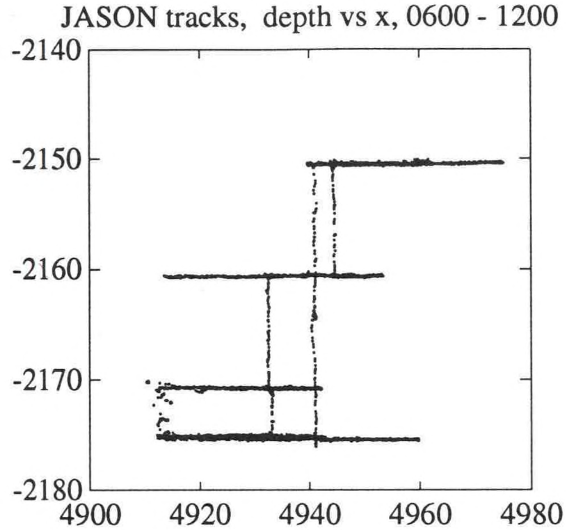


Figure 4. This plot shows tracklines for a six hour period, as seen from above (left), and the side (right).

ACKNOWLEDGEMENTS

The development of *Jason* was sponsored by the Office of Naval Research, contracts N00014-85-C-0410, N00014-86-C-0038 and N00014-90-J-1912. This work could not have been accomplished without the skill of the *Jason* operations team and the leadership of CREST project scientists Robert Ballard, John Delaney, and Russ McDuff. This paper is WHOI contribution number 8018.

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HIGH RESOLUTION 3-D SUBBOTTOM IMAGING SYSTEM 'KITE'

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ABSTRACT

A high resolution 3-D subbottom imaging system called 'Kite' has been successfully tested in shallow water near Miami Beach. The 'Kite' system is a 12-channel hydrophone array towed laterally, i.e., the hydro-phone array axis is perpendicular to the direction of the ship motion. An airgun source at the end of the hydrophone array is excited every two seconds while towed at 1 m/s. Each hydrophone signal is recorded at 16 kHz in 16 bits using a VAX computer and an A/D converter. The const-ruction of the 3-D subbottom image was made by using conventional multichannel seismic reflection data processing. The shear modulus, porosity and shear wave velocity images of the sub-bottom are constructed assuming the normal consolidation stress condition. The results show that the 'Kite' has a great advantage in that it produces high resolution 3-D subbottom images while its data can be handled in a conventional way.

INTRODUCTION

The seismic reflection method is a technique by which one maps the configuration and nature of remote and inaccessible subbottom layers. In this technique, a seismic disturbance is generated at or near the surface of the earth, and reflections, caused by changes in acoustic impedance of subbottom layer, are recorded at the surface on a spread of detectors at various distances from the source. One can construct an image of sub-bottom structures by the "contrast" between layers due to physical differences between interfaces (Silvia and Robinson, 1979; Telford et al., 1990).

To get the clear subbottom image, in conventional marine reflection seismology, a survey ship tows hydrophone arrays which are in-line with the ship's moving direction. The reason for this hydrophone spread is that the use of multiple source, multiple hydrophones per trace and the summing of common reflection point traces brings distinct improvement in the S/N. In other words, a typical marine multichannel data acquisition system brings multi-fold coverage, so that "good" 2 dimensional subbottom images are expectable (Mcquill et al., 1984).

In this paper, the 'Kite' system is introduced and discussed. The 'Kite' system employs an unconventional hydrophone array spread. In the 'Kite' system, a hydrophone array is towed laterally, so that the axis of hydrophone array is perpendicular to the direction of the ship. The record of each channel makes up a 2 dimensional seismic trace, and the records of all channels construct the 3 dimensional subbottom imaging. The assumption that little or no lateral geological changes is taken in the calculation of stacking velocities. The velocity vs. depth data are used to transform the time into the vertical distance in the seismic trace of each hydrophone in making the 3-D image.

KITE METHOD

Acquisition

In conventional marine seismic exploration, hydrophone arrays are in-line with the direction of the survey ship. The purpose of this in-line spread is to take advantage of stacking. The use of multiple sources and multiple hydrophones per trace brings multiple coverage of the same point of the subbottom. The summing of the multiple coveraged common midpoint(CMP) results in distinct enhancement in the S/N. The signal-to-noise ratio is increased through an N-coverage stack by $N^{0.5}$ (Yilmaz, 1985; Dobrin and Savit, 1988). In the process of stacking through normal move-out, interval velocities of subbottom layers are induced.

The 'Kite' system which is discussed in this paper employs a different hydrophone spread from the conventional method. Figure 1a is the schematic diagram of the 'Kite' system. As Fig. 1a shows, the axis of hydrophone array, boom, is perpendicular to the ship's tow direction, which is different from a typical marine seismic reflection survey in that the streamer is in-line with the ship's direction of motion. The field experiment as in Fig. 1b was performed, to compare the results of 'Kite' system and conventional method.

Subbottom features of the surveying area are, in nature, three dimensional. The main purpose of the 'Kite' system is to construct the reflectivity image of 3-D subbottom structures. In the 'Kite' system, each channel records a 2-D seismic section. A 2-D seismic section normally assumes that all signals come from the plane of the profile itself, although the 2-D section contains signals from all directions (Yilmaz, 1987). All channels together will construct a 3-D subbottom image with one sweep of the ship, while a typical marine 3-D survey is carried out by conducting many sweeps of closely spaced parallel seismic surveys.

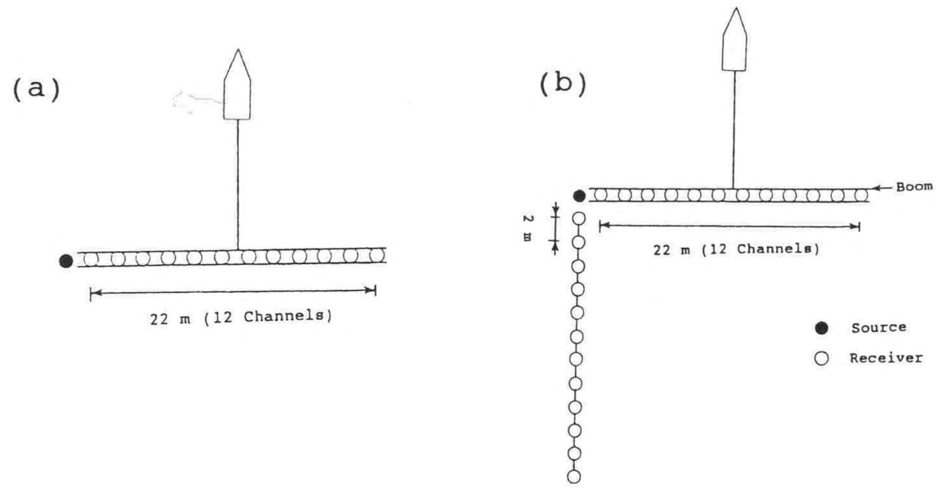


Fig. 1 (a) Schematic diagram of Kite system, (b) Kite system and conventional method ware performed to compare the results.

An airgun at the end of the hydrophone array is excited every two seconds while towed at about 2 knots (≈ 1 m/s). Hydrophone signals are recorded at 16 kHz in 16 bits using a VAX computer and an A/D converter, and the recorded data is multiplexed. Demultiplexing decomposes the record to the component channel signals prior to data processing.

Data processing

Data processing is applied to the raw data, i.e., each channel data. The conventional seismic data processing is used, such as gain control, frequency filtering and deconvolution. Figure 2a and b show examples of the processed seismic sections of conventional methods and 'Kite' system, respectively. Although 'Kite' data contains noise due to boom, Fig. 2a and b shows no big differences.

In conventional reflection seismology, one of the important steps is the stacking process, because the use of multiple sources, multiple hydrophones per trace, and the summing of common reflection point traces there is a distinct improvement in the seismic section. This process follows the normal moveout which needs the stacking velocities. Internal velocities of subbottom layers are deduced from stacking velocities. In the 'Kite' system, normal moveout process is performed in a perpendicular direction to ship's moving direction. However, common reflection points are smeared. Although the common reflection points do not coincide geometrically, the seismic events show the hyperbola curves from which stacking velocities are deduced. One can approximate the stacking velocity under the assumption that little or no lateral geological changes have occurred. Thus, assumed common reflection points produce the approximate stacking velocities of subbottom layers.

(a)

(b)

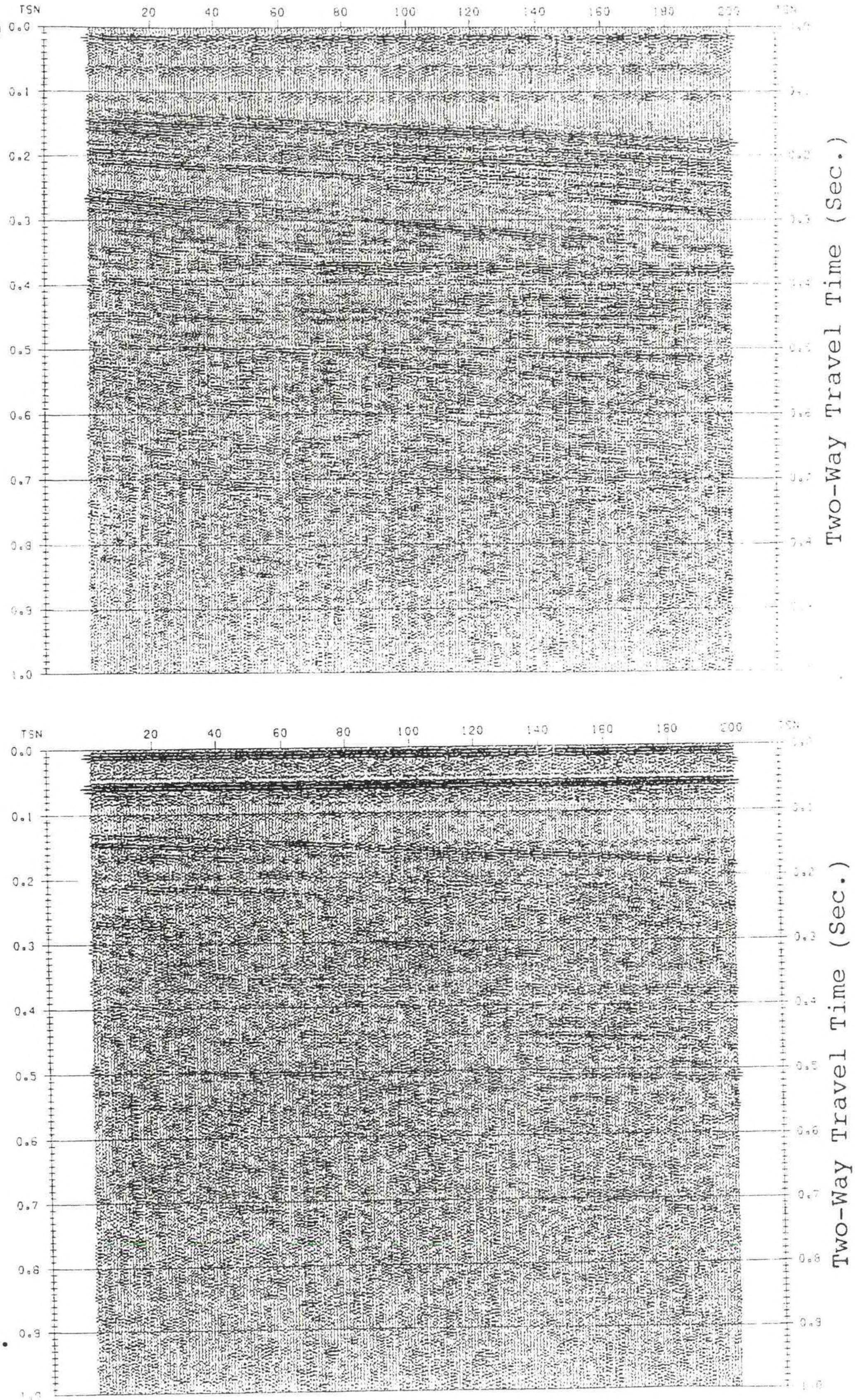
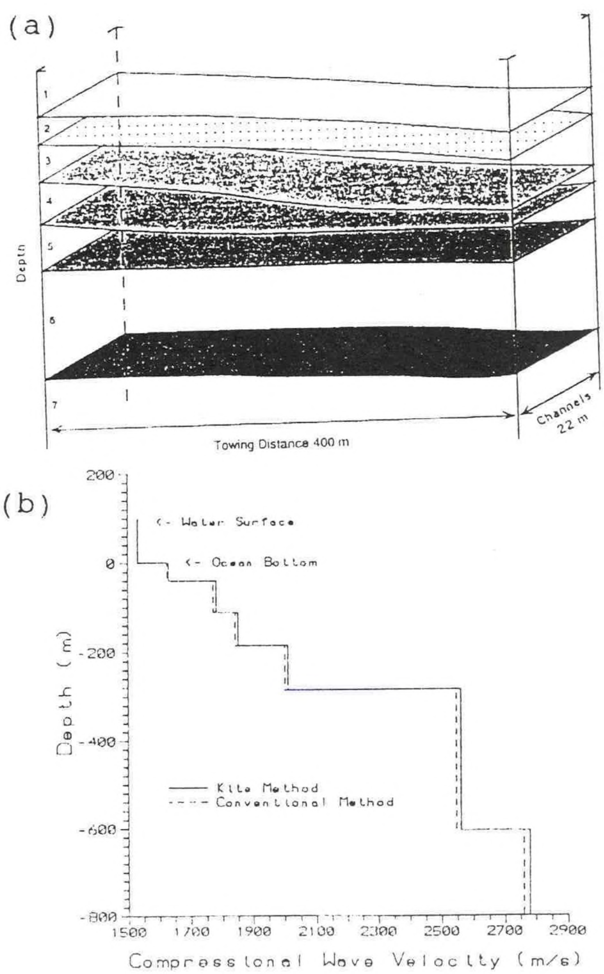


Fig. 2
(a)Seismic section by conventional method, (b)Seismic section by Kite method.

The imaging of the 3-D subbottom

Using stacking velocities, normal moveout is performed to correct each seismic section to the near channel. Seismic events of each normal-moveout-corrected seismic section are connected to those of adjacent seismic sections to construct the 3-D subbottom image. Figures 3a and b show a 3-D subbottom image and internal subbottom velocity profile of the upper 7 subbottom layers including the water layer, respectively. In the 'kite' system, this 3-D subbottom configuration is achieved with one sweep of towing receivers.



Physical parameters of subbottom layers

Estimated stacking velocities, i.e., root-mean-square velocities, give the approximate stepwise interval velocities using Dix's equation. In Fig. 3b, the velocities represent the interval velocities. The approximate interval velocities are in nature the compressional wave velocities (v_p). The shear modulus, porosity and shear wave velocities (v_s) are constructed using the compressional velocities assuming the normal consolidation stress condition (Yamamoto et al., 1989; Trevorrow et al. 1991).

The shear modulus μ, is one of the most important descriptive parameters of a marine sediment. A wealth of experimental data has been collected relating elastic, small strain ($<10^{-5}$) shear modulus to the depositional state of sediments (e.g., Richart et al. and Bryan and Stoll). The data indicate that the shear modulus is proportional to the void ratio ε, and total effective confining stress σ, by an empirical relation of the form (Yamamoto et al., 1989)

$$\mu = A\epsilon^{-m}\sqrt{\sigma}, \qquad (1)$$

where $A=1.835\times10^5$ Pa and $m=1.12$.

Fig. 3 (a) 3-D subbotomm image, (b) internal velocity profile.

This empirical relation is based on both laboratory and in situ seismic data from unlithified sandy, silty, or mixed-clayey sediments. The void ratio ε, which is the ratio of the volume of pore space to the volume of solids, is given by

$$\epsilon = \beta / (1-\beta), \qquad (2)$$

where β is the porosity, which is the volume of pore space per unit volume of sediment.

The shear modulus and sediment porosity are calculated from the compressional wave velocities (v_p):

$$V_p = \sqrt{H/\rho}, \qquad (3)$$

where $\rho = \beta\rho_w + (1-\beta)\rho_s$ and the subscripts (w,s) refer to water and solid, respectively. H is one of Biot's elastic moduli, related to measurable properties of the sediments by

$$H = K_s + \frac{4}{3}\mu + \frac{(K_r - K_s)^2}{(D_r - K_s)}, \qquad (4)$$

where K_r is the bulk modulus of the grain material($3.0X10^{10}$ Pa for silicates) and K_s is the bulk modulus of the skeletal frame and is given by

$$K_s = \frac{2}{3}\,[(1+n)/(1-2n)]\,\mu, \qquad (5)$$

(n is the Poisson's ratio).

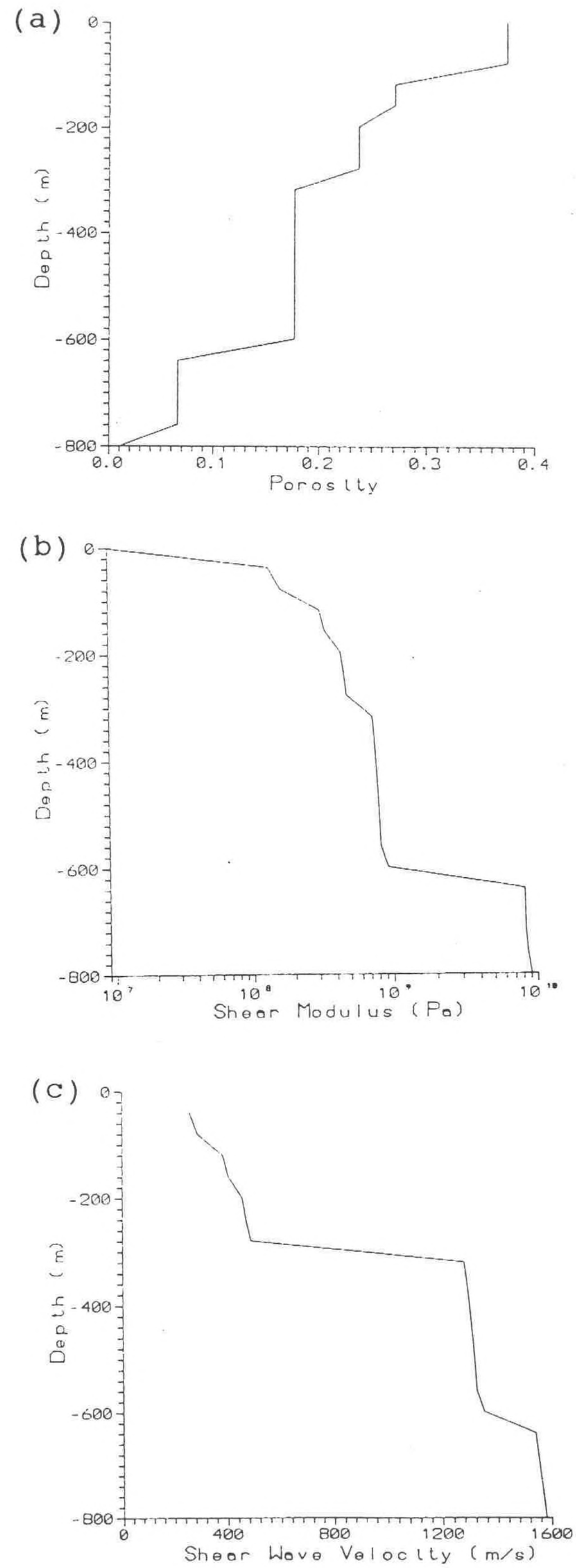


Fig. 4 (a) Porosity, (b) shear modulus, and (c) shear wave velocity profiles, using the internal velocities of Fig. 3.

The parameter D_r is given by

$$D_r = K_r[1+\beta(K_r/K_f-1)], \quad (6)$$

where K_f is the bulk modulus of the fluid component (2.31×10^9 Pa). From the knowledge of both the shear modulus and sediment porosity, the speeds of acoustic wave propagation in the sediment can now be estimated by the equation:

$$v_s = \sqrt{\mu/\rho}. \quad (7)$$

Figure 4 show the estimated porosity β (b), shear modulus μ (c), and shear wave velocities v_s (d) from internal velocity profile. These elastic parameters are all approximated values, keeping in mind the point that the stacking velocities are deduced under the assumption of horizontally homogeneous geology in the range from 10 to 20 meters in our research. Actually this assumption is valid, because the lateral geological facies changes are varied gradually, not abruptly. At least the geology can be considered the same in the range of 10 to 20 meters.

Conclusion

The results show that 'Kite' has a great advantage in that it produces high resolution 3-D subbottom images with a sweep of receivers while its data can be handled by conventional seismic data processing methods.

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THE ROBOTS ARE COMING TO THE OCEAN

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I. INTRODUCTION

The introduction of robots, or more precisely intelligent vehicles, represents a continuation of the industrial revolution that has been slowly progressing over the years. Initially, machines were introduced into the workplace to perform simple repetitive tasks faster and more accurately than humans. As the technical and economic impact of the machines was understood, fear was replaced by an appreciation of the measurable benefits. The departure point on the evolutionary scale is the numerically controlled (NC) machine that became possible with the introduction of electronic analog and digital technology. By means of electronic signals, the NC machine can perform a repeatable sequence of tasks, and outperform its predecessor, the single operation machine. Numerically controlled machines, programmed to perform a set of operations, work reliably and tirelessly, and in the days of cheap energy supply, relatively efficiently. Many of these machines are programmed to work with human interaction to provide some degree of intelligence and a knowledge of the operation. These devices are incapable of sensing their environments or of changing in real time their sequence of operations. To do a different job, the NC machine has to be reprogrammed to perform a new sequence of tasks. The advent of smaller, faster, and more sophisticated digital computers provided the means to replace the NC machine with an intelligent robot capable of operating in the depths of the ocean. Japan, France, Italy, United Kingdom, and the United States all have significant investments in intelligent machines for use in the ocean and in other applications. Modern technology allows designers and researchers to create machines that operate in unstructured environments using principals of vision, sensing, navigation, and learning to perform tasks.

The term "robota" is a poor choice since this word is widely misunderstood and represents a generic class of anthropomorphic non-human devices. Actually, the word robot is derived from the Czech term "robot" which means "forced labor, **drudery.**" It was first used in a 1920 play by the Czech author Karl Capek. The dictionary still defines a robot as resembling a human being. However, more modern definitions represent a more accurate view of this class of machine and an autonomous vehicle in the ocean can be called a robot. An undersea intelligent machine must be capable of doing work in a hostile environment and must have several degrees of freedom of motion. Most industrial robots are capable of six degrees of freedom involving shoulder swivel, elbow-extension, and wrist movement. The shoulder joint is the robot's base, providing movement in a circular plane and also shoulder swivel, that is, movement from a vertical axis through the base. Arm extension is accomplished by the elbow joint to carry the wrist with its gripper or tool to the workpiece. The wrist joint is usually capable of three degrees of freedom-pitch, yaw, and roll-thus providing the manipulator with wrist dexterity throughout the robot's entire range. Many other configurations are possible, utilizing various joint movement combinations for specific mechanical advantage. These highly complex machines exhibit difficult problems associated with their kinematics of motion, speed or cycle time, accuracy, and flexibility, to perform as many tasks as possible. Their major shortcoming, however, is their lack of ability to sense the environment. Sensory modalities, usually sight or touch, added to improved navigation and position location as real time inputs, provide much more flexibility and capability. Before discussing the impact of sensory inputs, let us look at the technology underlying these machines.

II. ENABLING TECHNOLOGIES

It is not my intention to provide you with a lecture on the various technologies that contribute to a robot system on an autonomous vehicle. However, I would like to present a brief overview so that those of you who are not familiar with the details of these complex machines, or who have only worked in specific technologies, can have some feeling for the device. As stated earlier, a robot system can range in complexity from a relatively simple "pick and place" manipulator mounted on a vessel to a highly complex mobile, intelligent, autonomous machine working in a hostile environment.

The "brain" that controls the robotic system is the computer control system. In a complex task environment such as the ocean, the robot uses a multispectral sensor system, and multiple networked computers, as well as advanced communications technology to maintain a distributed data base that represents a world model. The computer must formulate and evaluate alternative action plans, monitor the execution of current plans, and coordinate the actions of several moving components.

A. Hierarchical Control System

The development of robot control systems has advanced significantly since the days of the first robots. With the advent of computer controls came the simultaneous development of levels of control. In the early versions of control levels, one thought of three levels of control. The first and simplest level was for the operator of the robot, which allowed for minor modifications of the robot "program" and typically was achieved by providing tubular data to the program. A second level of control was achieved by the "applications programmer" who developed computer algorithms. These algorithms were designed to move the robot through the desired path in space, and to interact with any sensors connected to the robot. The third level of control was provided at the so-called systems level, wherein commands and capabilities for the application programmer were defined.

B. <u>Machine Intelligence</u>

Carrying out a plan and formulating a plan is the same for both machine and human intelligence when working in the ocean. Unexpected events can disrupt the best laid plans of robots, as well as those of mice and men. To execute a plan, a robot system uses the world model to compare the expected state with the state encountered by the sensory system. When differences occur, replanning takes place to define corrective action. For minor differences, e.g., small positional variances in location of the robot system, a corrective move is made to alter or fix the position and resume the plan. Major differences make the planned steps inoperative; too large a deviation from the pattern in Part One prevents the system from executing the planned action. In this case, failure is often reported with an explanation, so that the level above, with greater perspective, can replan the action. The nuances in this distinction between a plan that can be repaired and one that must be scrapped are still the subject of research. Today, only the simplest situations can be handled by this method.

C. <u>Sensory Perception</u>

The sensory system monitors the robot and provides feedback information on the state of the environment and the robot itself. The task of the sensory system is to deal with predictive, incomplete, and conflicting information. Predicting a future state can be achieved only in terms of a carefully formulated model reference of the system and its operation. The obtained data may be excessive, imprecise, or incomplete, yet they must be reduced and interpreted for use by the decision making part of the system. It will be increasingly common to have conflicting data from the sensors resolved into a balanced data set called sensor fusion. More will be said about sensors further on in this discussion.

The need for accuracy, reliability, and special operating conditions in robotic applications in the ocean is expected to require special computer architectural designs because the speed and memory capacity of today's robots generally limit additional tasks, such as control of dexterous end effectors, processing of vision data or addition of AI-based programs. In particular, the control of dexterous end effectors may require a complex additional computer, In some cases, new designs will tax the state of the art of computer architecture for some time.

D. <u>Sensors</u>

As in humans, sensor systems are a collection of individual sensors and their transducers. An important issue in sensor systems is the resolution of data reported by two or more sensors. This is handled in some form by the sensory part of the control system. However, aspects of the data-in-conflict problem arise in a specific sensor when a prediction has been made regarding what is expected. This prediction capability will be the norm in the future as robotic applications and their controllers grow more sophisticated. In this environment a sensor is told what to expect based on the other factors known to the control system. When the unexpected happens, the robot should not respond as though the expected was encountered, for then we would not need the sensor. In fact, the sensor is most valuable when the unexpected occurs. Thus a dimension of the data-in-conflict situation occurs in resolving the data seen by a single sensor and the expectation set up by a prediction.

Tactile sensors are a special type of force sensor that give the robot a sense of touch. In tactile sensing three-dimensional space can be explored to determine properties of the robot environment. Tactile sensing is a transduction process in which the features of an object are converted into signals. In some applications, mechanical tactile sensing has more capability than human sensing.

Position sensors can vary physically with the task and robot system. However, they are always designed to give the robot information about its location in the ocean environment which is extremely difficult to characterize.

Imaging sensors are not restricted solely to the visible spectra or TV cameras. A laser range finder can capture a depth image so that each element in the array represents the distance along a path normal to the sensor to the object in the field of "view." Various forms of spectral image cameras, including visual and infrared, are in use. Also various range images are routinely acquired with laser range finders and acoustic systems.

E. <u>End Effectors</u>

End effectors are the tools attached to the end of the manipulator. They may be either the specialized tools attached to the end plate of the robot (drilling, routing, and welding) or dexterous multi-fingered hands that allow general manipulation of the work in progress. Some end effectors are multi-purpose devices in the same sense that the human hand is able to hold a hammer, screwdriver, or other tool. Generally, the complexity of the terminal device is an inverse function of the complexity or dexterity of the arm. As the technology matures, it is expected that general purpose terminal devices (hands) will reduce demands for versatility on the manipulator arm, i.e., small end effector motions (in the form of a three-DOF to six-DOF micromanipulator) will make large system motion less necessary. The normal medium size gripper of today is a simple pair of parallel fingers capable of holding a 5-inch weight of 10 lbs. Generally, these devices are clumsy and require excess maneuverability to grasp a generic object. Frequently, they incorporate some elementary force and proximity sensing. End effectors for drilling, sanding, and painting are being developed. Specialized tools of the type being considered for the space station are also being developed or can be found in other applications such as remote maintenance of nuclear reactors. These tools must be relied on to perform precision operations at a remote location such as during undersea station assembly or as the result of damage to an inplace structure.

F. <u>Human Interface System</u>

Semiautonomous robots require a far more complex human interface than autonomous robots. Man and robot each are part of a symbiotic system in which the human operator provides guidance while the robot does the work. At one extreme of this relationship is the pilot who flies a robot plane based on sensor data fed to a ground or airborne human interface station. Many so-called tele-operated systems are variations on this theme. NASA has one on the space shuttle, and many are used in nuclear reactors, underseas, and elsewhere. At the other end of the spectrum, humans do not control the actuation system, but communicate with the computational (cognitive) side of the robot. Here the person aids in decision making, data interpretation, and in planning or evaluating plans. Thus, the human interface can vary from a simple set of switches, to computer terminals, fancy harnesses, and complex multi-screen graphics systems; and all depend on the type of interaction needed for the robot and the job to be done.

The overall question of teleoperation involves the relative need and what type of tasks will be suitable for human intervention (telerobotics, supervisory control (telepresence), or direct human control (teleoperation).

G. Tele-operation

Tele-operation often has been interpreted as an archaic class communication link between similar master and slave robot subsystems. Telepresence suggests, however, a full commitment by the operator in the performance of the tasks. In some specialized, unstructured, or emergency tasks this may be the best use of resources. For tasks that can be structured (and they should be if at all possible), this level of operator commitment would not be economical.

To attain this goal of supervised autonomy, where humans plan operations and then intervene only when necessary during execution, a level of internal decision making must be achieved. If this level is attained, the data and criteria prioritization would be the same either to support computer or human decision making.

H. Mobility and Portability

For mobile robots operating in the ocean, no fixed base can be used as a coordinate reference. This constraint introduces significant navigation and parametric location requirements. Research problems include navigation and positional accuracy, stability in rough terrain, and teleoperation from a stand-off position.

Mobility implies that the system would be able to traverse an obstacle strewn area. To date, no such system exists in the general sense. On land special tracked vehicles, track followers, and wheeled vehicles are available that can move over relatively smooth surfaces (or fixed tracks) with minimum obstacles. Unfortunately, in the sea many applications require greater capability in dealing with obstacles.

III. UNDERSEA VEHICLES

Several developments over the years and an advancing technology helped move the field of robotics into new applications. The major advance was VLSI and microminiature components that permitted the machine to carry an on-board computer and sensing systems. Advances in computer science and artificial intelligence also contributed to an enhanced capability to operate in an imprecise environment and to learn to react to a domain that was not designed for the presence of a working machine. The growing list of applications also showed that the robot may be more effective if it does not exhibit anthoropromophic characteristics. These robots are coming but you may not recognize them.

One of the most useful applications of intelligent machines and robots is in the undersea environment. Today, the United States and other countries are interested in utilizing the coastal ocean for many reasons. Applications such as energy conversion, structures, mineral exploration and resource recovery are natural problems for autonomous vehicles outfitted with special purpose sensors and workstations. Ocean science, environment, and living resource recovery are just a few more applications. These machines are generally not anthropomorphic since man was not designed to operate for long duration in a below surface water environment. Examples of different configurations, missions, control and communication techniques and place of origin are too numerous to mention. They range from bottom exploration and working vehicles to scientific measurement vehicles sampling the water column characteristics. Other examples include undersea walking machines for inspection of port and harbor facilities, mining robots, and undersea construction. Both the United States and Japan are interested in this technology and joint projects are highly desireable.

I. International Interest

At the Economic Summit held at the Chateau Versailles in 1982, the heads of the seven major industrial countries recognized the contribution that robotics could make and formed a working group to consider research in the area. This working group evolved into the International Advanced Robotic Programme (IARP) which is still in existence and has now grown to include several other countries as members (participants) or as observers.

The IARP has promoted international activity in the field of ocean robotics by encouraging and supporting 1) the exchange of international study missions, 2) Workshops on various application areas, 3) Exchange of researchers, 4) Collaborative studies, and 5) Status reports. The IARP has proven to be an excellent example and model for non-interfering international cooperation.

Let me close by adding two notes of reality to a subject that science fiction writers like to deal with. Robots have no emotions and no good or evil intentions. They do not have mood behavior, they do not sulk, and there is no place for a psychiatrist in this business except to talk to frustrated designers.

Second, I must make a plea for the environment and respect for the other creatures inhabiting the earth and the sea. Developing the ocean resources with the aid of robotics must be a component of sustainable development or we will destroy one of the earth's most precious components. We must keep the environment in the forefront of our thinking because one thing is certain, the robots are coming.

A LOOK AT ROVs

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Introduction

Where did ROVs come from? Why and how were they conceived and developed? What are they doing, and where are they going? This paper is a perspective on ROVs, AUVs, and UUVs—the family of unmanned undersea vehicles. My first task at my first job after college was at the Naval Ordnance Test Station (NOTS) Pasadena, and I was sent to the Morris Dam test site to fix a rocket launcher used for water-entry projectile tests. I asked if the test model was recovered, and I was told the whole launcher needed to be recovered since it had blown apart and was scattered across the bottom of the lake. The propulsor was hydrogen, plus a spark, which thus created a gas that propelled the hydro-ballistic model into the water at high velocity. The launcher was blown to pieces. So began my introduction to underwater search and recovery, an objective I have been interested in ever since.

During the 1950s, most torpedoes could be made to be buoyant at the end of their run, and even if they sank in depths of less than 130 feet, divers could recover them. Nevertheless, many were "lost." By the late 1950s, three weapons development programs underscored the need for providing a means to work on the seafloor. Both the ASROC depth bomb and the SUBROC depth bomb could not be made buoyant at the end of their tests. The bombs went deeper than divers' capabilities and yet had to be retrieved in order to recover internal data recorders. The third program, the underwater launch project for the Polaris fleet ballistic missile (FBM) program, required deep undersea placement of instruments, inspection of undersea sites, and recovery of components. Also at this time, torpedo programs were requiring deeper testing and needed a deep recovery system. These factors were the driving forces for the development of the early ROVs in support of military operations.

Fortunately, John Harter, a forward-thinking engineer in what was then BUSHIPS, had an idea to put a set of propellers on a television camera in a waterproof housing and operate it undersea via a cable. He prepared a specification and let a contract to the VARE Corporation to build two demonstration vehicles. In the meantime, we at NOTS Pasadena had devised a snare system with a television camera and acoustic pinger receiver and were recovering objects from depths to 2500 feet. This clumsy, but successful system was manpower-, ship-, anchoring-, and time-intensive. About 120 test units were recovered by this system in the late 1950s. We were fortunate to receive one of the VARE vehicles to evaluate on our undersea test range. All of the components (large commercial broadcast-type television camera, electric motors, and compass) were housed in large, heavy, water-tight containers with stuffing tubes and rotary seals and flat glass windows with rubber gaskets. Even so, the vehicle worked. Our engineers added a recovery arm and an acoustic pinger receiver and went after torpedoes. Use of this VARE vehicle proved the viability of an ROV work system. The first system required a great amount of maintenance, so we modified the VARE system by jacking up the compass and building a new vehicle under it. This was called the Cable-Controlled Underwater Recovery Vehicle (CURV).

Why Man?

In 1972, a meeting was held at Airley House in Virginia to plan the NOAA Manned Undersea Science and Technology (MUST) Program. The meeting was attended by most of the key diving and manned undersea vehicle engineers and operators, some of whom are here today. My friend, Jack Boller, asked me to shake things up a bit at the kickoff dinner by giving a talk questioning, "Why put man in the undersea environment?" and recommending serious consideration of remotely operated vehicles for each requirement. My "Why Man?" talk to these attendees almost got me booed off the stage. But, by the end of the week, serious consideration was being given to the capabilities of ROVs. This was, I believe, a major event in developing interest in and acceptance of ROVs.

In 1973, a Marine Board study defined the requirements for inspecting offshore structures and pipelines. One small part of the report referred to the possibility of one day supplementing divers' capabilities with an ROV. Now, almost 20 years later, worldwide application of ROVs is so common that an article in the February 1992 *Maritime Reporter* noted completion of a contract.

"Sonsub Completes Diverless Inspections on Marathon Oil Platform"

Sonsub Inc. has completed a contract with Marathon Oil Company which called for a total diverless subsea inspection using a Hysub 40 Remotely Operated Vehicle (ROV). The ROV, which was mobilized aboard the American Express Petromarine, conducted cathodic protection inspections, still photography, and video filming on Marathon Oil's West Delta Platform in Block 143 of the Gulf of Mexico. The work was carried out in 369 feet of water on a turnkey basis.

Development of the ROV Family

Many vehicle systems were developed in response to new requirements. Military test ranges needed deeper, shallower, faster, slower, bigger, smaller, more dexterous, simpler, and specific designs for specific devices. Also, commercial requirements exploded with the rapid expansion of the offshore industry. The following are some representative systems developed in the 1960s and 1970s.

U.S. Navy

VARE
CURV I, II, III
SOLARIS
WSP on CURV III
HYDRAULIC SNOOPY
ELECTRIC SNOOPY
SCAT I & II
RUWS
FOCUS
MNV

Commercial

ANTHROPOMORPHIC Vehicle
FLYING EYE BALL
RCV 125 & 250
SCORPIO, SCARAB, DEEP DRONE
RECON 1 -> V, TRITON
TREC, TROVE, DART
ANGUS I, II, & III
CONSUB I & II
DUPLUS I & II
TROJAN
SEA OWL, SEA EAGLE
KRAB
PAP I -> 1000
RTV, HORNET

During much of the 1960s and early 1970s, the CURV family of vehicles was on standby to immediately respond to undersea emergencies, such as the H-bomb lost off Palomares, Spain; the rescue of the *Pisces III* submersible with its two occupants; and the recovery of aircraft and helicopters for critical diagnoses. Now, such emergencies can be handled by a capable ROV working nearby in most areas of the world.

During the last decade, more sophisticated and simpler unmanned undersea vehicles were developed for particular missions. These are typified by

ARGO/JASON/JASON, Jr.
PHANTOMS 1 -> 300
DOLPHIN 3000 & 6000
MT88 and TYPHIONUS
Reconstructed CURV III
AUSS
ATV
XP 21

A few years ago, the listing of ROVs passed 1000. We must be near 2000 by now, just counting PHANTOMs, PAPs, and MNVs. Truly, there are capable remotely operated work systems available and working in all of the oceans on earth, and in a couple of the seas of Mars.

Future

This decade has provided adequate evidence of the requirements for, development of, and useful operations by remotely operated vehicles and their cousins, autonomous undersea vehicles (AUVs). Neural networks, fuzzy logic, Kalman filtering, voice control of manipulators or other vehicle systems, and digital processing of data, communications and imaging are just a few of the existing new technologies being applied to undersea vehicles. There are very good papers at this meeting covering all aspects of ROVs. Brad Mooney, Silvia Earl, and others are developing a thrust to provide a "deepest presence" in the oceans. Unmanned vehicles will complement manned systems in this deep ocean venture. The recent increased interest in assessing and developing ocean resources provides major challenges for new initiatives for all ocean tools, including the application of remotely operated vehicles both on the surface and in shallow water, as well as in the deep ocean. The attendees at this meeting and the challenges to continue exploring and working in the ocean assure a vibrant future for all types of unmanned undersea vehicles (UUVs). The current U.S. National Research Council Marine Board study on "Undersea Vehicles for Civil Use" also opens new vistas for application of our chosen field. I see continued needs for innovation and development in the exciting world of ROVs, AUVs, and UUVs.

SUBMERSIBLE SAFETY: NEW DEVELOPMENTS IN
SHALLOW WATER SUBMERSIBLE RESCUE EQUIPMENT AND TECHNIQUES

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Safety of our ship and submersible personnel is of the foremost concern at Harbor Branch Oceanographic Institution. Since 1971, when Johnson-Sea-Link I was commissioned, she has accumulated in excess of 3100 dives followed by Johnson-Sea-Link II which was commissioned in 1975 and has logged over 2300 dives giving an impressive total of over 5400 dives to depths of 3000 fsw.

In the early days, we developed rescue equipment such as the recovery reel that required another manned submersible to effect a hook up and either jettison or surface with it. Also devices that could be lowered from the surface such as the sliding drop lock, a weighted assembly that is grooved on one side to fit around the buoy line, went through a trial and error period but never quite reached a point where they could be used reliably in a rescue scenario. Even though we had the ability to attach a lift line to a stricken vehicle, we never had the equipment (winches) aboard ship capable of pulling the vehicle to the surface. Primarily, self-help relied on the fact that we had two submersibles that operated within twelve hours of each other.

For the past 10 years, operations tended to take our ships in opposite directions eliminating the self-help rescue capabilities. Also, during the period 1973-1984, the size of the vessels (125' R/V JOHNSON and 100' R/V SEA DIVER) eliminated the possibility of carrying on board any type of rescue equipment such as a large winch, an ROV system, or method of attaching a lift line to a stricken vehicle.

With the commissioning of the 176' R/V SEWARD JOHNSON in 1985, the opportunity to carry an ROV system in addition to the submersible was now available. Adequate deck space for a rescue winch was also available. Several attempts to couple a lift line to a stricken sub (simulated) were conducted with the ROV CORD (Cabled Observation Rescue Device) with unsatisfactory results. Problems occurred with the lift line becoming entangled with the ROV umbilical as it was being carried to the bottom. Another attempt using the vessel's anchor as a klump weight to carry the lift line down resulted in several problems; one being a 1500 lb anchor dangling above the submersible, and another being the necessity for the ship to hold station within 100' of the submersible, to facilitate the CORD ROV's attaching of the lift line to the submersible. This also resulted in numerous entanglements. That is not to say that with persistence, an attachment could have been made.

More recently, we have rekindled an old idea; that of using a **Pull-Down Retriever** device that was designed in 1973 by E.N. Rosenberg and S.F. Moran from the Ocean Technology Department of the Naval Undersea Center in San Diego, CA. We felt the concept was solid and merited a review to determine whether or not it could become an effective rescue device. Through the efforts of HBOI Engineer Chris Tietze, a working model was fabricated of aluminum incorporating design changes that enabled the device to be placed on a line without releasing the line.

Initial in-water tests were conducted with the prototype retriever starting at 100 fsw and progressing to 1300 fsw. Strategically placed video cameras mounted on the Johnson-Sea-Link recorded the results for later analysis. Based on the results of the shallow water tests, it was decided to proceed with fabrication of a stainless steel retriever and outfit the R/V SEWARD JOHNSON with a deck mounted winch capable of storing 10,000 feet of .670 nylon jacketed Kevlar lift line. A 36 inch diameter snatch block was purchased and configured for installation on the 'A' frame launch and recovery system. Until now all tests were conducted without the aid of a winch and block and no actual lift was attempted.

The equipment is separated into two categories, the submersible-carried buoy system and the vessel-carried retriever system. In addition a suitable small boat is necessary to execute the operation. Each of these components is essential for the system to work. Construction and complexity may vary somewhat depending on the type of vehicle and space available for installation.

The Buoy System

The buoy system on the Johnson-Sea-Link (J-S-L) consists of four major components: the buoy, buoy line, extension tube and submersible locking cone.

The buoy is a Polyform A5 with a circumference of 90 inches. It has a buoyancy of 396 lbs. It has been fitted with four .750 inch relief valves to vent excess air during its ascent. It is also fitted with another relief valve venting inward to allow sea water to enter it during descent. Only enough water enters the buoy to reduce squeezing and creasing of the folds when it is stored and at depth. The size and type of buoy used is strictly up to the operator and the conditions expected in the operations sight. In the case of the J-S-L's: severe surface currents are often encountered. With this in mind, we have chosen a high lift buoy with an average surfacing time of about five minutes. This is very important to us because in some areas dynamic drag on the buoy line will drag the buoy under if it is not recovered and the line taken under tow quickly. The buoy is stored in a funnel shaped device that allows it to be collapsed inward to reduce its size and is mounted rigidly to the submersible frame. Self-locking cable ties are used to secure the folded buoy in the funnel and are broken when the buoy is inflated during deployment. Air from the submersibles banks is used to inflate the buoy and is introduced through a quick disconnect, similar to a football inflator. Once the buoy has broken free from its storage funnel it hangs from the locking cone and extension tube. It continues to inflate until it reaches sufficient buoyancy (about 100 lbs.) to break self-locking cable ties on the locking cone which allow it to ascend.

The buoy line is stored on a 4.5 inch wide by 22.5 inch diameter reel which is located under the funnel on the inner side of the starboard ballast tank between frame members and the pilot sphere. It holds 5,000 feet of nylon jacketed .134" Kevlar line with a minimum breaking strength of 2,300 lbs. The buoy end of the line passes through a special mounting fixture on which the storage funnel is attached and the locking cone and extension tube are secured. The extension tube is allowed to slip down through the attachment block when in the stored position to save space. The buoy line is kept from unreeling with a loop of bungie cord which is stretched from a frame member, over "top dead center", to one of the four drag fins on the storage reel. The fins keep it from over spinning or backlashing during the buoy's ascent. Small self-locking cable ties are also used in strategic places on the reel to keep the line from back lashing during the inflation sequence. After the buoy has reached the surface, all the line is pulled off the reel until the bitter end is reached. This end of the line is not attached to the reel. Instead it terminates in an aluminum block which is allowed to spin free of the reel and anchor in the under side of the attachment block. All of the line passes through the center of the locking cone and extension tube. The funnel and mounting fixture are attached to a frame member capable of withstanding the total lifting forces expected on the submersible.

The extension tube is 24 inches in length by .750 inches in diameter with a .250 inch through hole to allow passage of the Kevlar buoy line. The hollow extension tube has a 2 inch ball joint on either end. When pulled up into place by the inflating buoy, it can swivel in the direction of the ascending buoy line as it is unreeled through it.

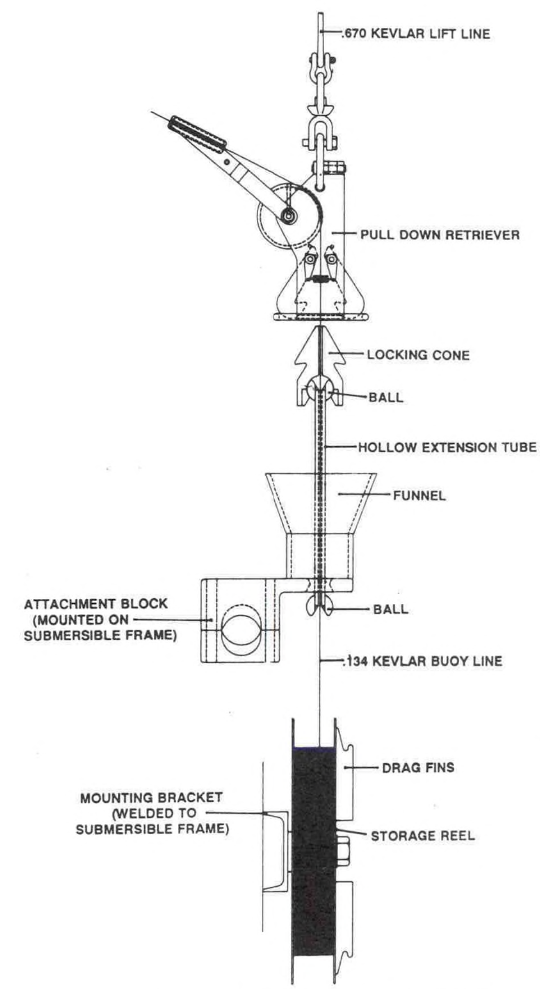
The locking cone is the connecting point between the submersible and the **Pull- Down Retriever.** It is fastened to the attachment block by the hollow extension tube. The cone is also drilled for line passage.

When all the buoy line is stretched out, the extension tube and locking cone will be perfectly aligned with the buoy line. This is essential if the retriever is to lock on to the cone properly. The locking cone must be the highest structure on the submersible in order that the retriever have clear access to it from any direction. The extension tube is constructed of titanium 6AL-4V, the locking cone of 6061T6 aluminum.

The Pull-Down Retriever System

The **Pull-Down Retriever** system carried on board the surface support vessel consists of a deck mounted winch, lift line, large snatch block, and the retriever assembly.

The retriever assembly is basically a snatch-block with locking hooks and weighs 20 lbs. It does, however, have some very special features. The retriever can completely split in two at its hinge point. This permits the user to attach it to the buoy line without threading it through the device or detaching the buoy. This is very important if tension is to be maintained on the buoy line at all times. Sliding clips grasp the four pins which pass through the side plates, rejoining the device. There are two line guides on the retriever; a guide arm at the top, and a ring at the bottom of the device. These keep the buoy line directed into the sheave regardless of the direction the retriever is going. The hooks slide through a female guide cone (not shown) which help align the locking cone and the retriever. A spring is used to pull the two hooks together whether or not there is tension on the device. (Figure 1)



PULL DOWN RETRIEVER SYSTEM

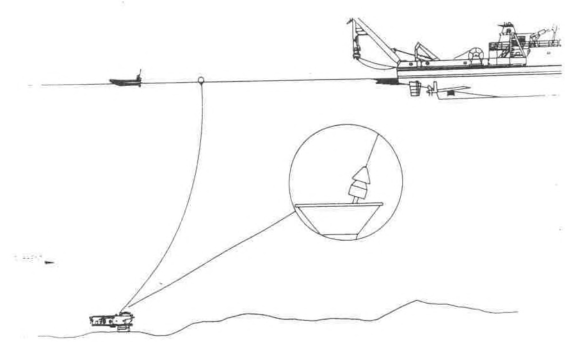
Figure 1

The lift line is attached to a ring that passes through an opening in both side plates of the retriever. This permits a high strength connection to both plates, and still allows the device to open. The design load for the retriever is 25,000 lbs.

The winch used in the tests was a hydraulic storage reel with approximately 5000 lbs. of line pull. It was welded to the aft deck in line with the center of the 'A' frame.

The lift line is .670 diameter Kevlar with a nylon jacket. Six thousand feet was available for this series of tests. The breaking strength is 33,000 lbs. The specific gravity is approximately 1.4 making it slightly negative so that it sinks with the retriever instead of forming an upward catonary.

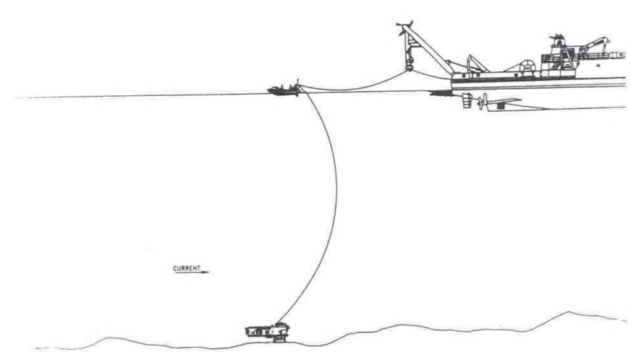
The block utilized is 36 inches in diameter with a releasable top bail to facilitate passage of the lift line with shackle attached. The attachment to the 'A' frame telescoping lift leg was accomplished with heavy chain. Figures 2-6 depict a J-S-L rescue scenario.



BUOY ON SURFACE

Submsersible is unable to surface. Pilot or observation compartment operator releases rescue buoy which carries Kevlar line to the surface. Upon release of the buoy, the locking cone is extended above the submersible using a hollow titanium extension tube through which the Kevlar line passes.

Figure 2

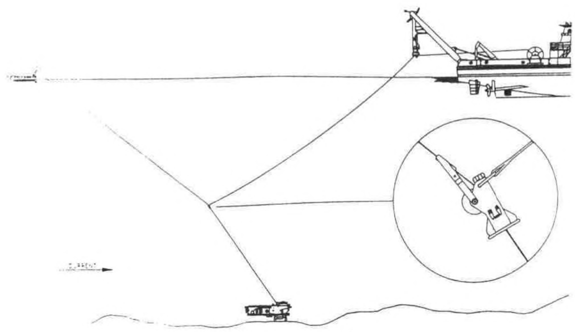


BUOY IN BOAT/TRANSFER RETRIEVER

Once buoy is sighted on surface, small boat retrieves it. Slack is removed from buoy line. Retriever and lift line is passed from mother ship to small boat.

Retriever is locked around the buoy line. At no time is buoy line released.

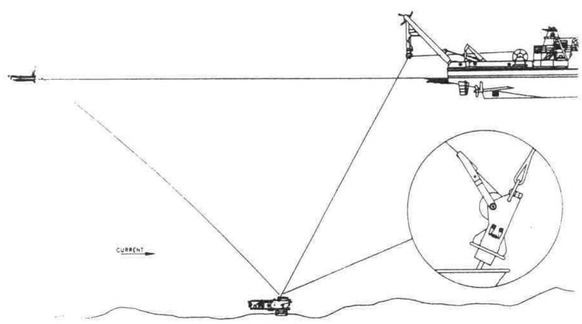
Figure 3



RETRIEVER PULLING DOWN BUOY LINE

Small boat pulls buoy line up current. Mother ship pays out lift line as it moves down current allowing retriever to move down buoy line. The greater the angle between the buoy line and the lift line, the easier it is for the retriever to travel in a downward direction.

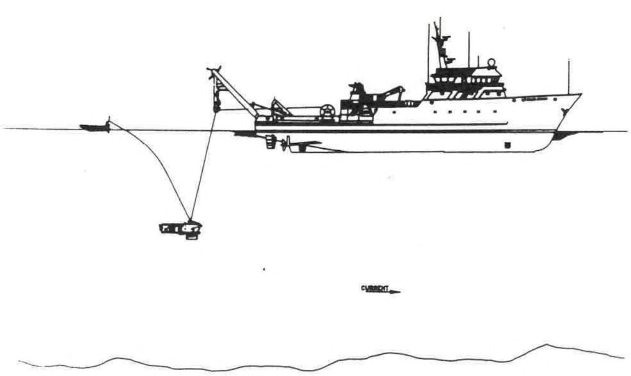
Figure 4



RETRIEVER CONNECTED

The retriever, which is spring loaded, snaps on to the locking cone upon reaching the submersible.

Figure 5



RECOVERY

Submersible can now be winched to the surface. Buoy line slack is taken up by small boat.

Figure 6

Pull-Down Retriever test results

The continuing development of the **Pull-Down Retriever**, based on the prototype (aluminum retriever) test results from 1989 and 1990, and resulted in construction of two stainless steel functional retrievers with associated hardware. The biggest change in the operational procedures was the addition of the hydraulic winch and 36" diameter snatch block to handle the lengthened (4000'-6000') Kevlar rescue line. This enabled us to conduct a real life rescue scenario from start to finish. A dedicated series of submersible dives were conducted in November, 1991 at various depths to allow for repeatability of our rescue techniques.

The following dives were conducted utilizing R/V SEWARD JOHNSON and J-S-L II. Each one leading to improvements in operational procedures. We learned as much from our failures as we did from our successes.

Dive 1 (J-S-L II Dive #2305 Depth 2176 fsw):

J-S-L descended to bottom, flooded down heavy (approx. 300 lbs), released rescue buoy. Buoy was retrieved on surface by small boat. All buoy line was pulled out taut (4000'). Two Klein grips (quick release device to hold cable) were installed on buoy line and tension was applied using small boat. R/V SEWARD JOHNSON approached small boat by backing down on their location. Upon reaching the small boat, the lift line was passed to them from the stern and connected to the retriever which was already attached onto the buoy line between the two Klein grips. The Klein grip attached to the stern of the small boat was then released to allow the retriever passage down the buoy line. It was then reinstalled behind the retriever and tension resumed prior to releasing the retriever. The retriever was then released and lift line was payed out from the R/VSJ at a rate that was deemed appropriate for the retrievers anticipated descent. During this procedure, R/VSJ was moving away from the small boat approximately 180° opposite of the heading of the small boat toward the location of the J-S-L. As the line was payed out, R/VSJ eventually passed over the J-S-L and continued approximately 1800 yds beyond. All 6000 ft of lift line was deployed with no hook up by the retriever taking place. Various tactics were then employed to try to remedy the situation such as backing down with the ship, taking up lift line on the winch, redirecting the small boat, increasing tension on the buoy line with the small boat, all of which failed to initiate a hook up. After 3+ hours of frustrating attempts, it was decided to abort the dive and recover the hardware due to suspected fouling.

Discussions after the exercise resulted in several speculations as to the nature of the failed attempt. The following circumstances may have contributed to the inability to hook up.

1. The method in which R/V SEWARD JOHNSON approached the small boat for lift line transfer, i.e., vessel backing down toward small boat resulting in inability to maintain heading and position instead of a starboard side underway approach on small boat similar to J-S-L recovery approach. This would allow the R/VSJ to attain the proper heading and speed for deployment of the retriever after line is passed to small boat.

2. Paying lift line out faster than the sink rate and the forward velocity of the R/VSJ.

3. Tensioning of buoy line by small boat, i.e., in retrospect it was thought that more tension should have been applied throughout the entire scenario. Lack of adequate tension was thought to create a dog leg in the buoy line which stopped the retriever's descent. Also, during this procedure, the J-S-L was physically being dragged, at times, and additional ballast was added. This still resulted in movement of the J-S-L.

Dive 2 (J-S-L II Dive #2306 Depth 1825 fsw):

J-S-L descended to bottom, flooded down heavy (approx. 700 lbs), proceeded to release rescue buoy. Buoy released and started ascent but became entangled when reel backlashed. The dive was then aborted and after evaluating the problem, it was decided that the buoy line could not be repacked adequately while the reel was installed on the J-S-L. The reel was then removed from the J-S-L, the line was unreeled onto another empty spool and carefully rewound to make each lay tight and level. This took approximately 3 hours. Subsequently, the same amount of time was expended after each buoy deployment, in addition to reterminating which took another 3 hours.

Dive 3 (J-S-L II Dive #2307 Depth 1910 fsw):

J-S-L descended to bottom, flooded down heavy (approx. 700 lbs.), proceeded to release rescue buoy. Buoy released and took approx. 4 minutes to reach the surface. Buoy was retrieved on surface by small boat. All buoy line was pulled out taut. Two Klein grips were installed on the buoy line, and tension was applied using small boat. R/VSJ approached small boat in the same manner as a J-S-L recovery. Upon reaching the small boat, which passed slowly down the stbd side of the vessel, the lift line was passed to them at approx. mid-ships (allowing for several attempts, if needed) and connected to the retriever which was already attached onto the buoy line between the two Klein grips. The Klein grip attached to the stern of the small boat was then released to allow the retriever passage down the buoy line. It was then reinstalled behind the retriever and tension resumed prior to releasing the retriever. The retriever was then released and the lift line was payed out from R/VSJ at a much slower rate than the first attempt. Vessel speed was also reduced to bare steerageway. During this procedure, R/VSJ was moving away from small boat approx 180° opposite the heading of the small boat. The small boat's heading was determined by the bottom current reported by the J-S-L and by the offset of the buoy upon reaching the surface. As the line was payed out, R/VSJ eventually passed over the J-S-L and continued approx. 1500 yds. beyond the J-S-L.

Approx. 5500 feet of lift line was deployed and the winch was secured allowing the R/VSJ to tension the lift line. This resulted in pulling the J-S-L and the small boat indicating that we were putting a dog leg in the buoy line. We immediately started backing down on the lift line allowing the small boat to retension, eliminating the dog leg, and allowing the retriever to continue its downward path resulting in a hook up. Weather conditions dictated numerous corrective maneuvers to maintain the proper pulling angle and alignment between R/VSJ and the small boat. From the time the buoy reached the surface to final hook up of the retriever was 2 hrs. 15 minutes. R/VSJ, upon hook up, immediately began backing down in the direction of the lift line recovering the excess. Once the lift line angle returned to vertical as indicated by the submersible via the underwater telephone (UQC), the J-S-L was lifted off the bottom and winched toward the surface. At approx. 40 ft. below the surface, the J-S-L blew its ballast tanks and surfaced. This was done for safety reasons as the distance between the J-S-L and the stern of R/VSJ was critical. At this point, the swimmer attached the tow line, the J-S-L was pulled into position behind the stern, the lift line was slacked off, the a-frame was then moved to the inboard position, the snatch block was then removed and the a-frame was then moved back to the outboard position and a normal recovery was then accomplished.

Dive 4 (J-S-L II Dive #2308 Depth 2393 fsw):

Other than the depth, which was approx. 500 ft. deeper, and surface conditions, with wind in excess of 20 mph throughout the exercise, the scenario was identical to dive #2307. It took 1 hr. 17 min. from the time the buoy reached the surface until the retriever locked on and 1 hr 6 min. from the time the retriever locked on until J-S-L reached the surface. The rigging of the snatch block was changed from the stbd side of the teleleg to the aft center of the teleleg for this exercise. This allowed us to recover the J-S-L with the snatch block in place eliminating the need to move the a-frame in and out or remove the lift line prior to recovery. The result was a much smoother operation with a direct lift up to the point of inserting the drop lock.

Summary

Obviously there is no sure fire rescue system that will adequately cover all possible situations where a submersible is unable to surface, whether it be entanglement or some other reason. Each new system or method is just another tool among many tools that allow for an immediate response to a situation that will only get worse as time passes. That is not to say don't "push the panic button" by all means this is a must, and with modern communication systems available, notification can be almost immediate. While the proverbial gears are turning to get help on the move precious hours are being lost. Even with up to five days life support, weather conditions can change from good to bad, panic can set in, batteries will get weaker and anything else that can go wrong will . . . Murphy's law.

Almost all submersible operators are presently engaged in development of a variety of rescue techniques. Remotely operated vehicles (ROVs) are among the favorite methods employed especially in the case of the deeper operating vehicles 2000-6500 meters. In some cases ROVs are built concurrently with the submersible. Other methods employ a sub surface buoy that can be released to rise several hundred feet above the submersible with a locating beacon attached that allows the surface vessel to make controlled passes and attempt to snag it with a variety of grappling devices.

There are several overriding factors that provide the impetus to continue to design, develop and test new devices and methods for self-help rescue. The most important being that the oceanographic community cannot afford a submersible accident resulting in loss of life and ultimately loss of support both financially and philosophically. Additionally with operations spreading to the four corners of the world, outside help cannot respond in time.

Support, both moral and financial, are essential ingredients needed in the pursuit of developing equipment and methods. Harbor Branch management from the C.E.O. on down fully support and encourage development and implementation of equipment and techniques to enhance our self-help rescue capabilities.

What's in the future: Harbor Branch's Ocean Engineering R & D Division is currently redesigning two Mini Rover Mark IVs with an operational depth of 3000 fsw to become a permanent part of J-S-L support. The systems are small in size, light weight, simple to operate, repair and maintain. They will accompany the J-S-L's aboard ship on all missions and can be used for science in addition to the primary function of reconnaissance of a stricken submersible. It will also be possible to effect a hook up to the submersible utilizing the Mini Rover Mark IV by lowering a klump weight attached to the lift line already carried on board.

Tourist Submersible Safety Considerations

by John A. Pritzlaff
Westinghouse Oceanic Division
Annapolis, Maryland

The design and construction of tourist submersibles is usually done under the cognizance of one of the major ship classification societies. Operational activities have no safety standards other than those established by the operators themselves. Some are very good, others with limited financial resources are not so good.

Key Safety Points that have been made before, with respect to Tourist Submersible Safety and are worth repeating again are:

- Tourists are paying for a fun-type entertainment ride. They have a right to expect it to be safe and comfortable.
- The Submersible Operating Company is providing this entertainment experience in order to make money.
- Personnel must have the qualifications and training to do the job that they are assigned to do.
- Operational Plans and Procedures are needed to describe and document:
  - How the vessels are handled
  - How the people are handled
  - How maintenance is handled
  - How emergencies are handled
- Operational plans describe and document what is to be done.
- Operational procedures describe and document how it is to be done.
- Tourist submersible equipment must consider and address the numbers and types of tourists involved in the transport and diving activity. They may be:
  - Young/old
  - Agile/clumsy
  - Healthy/sick.

  This consideration must include normal and emergency conditions.
- One operator's accident or bad entrapment incident will get worldwide publicity and would hurt business for all operators.

A Tourist Submersible Safety and Operational Guideline Book is being generated by technical Submersible Panel and Undersea Vehicle Committee members from the Society of Naval Architects and Marine Engineers (SNAME) and the Marine Technology Society (MTS).

The book is divided into five main sections, Introduction, Personnel, Plans and Procedures and Equipment and Appendices. The six appendix sections include the following subsections:

Appendix I:

- o US Coast Guard Navigation and Inspection Circular - NVIC)
- o Guidance for Certification of Passenger Carrying Submersibles
- o Guidelines for Stability of Small Passenger Submersibles
- o Discussion paper "US Coast Guard Regulation of Passenger-Carrying Submersibles" published by SNAME, 6 November 1991.

Appendix II:

Department of Transportation Systems Center - System Safety Analysis of Passenger Carrying Submersibles.

Appendix III:

National Research Council Marine Board - Assessment of Passenger Submersible Safety

Appendix IV:

The Merchant Shipping (Submersible Craft Construction, Equipment and Survey) (Cayman Islands) Regulations, 1991.

Appendix V:

Minutes of the 1990 Tourist Submersible Operational Safety Workshop.

Appendix VI:

Technical and Ship Classification Society Tourist Submersible Discussions.

It is hoped that the generation and industry application of this Operational Safety Guideline Book will enable the Tourist Submersible Industry to grow in a safe and profitable fashion.

At some time in the future it is expected that a second Tourist Oceanology International will be held and that a concurrent tourist submersible Safety Workshop will be held. At this workshop, the use experience of the Safety Guideline Book would be reviewed along with the Operational Safety aspects of the tourist submersibles themselves.

The summary of tourist submersible operational activities can be seen on the attached chart, where most all of the built and building submersibles are listed.

Atlantis as can be seen is the largest builder/operator with 12 submarines.

W-Sub has built 6. Submarine OY has provided 3. Both of these companies are personnel related to the Wartsila Laivateollisuus yard which produced the 4 Maria class submarines.

Recently introduced in the Monte Carlo, Monaco tourist excursion scene is the Comex Seabus. Coming into the market place soon, will be the Bruker Seamaid TS (Figure 1) and Intersub's, Coral Ranger. (Figure 2)

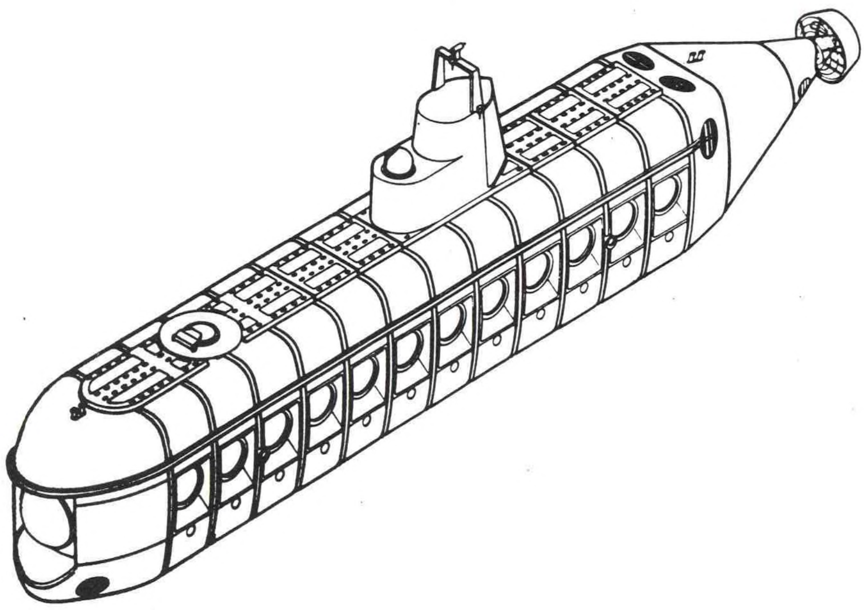


FIGURE 1

LINE DRAWING OF
THE BRUCKER SEAMAID TS

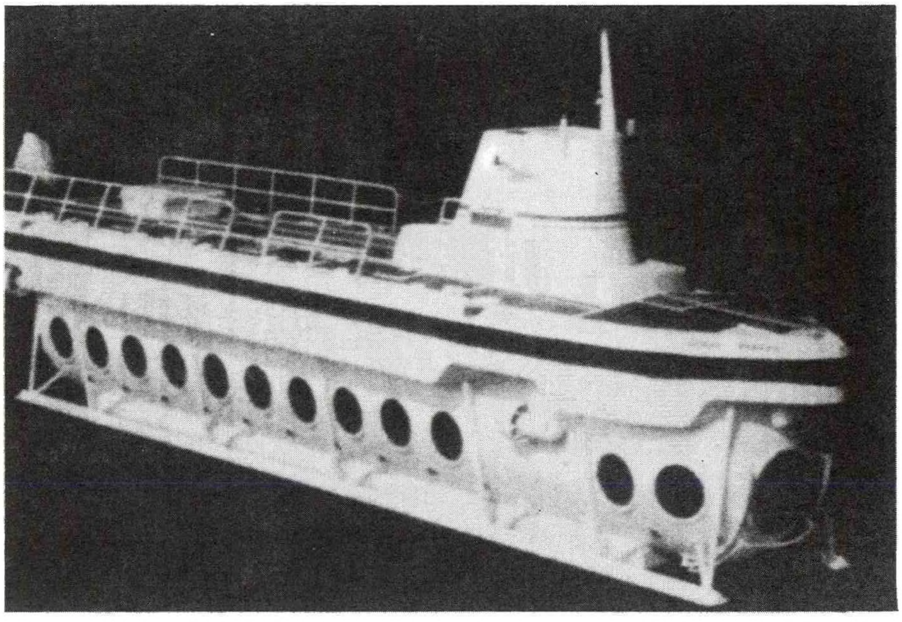


FIGURE 2

MODEL OF INTERSUB'S
CORAL RANGER

Some tourist submersible marketing "experts" have predicted that during the '90s the 50 to 60 prime submarine diving sites will be filled and that continued expansion of the industry will slow, if not stop.

Other approaches to fun and excitement in and under the water can be expected to see introduction and use in this time frame and into the future. The semi-submersible tourist boat - as currently being used off the Great Barrier Reef in Australia, is one alternative. It is essentially an extension of the glass bottom boat where the passengers descend below the water line to view the sea through large plastic windows. (Figure 3.) The viewing experience is much like that of the tourist submarine without all of the technology complexity. This semi-submersible type craft is now being built in the United States under the Nautilus name by Subsea Systems of Placerville, California.

On shore and near shore aquariums are also seeing increased attention in the entrepreneurial quest for the world-wide recreation dollar and yen.

For the tourist submersible industry to grow and prosper it must be safe. The SNAME/MTS safety Guideline Book is but one step in that direction. The builders, owners, and operators must all think and practice safety - for the passengers, the crew and the boats.

Also included in this Tourist Submersible Safety discussion is a copy of the Cayman Island Merchant Shipping Regulations (1991) for Submersible Craft and Construction Equipment and Survey and Submersible Craft Operations.

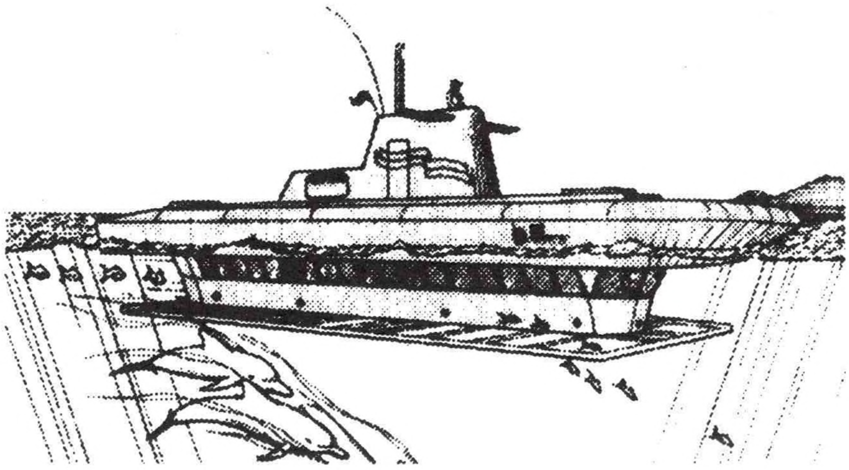


FIGURE 3

LINE DRAWING OF THE NAUTILUS
SEMI-SUBMERSIBLE
TOURIST BOAT

Tourist Submarines: Inactive, Operational & Under Construction*

#	Yr	Submarine	Cap	Location	Owner/Operator	Designer/Builder
1	83	PC-8	2	Grand Cayman - Bulgar.	RSL - S.A.S.	Perry
2	84	PC-1802	3	Grand Cayman	RSL - Inactive	Perry
3	85	PC-1205	2	Grand Cayman	RSL - Inactive	Perry
4	85	Atlantis I	28	Grand Cayman	Atlantis - Inactive (refit)	Atlantis
5	87	Atlantis II	28	Barbados	Atlantis	Atlantis
6	87	PC-1201	2	Rota, Marianas	M.I.C. Corp. - For Sale	Perry
7	87	Atlantis III	46	St. Thomas, USVI	Atlantis	Atlantis
8	87	Pisces II	2	Grand Cayman	RSL	Hyco
9	87	Mareia I (RS250)	48	Saipan	Dosa Subsea	Laivateollisuus/Wartsila
10	88	Aquarius	2	Oahu- Seattle	Sub Voyages - Inactive	Hyco
11	88	PC-1601	3	Scotland	L. Segura - Incomplete	Perry/Fluid Energy
12	88	PC-1805	3	Florida	Belaya - Inactive	Perry
13	88	Looking Glass (LG50)	48	St. Thomas	N/A - For Sale	Fluid Energy
14	88	Golden Trout (RS250)	48	Canary Islands	Subtrek	Laivateollisuus/Wartsila
15	88	Atlantis IV	46	Kona - Oahu- Maui HI	Atlantis Subs Hawaii LP	Atlantis
16	88	Enterprise (LG50)	48	Bermuda	Enterprise Submarine	Fluid Energy
17	88	Mareia II (RS250)	48	Cheju-do Is., S. Korea	Daekuk Subsea	Laivateollisuus/Wartsila
18	88	Atlantis V	46	Guam	Atlantis	Atlantis
19	89	Coral Adventure (RS250)	48	Kagoshima, Japan	Time Associates	Laivateollisuus/Wartsila
20	89	Atlantis VII	46	Oahu - Kona, Hawaii	Atlantis Subs Hawaii LP	Atlantis
21	89	Moglyn	40	Okinawa	Japan Sub. Tourism Ltd.	Mitsubishi Heavy Ind.
22	89	Golden Salmon (RS250)	48	Canary Islands	Subtrek	W-Sub
23	90	Dolphin I (Non-classified)	8	Curacao	Hopefully Inactive	Plongée
24	90	Mergo 10	10	Switzerland; Florida	M&W - Lease start-up	Malmari & Winberg
25	90	Sinbad (Mark III)	48	Hurghada, Eygpt	Sinbad Tourism Co.	W-Sub
26	90	Jacqueline SM-100	48	Elat, Israel	Scandive/Coral World	Submarine Oy/Frabeco
27	90	Atlantis VI	46	Aruba, Antillies	Atlantis	Atlantis
28	91	Odyssey I	36	Sint Maarten, Antillies	Submarine Safaris	Int'l Sub. Engineering
29	91	Sub Fun (Mark III)	48	Alicante, Spain	Sub Fun SL	W-Sub
30	91	SPT-16*	16	for sale - Switzerland	N/A	Piccard/Sulzer
31	91	Odyssey II	36	Bali, Indonesia	PT Sub. Safaris Asia	ISE
32	91	Seeview* was PC-15C	8	for sale - Florida	P. Hoffman - Incomplete	Perry/Roger Cook
33	91	SMAL 5*	5	Martinique, FWI	N/A	SMAL Industries
34	91	SMAL 5*	5	St. Martin, FWI ?	N/A	SMAL Industries
35	91	Mundo Magico (Mark III)	48	Marbella, Spain	Top Diving S.A.	W-Sub
36	91	Atlantis IX	46	Oahu, Hawaii	Atlantis Subs Hawaii LP	Atlantis
37	91	Atlantis X	46	Oahu, Hawaii	Atlantis Subs Hawaii LP	Atlantis
38	91	Atlantis XI	46	Grand Cayman	Atlantis	Atlantis
39	92	Seabus	44	Monte Carlo, Monaco	Comex + others	Comex
40	92	Hai Yan No. 1 (Mark III)	48	Taiwan, R.O.C.	Jan-An Steamship Co.	W-Sub
41	92	Nemo Primero (Mark III)	48	Mallorca, Spain	Nemo Submarines	W-Sub
42	92	Seamaid TSIV*	48	Martinique, FWI	Matcosub	Bruker Meerestechnik Gmb
43	92	Seaview*	10?	Michigan	Seaview- Status unknow	Seaview/Will Forman
44	92	Atlantis XII*	46	Mexico	Atlantis	Atlantis
45	92	SM-100/26*	24	Mediterranian	N/A	Submarine Oy
46	92	SM-100/26*	24	Pacific	N/A	Submarine Oy

Year - refers to year first in service, or expected to enter service as a tourist submarine; not year of manufacture

Submarine - name of vessel and (model type or number)

Capacity - number of passengers not including pilot

Location - first entry is original location as tourist submarine, last entry is current location. Submarine is active unless comments denote otherwise, in which case the location is where the vessel is currently stored or in refit

Operator - name of operating entity. Last comment reflects current status. N/A reflects unknown or confidential information with regard to operator.

Designer/Builder - vessel designer is first entry, followed by builder name if different

* - denotes vessel currently under construction

All entries thought accurate as of April 6, 1992

THE MERCHANT SHIPPING
(SUBMERSIBLE CRAFT) LAW
1991

CAYMAN ISLANDS

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THIS APPENDIX IS INCLUDED AS AN EXAMPLE OF THE SUBMERSIBLE REGULATIONS ENACTED BY A PRUDENT MARITIME STATE TO ENSURE THE SAFETY OF LIFE AND EQUIPMENT WHILE OPERATIONS ARE CONDUCTED IN WATERS UNDER THEIR JURISDICTION.

IT SHOULD BE NOTED THAT THESE REGULATIONS IN SOME AREAS DUPLICATE CLASSIFICATION SOCIETY RULES AND A FEW AREAS MAY BE MORE STRINGENT. DISCUSSIONS WITH THE CAYMAN ISLAND AUTHORITIES ARE RECOMMENDED FOR TOURIST SUBMERSIBLE ACTIVITIES PLANNING CAYMAN ISLAND OPERATIONS.

CAYMAN ISLANDS

Supplement No. 1 Published with Extraordinary Gazette dated Monday, 24th June, 1991

THE MERCHANT SHIPPING (SUBMERSIBLE CRAFT CONSTRUCTION, EQUIPMENT AND SURVEY) (CAYMAN ISLANDS) REGULATIONS, 1991

THE MERCHANT SHIPPING (SUBMERSIBLE CRAFT) LAW, 1991

THE MERCHANT SHIPPING (SUBMERSIBLE CRAFT OPERATIONS)(CAYMAN ISLANDS) REGULATIONS, 1991

In exercise of the powers conferred upon the Governor by section 16 of the Merchant Shipping (Submersible Craft) Law, 1991, the following regulations are made –

Citation, commencement and interpretation.

1.- (1) These regulations may be cited as the Merchant Shipping (Submersible Craft Operations) (Cayman Islands) Regulations, 1991, and shall be deemed to have come into force on the 1st day of June, 1991.

(2) In these regulations, unless the context otherwise requires –

"approved doctor" means a doctor approved by the Governor as competent to examine pilots and crew;

"co-pilot" means the person appointed as second in command of a sumbersible craft;

"crew" means the person or persons within the submersible craft required to operate the craft or its equipment;

"diving chamber operator" means a person specially trained and qualified in the use of diving recompression chambers;

"diver lock-out submersible craft" means a submersible craft, a compartment of which allows underwater access for personnel and with a means of controlling the differential pressure between the inside and outside environment;

"master" means the person in charge of the parent craft;

"operations controller" means the person appointed by the owner pursuant to regulation 5(1)(d);

"operations manual" means the manual referred to in regulation 5(1)(h) and Schedule 1;

"parent craft" means any vessel, structure or place from which a submersible craft is launched or recovered or from which it is supported or operated;

"passenger" means a person who is not crew;

"pilot" means the person appointed to command the submersible craft or, in the case of a submersible craft which is an atmospheric diving suit, to operate that diving suit;

"the Law" means the Merchant Shipping (Submersible Craft) Law, 1991;

"submersible operation" means any operation of a submersible craft and its supporting equipment to which these regulations apply;

"supporting equipment" means the launching and recovery gear used in connection with a submersible craft.

(3) References in these regulations to the owner of a submersible craft or supporting equipment, are, for the purpose of the application of any provision of these regulations in relation to any particular submersible craft or supporting equipment, references to the person who at the relevant time has the management of that submersible craft or supporting equipment.

Application.

2. (1) Subject to paragraph (2), these regulations apply to any submersible craft which –

(a) is registered in the register of submersible craft; and

(b) is required to be registered in the register of submersible craft under section 5(2) of the Law, whether it is so registered or not.

(2) These regulations apply to any supporting apparatus which is used in connection with a submersible craft to which these regulations apply.

Master of parent craft.

3. The master of a parent craft shall –

(a) ensure that no operation or activity which is likely to be a danger to any person engaged in the submersible operation is carried on from or on the parent craft;

(b) before commencing any activity which in his opinion might affect the safety of the submersible operation, advise the operations controller;

(c) ensure that the area of the parent craft on or from which any part of the submersible operation is carried out is maintained in a condition suitable and safe for that purpose;

(d) before the submersible operation begins and at adequately frequent intervals during the course of such operation, ensure that the operations controller is provided with meteorological and oceanological forecasts for the relevant area;

(e) warn the operations controller of the approach of any vessel which is or might become a hazard to the parent craft or the submersible craft;

(f) take such steps as circumstances may require to warn vessels in the vicinity that a submersible operation is in progress from or near the parent craft;

(g) in the event of a casualty, ensure notification by the operations controller to the owner as required under regulation 13.

Owners of submersible craft.

4. The owner of a submersible craft shall take all practicable steps to ensure that these regulations are in all respects complied with by those persons upon whom duties are imposed by these regulations.

5. (1) The owner of a submersible craft which is engaged or about to engage in a submersible operation shall make adequate arrangements and submit proposals for the approval of the Chief Marine Surveyor for the safe conduct of the submersible operation, and in particular, but without prejudice to the generality of the foregoing, shall –

(a) ensure that there is a safe and suitable platform or other area of the parent craft from which the submersible craft can be launched, recovered or supported;

(b) ensure that all plant and equipment necessary for the safe conduct of the submersible operation is available for use;

(c) ensure that there are adequate and effective means of communication and means of recording communication between the submersible craft and the place from which the submersible operation is controlled;

(d) appoint, in writing, a person to control the submersible operation; such person shall have adequate knowledge of the techniques to be used in the submersible operation;

(e) appoint, in writing, to command the submersible craft one or more persons who are qualified under regulation 9 to pilot that submersible craft;

(f) appoint sufficient personnel other than those required by sub-paragraphs (d) and (e) of this paragraph to enable the submersible operation to be carried out in a safe manner;

(g) require all persons engaged in the submersible operation to obey the instructions of the operations controller;

(h) issue an operations manual relating to the matters specified in this regulation and Schedule 1 for regulating the safety and conduct of all persons engaged in the submersible operation under his control;

(i) where the submersible operation includes diving operations from a diver lock-out submersible craft, ensure that the operations controller is provided with a copy of an approved diving manual, also that a qualified diving chamber operator is present;

(j) provide the operations controller with an operations log book;

(k) prepare a contingency plan taking into account all rescue services which are readily available to be called upon in an emergency, and make copies of that plan available to the operations controller, the master, the pilot and to all the authorities and rescue services necessary for its effective execution;

(l) where the submersible craft is a one-man submersible craft, provide –

(i) a second fully operational submersible craft capable of operating in the maximum depth of water in which the craft is to be located together with a pilot, present at the work site; or

(ii) a second fully operational submersible craft and pilot capable, together with all necessary equipment, of being transported to the work site and being ready to dive within a period of not more than one third of the life-support time which would remain on completion of any planned operation of the submersible craft originally taking part in the operation or within 24 hours of the emergency arising, whichever is the shorter; or

(iii) an operational diving team, fully mobilised at the work-site, capable of diving into the depth in which the submersible craft is to operate within a period of 10 hours; or

(iv) an equivalent, proven effective arrangement approved by the Chief Marine Surveyor available for immediate deployment and capable of effecting a recovery within the time limits prescribed in sub-paragraph (ii) of this paragraph;

(m) inform any harbour or marine traffic control authority whose authority extends to the area where the submersible operation is to take place, of the nature and proposed time and location of the submersible operation;

(n) ensure that there are in force in respect of the submersible craft and supporting equipment the safety certificates issued under section 13 of the Law;

(o) ensure that a list is maintained of all personnel involved in the submersible operation which shall include the following information about each person –

(i) his name;

(ii) his address;

(iii) the capacity in which he is employed if applicable.

(2) The owner of a submersible craft shall retain the operations log-book referred to in paragraph (1)(j) for at least two years after the date of the last entry made therein.

Operations controller.

6. Every operations controller shall ensure that the submersible operation for which he has been appointed is being carried out safely and in accordance with the operations manual issued by the owner of the submersible craft pursuant to regulation 5(1)(h).

7. (1) The operations controller shall not permit the submersible operations to begin unless –

(a) the master has confirmed in the light of his duties under regulation 3 that it is safe to do so;

(b) there is produced to him a valid safety certificate issued by the Certifying Authority under the Law in respect of the submersible craft and its supporting equipment;

(c) regulation 5(1)(m) has been complied with;

(d) records show that post-dive checks carried out on the submersible craft and all its associated systems after its last previous dive and that any defects indicated by such checks have been made good and signed for by the person responsible for maintenance of the submersible craft and countersigned by the operations controller;

(e) a pre-dive check on the submersible craft and its associated systems has been carried out within 6 hours of the commencement of the dive by the pilot and the pre-dive check list has been signed by the pilot and countersigned by the operations controller;

(f) he has ensured that the pilot is familiar with the matters referred to in Schedule 1 and has been briefed on, and provided with, a copy of the emergency procedures laid down in the operational manual;

(g) the pilot and the crew (if any) of the submersible craft have been fully briefed as to their duties and mission;

(h) the wind, the state of the sea, visibility and predicted tidal currents are within the specified limits for safe operation as detailed in the operations manual;

(i) the submersible craft has adequate mid-water control, and the water depth is not greater than the maximum operating depth of the submersible craft;

(j) the pilot and crew are fit to carry out their duties;

(k) the supporting equipment has been checked and is in working order;

(l) a sufficient number of competent persons are present to operate any plant, equipment, or other facilities necessary for the safe conduct of the submersible operation.

(2) The operations controller shall ensure that the communications systems referred to in regulation 5(1)(c) are tested at the earliest possible opportunity in the submersible operation and are in good order.

8. The operations controller shall ensure that an accurate record of the matters specified in Schedule 2 in respect of each dive made by the submersible craft shall be entered in the operations log book referred to in regulation 5(1)(j) and shall countersign the entries after each dive by the submersible craft has been completed.

Requirements of pilots.

9. (1). A person shall not be qualified to be the pilot of a submersible craft unless he has –

(a) had previous experience in, and is competent in, the operation of the submersible craft which he is to pilot; or

(b) (i) received adequate theoretical and practical instruction in the operation of that submersible craft under the supervision of a person who is himself qualified under subparagraph (a) above to operate that submersible craft; and

(ii) demonstrated his ability to control the submersible craft and shown himself to have the necessary practical and theoretical knowledge of the submersible craft; and

(c) a current medical certificate issued not more than 12 months previously by an approved doctor certifying that he is fit to perform the duties of a pilot in that type of submersible craft.

(2) In a submersible craft which carries more than 6 passengers a co-pilot shall be appointed who is capable of –

(i) safely surfacing the submersible craft;

(ii) manoeuvering the submersible craft in the event of an emergency; and

(iii) operating all emergency systems and equipment on board the submersible craft.

10. Notwithstanding regulation 9(1)(b), a pilot in a one-man submersible craft or atmospheric diving suit while undergoing instruction for the purpose of obtaining the practical experience referred to in regulation 9(1)(b) shall be exempt from the requirements of that paragraph provided that –

(a) the training dives are being carried out in suitable environmental conditions; and

(b) during the training dives he is continuously under the direct supervision of a person qualified under regulation 9(1)(a) to operate that submersible craft.

Duties of pilot.

11. The pilot of a submersible craft shall –

(a) so operate the submersible craft as to ensure its safe operation and the safety of any crew and passengers;

(b) carry out the pre-dive and post-dive checks described in regulation 7;

(c) be fully conversant with the operational and emergency procedures to be adopted and shall brief any passengers and crew accordingly;

(d) ensure that the submersible craft has an adequate reserve of buoyancy and stability;

(e) keep a pilot's log book, which shall contain his signature and photograph, and enter therein the matters specified in Schedule 3 which entries shall be countersigned after each dive by the operations controller;

(f) retain that pilot's log book for a period not less than 2 years from the date of the last entry made therein.

Crew and passengers.

12. (1) Every member of the crew of, and every passenger in or on, a submersible craft shall –

(a) obey the orders of the pilot;

(b) observe all safety precautions; and

(c) be conversant with emergency procedures.

(2) Every member of the crew shall hold a current medical certificate issued by an approved doctor not more than 12 months prior to engaging in any submersible operation, certifying that he is fit to participate in a submersible operation.

Reports Of casualties.

13. Where a casualty has occurred the operations controller shall –

(a) in the most expeditious manner practicable inform the owner of the submersible craft when and where it occurred giving him the name of any person killed, lost or injured;

(b) enter in the operations log book the particulars of the casualty as specified in Schedule 4 and shall sign that entry;

(c) within three days of the casualty, deliver a copy of such particulars to the owner of the submersible craft.

14. The owner of a submersible craft shall –

(a) upon being informed of a casualty, give to the Chief Marine Surveyor, as soon as possible, such information about the casualty as he may have;

(b) within three days of receiving the copy particulars referred to in regulation 13(c) deliver a copy of those particulars together with his own name and address and the name and address of the pilot of the submersible craft to the Chief Marine Surveyor;

(c) if it comes to his knowledge that any person has died as a result of the casualty, inform the Chief Marine Surveyor of the death notwithstanding, if such be the case, that he is required to send a return of the death to the Registrar of Shipping.

Returns of injuries.

15.- (1) The owner of a submersible craft shall make a return of every accident, injury or disease (other than an injury already notified under regulation 14) suffered by any person, in connection with or working from the submersible craft, who is injured in the course of any submersible operation and by reason of which such person is disabled from work for a continuous period of three days or more.

(2) A return under this regulation –

(a) shall relate to a period of three months ending on the last day of March, June, September or December;

(b) shall be made to the Chief Marine Surveyor within 10 days after the end of the period to which it relates; and

(c) shall contain particulars of the following –

(i) the registration number, name or other designation of the submersible craft;

(ii) the name and address of the owner of the submersible craft;

(iii) the name of each person who suffered an accident, injury or disease and the name and address of his employer; and

(iv) the date and time of any accident or injury and the date when the symptoms of any disease were first observed;

together with a brief description of the accident, injury or disease.

Offences.

16.- (1) A person who contravenes any provision of these regulations shall be guilty of an offence and liable upon summary conviction to a fine not exceeding ten thousand dollars in respect of any one contravention.

(2) In any proceedings for an offence under these regulations it shall be a defence for the person charged to prove –

(a) that he exercised all due diligence to prevent commission of the offence; and

(b) that the offence was committed without his consent, connivance or default.

SCHEDULE 1
(Regs. 5(1)(h) and 7(1)(f))

MATTERS IN RESPECT OF WHICH WRITTEN PROCEDURES ARE TO BE MADE IN THE OPERATIONS MANUAL

Personnel:

1. Chain of command.
2. Responsibilities, authority and duties.

Operational Planning:

1. Mission planning.
2. Safety planning.
3. Movement and position reporting.
4. Operational environmental limitations.

Operational Procedures:

1. Planned maintenance.
2. Pre-dive and post-dive check-lists.
3. Maintenance of pilots, submersible operations, surface and underwater communications logbooks.
4. Pre-dive and post-dive briefings.
5. Routine operational procedures.
6. Submersible craft communications procedures.
7. Support craft position.
8. Estimation of stability and reserve of buoyancy.
9. In the case of diver lock-out submersible craft, particular aspects relating to diving from it.

Emergency Planning:

1. Problem identification.
2. Status of equipment and support services.
3. Self-help plan.
4. Outside help plan.
5. Diving or other medical services.

Emergency Procedures:

1. Position marking.
2. Initiation responsibilities.
3. Search procedures for lost submersible craft.
4. Recovery of disabled submersible craft.
5. Submersible craft emergency procedures.

Emergency Equipment:

1. Parent craft.
2. Submersible craft.
3. Launch and recovery.
4. Ancillary equipment.
5. Communications.

SCHEDULE 2 (Regulation 8)

MATTERS IN RESPECT OF WHICH ENTRIES ARE TO BE MADE IN THE SUBMERSIBLE CRAFT OPERATIONS LOGBOOK

(a) the name of the owner of the submersible craft;

(b) the name or designation of the submersible craft;

(c) the date or dates on which, and the period during which the submersible craft made its dive;

(d) the name or other designation of the parent craft, offshore installation or work site from which the submersible operation is carried on and the location of that craft, offshore installation or work site;

(e) the names of the submersible craft crew, and of any passengers, engaged in the dive and their respective duties;

(f) the times of the main events of the dive;

(g) the maximum depth reached in the course of the dive;

(h) the nature of the submersible operation with a description of the work carried out and problems encountered;

(i) the weather and bottom conditions;

(j) any other factors relevant to the safety or health of the persons engaged in the operation;

(k) particulars of any emergency which occurred during operation and of any action taken;

(l) particulars of any environmental factors affecting the operation;

(m) particulars of any casualty which occurred during the operation.

SCHEDULE 3 (Reg. 11(e))

MATTERS IN RESPECT OF WHICH ENTRIES ARE TO BE MADE IN THE SUBMERSIBLE CRAFT PILOT'S LOGBOOK

The following matters shall be entered in the pilot's logbook in respect of each submersible operation in which he takes part:-

(a) the name and address of the owner of the submersible craft;

(b) the name or designation of the submersible craft;

(c) the date and dive number of the submersible craft;

(d) the name or other designation and the location of the parent craft;

(e) the area of operation and the maximum depth reached;

(f) the time from shutting the submersible craft hatch to opening the hatch on completion of the dive;

(g) the task or tasks undertaken by the submersible craft;

(h) details of any diving operations carried out from the submersible craft;

(i) any other factors relevant to the safety or health of the crew or passengers of the submersible craft.

SCHEDULE 4 (Reg. 13(b))

PARTICULARS OF A CASUALTY

1. The date and time of the casualty.

2. Where the casualty occurred on board the submersible craft, the place on board the craft where, and the position of the craft when, the casualty occurred.

3. Where the casualty occurred other than on board the submersible craft, the place where, and the position of the craft when, the casualty occurred.

4. A description of the casualty, and of any submersible operation being carried out, and any plant or equipment being used, at the time the casualty occurred.

5. A description of any damage substained by the submersible craft or any plant or equipment at the time the casualty occurred and the name or other designation and port or place of registry (if any) of any other craft involved.

6. The name of any person killed, lost or injured in the casualty; the name and address of his employer; and a description of any injury, including an injury resulting in death, substained by any person in the casualty.

The name and address of any witness to the casualty and the name and address of his employer.

Made in Council this 11th day of June, 1991.

MONA N. BANKS-JACKSON
Clerk of the Executive Council.

Coastal Ocean Space Utilization

Aiming at Port and Harbour Technology Mild to Human Beings and the Earth

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Preface

Japan is now approaching toward a matured society in the twenty-first century with progress in internationalization, information and urbanization. The people's needs are sophisticated in every aspect of the society.

The ports and Harbours Bureau of the Ministry of Transport formulated and announced a long-term port and harbour development policy, "Ports and Harbours Toward the Twenty-first Century" aiming affluent waterfront, in 1985, and a coastal area development policy, "Coastal Area Toward Twenty-first Century" for creation of affluent coast area, in 1990.

It is contemplated to provide a comprehensive port and harbour space and to improve the quality of such space with good balance maintained among the functions of "physical distribution", "industries" and "lives of people" with emphasis placed on enhancement of the quality of convenience or beautiful environment. For development of the coast area, it is intended to preponderantly develop the facilities of good quality with consideration given to the facet of utilization along with early implementation of safety and conservation of national land. And, these two long-term policies equally stress the importance of the technological development required for realization of the objectives.

On the other hand, motivated by enhancement of environment and resource/energy problem in the global level, the concept of "sustainable development" has been proposed recently.

Further, with progress of the global and borderless economic activities, international communications and contributions to the world are required even in the area of ports and houbours technological development.

Thus, we have selected the following two as principles in order to promote technological development of ports and harbours.

(1) Formation of waterfront which is mild to human beings and the earth.

(2) International exchange of people and information, and contribution to the world.

Development of the port and harbour technology in Japan has been mainly carried out by the State, but the technical faculties in private enterprises have also greatly developed. Since recently remarkable progress has been made in advanced technologies, outstanding leap of the technologies of ports and harbours could be possible by the use of advanced technologies.

In order to propel the technical development of ports and harbours powerfully under these circumstances, it is considered to be effective to clarify the targets of technical development and to obtain a nation wide understanding from the Japanese people by showing the promoting methods, which are conducted by the Ministry of Transport,port authorities, third sectors, and private enterprises respectively or cooperatively, or by showing how to support the development by the Ministry of Transport.

Therefore, the Ports and Harbours Bureau of the Ministry of Transport has formulated a policy necessary for facilitating the development of port and harbour technology of Japan toward the twenty-first century as "Long-term Policy for Technological Development of Ports and Harbours" .

1.Priority Subjects of Technological Development

In order to carry out the technological development smoothly and efficiently, the targets of technological development were set and the subjects of the technological development were selected in consideration of the long-term policies on ports and harbours and coastline. And judging from the change in the socio-economic situation surrounding the ports and harbours and from the evaluation of the present and future technology the following ten items were chosen as the priority subjects of the technological development to be pushed on toward the twenty-first century.

o Improvement in quality of the port and harbour space.
o Creation of new coastal space.
o Creation of better coastal environment.
o Promotion of the countermeasures to wastes.
o Construction of high efficiency terminals.
o Promotion of countermeasures to global warming.
o Improvement of the safety and disaster prevention at the waterfront.
o Labor saving in port and harbour works.
o Improvement of the durability of port and harbour facilities.
o Cooperation for the developing countries.

<u>(1) Improvement in Quality of Port and Harbour Space</u>

The ports and harbours have been constructed from a viewpoint of placing stress on the efficiency of physical distribution and industries functions. But, as the society matures, quality improvement of facilities is called for, and the creation of a comprehensive port space is needed where the physical distribution, industrial functions and the living functions are in harmony.

Hereafter, therefore, it is required to exactly grasp the multifarious demands for the port space and thus to form a port space which is mild to human beings and the earth, easy to use, beautiful and of high quality. Then, there should be developed the technologies for facility planning, environmental creation and landscape formation.

(2) Creation of New Coastal Space

We are running short of places suitable for ports and harbours as the development of ports and harbours proceeds. The new locations will have to be sought in the large waterdepth and high wave water area of the offshore and the very soft ground water area. To make it possible to construct the port facilities more economically and efficiently under such strict natural conditions, it is required to develop the construction method of an offshore artificial island or new type structures and the improvement method of the ground.

(3) Creation of Better Coastal Environment

On account of the improvement of the people's lives and the diversification of sense of values, the present focus concerning the environment has shifted from prevention of pollutions to realization of a higher level environment. For promotion of the sustainable development particularly, conservation of the environment including creation of a better environment is important. Then, the technology of water purification by dredging or covering the bottom sludge by sand should be further improved. For the coast, the technology concerning the artificial tideland or beach should be developed.

(4) Promotion of Countermeasures to Wastes

Since the wastes will continue to increase, countermeasure to wastes is now one of the important and urgent problems in the global environment. Then, there should be developed the technologies for safe and economical treatment and disposition of wastes, for improvement of the foundation for earlier use of the reclaimed land and for regeneration of wastes as new materials.

(5) Construction of High Efficiency Terminal

Amidst the growing demand for modal shift from automobile to shipping, it is required in ports and harbours to increase efficiency of the facilities and to expedite the development of a terminal making the best use of the features of the techno-superliner and other new type superspeed ships. Then, it is required to develop technological systems like the rapid berthing/undocking system and high speed cargo handling system for securing high speed marine transport.

Also, development of high grade container terminals provided with sufficient water depth, extensive yard and highly efficient cargo handling system is urgently called for in order to cope with increasing foreign trade container cargoes and the increasing size of the container ships, and the technology for the foregoing should be developed.

(6) Promotion of Countermeasures to Global Warming

The rise of sea level due to global warming is predicted. If it occurs actually, the waterfront area of our country will receive a serious damage. Thus, the development of technologies for port facilities against the rise of sea level should be made.

(7) Improvement of the Safety and Disaster Prevention at the Waterfront

Japan is an earthquake country and is often attacked by typhoons and has many natural disasters every year. The ports and harbours are forming waterfront areas of cities and are often subject to natural disasters, and should a disaster occur, serious damages are anticipated over an extensive area. It will be more important not only to make good use of the waterfront but also to enhance the safety and disaster prevention of the waterfront. The technologies of countermeasures to earthquakes directly above the focus should be developed.

(8) Labor Saving in Port and Harbour Works

In the port construction industry, shortage and aging of workers have become a serious problem, and for improving the safety and work efficiency of the port construction works more than ever, there should be developed submarine robots, automation technology of the port works and port structures suited for labor saving.

(9) Improvement of the Durability of Port and Harbour Facilities

With increase of the total stock of port and harbour facilities, the maintenance and repair costs will increase. Adequate maintenance and management are important. On the other hand, shortage and aging of the workers are becoming serious in the field of ports and harbours.

Thus, while the development of the repair technology should be made, the technology intended for maintenance free structures will have to be developed for reducing the cost of maintenance.

(10) Cooperation for Developing Countries

Our country has so far extended to the developing countries the economic and technical cooperation concerning to the planning and construction of ports and harbours for development of their economy and society. With rise of the position of our country in the international society, appropriate technologies adjusted to the natural environments and economic and social conditions of the developing countries should be developed in order to promote positively the overseas economic and technical cooperation.

2. Roles of Technological Development Entities

The Ministry of Transport(central government), port management bodies(local government), third sectors, private enterprises, universities and public service corporations should respectively develop the technologies which they consider to be necessary, appropriate for their services and technological development faculties,and at the same time, these technological development entities should,as a rule, exert their autonomous efforts for securing the fund and human resources for the technological development.

In the Ministry of Transport, the Port and Harbour Research Institute(PHRI), which is a national research institution, and the Investigation and Design Offices, Machinery Offices and Port Construction Offices of the District Port Construction Bureaus which are responsible for the port construction works in each district, cooperate with one another to develop comprehensively the port and harbour technologies making the most use of their respective characteristics.

In particular, PHRI has been conducting, as a comprehensive research organ covering the whole technology concerning the ports and harbours, extensive researches, technical developments and technical exchanges covering from fundamental fields to applied ones. And PHRI has a role of systematic accumulation of the data of port and harbour technologies in Japan. The development results and accumulated data have been offered to the national organs and port management bodies and also to the private sector and are transferred in an appropriate form to the developing countries as part of the international technological cooperation.

However, regarding to the technological development in a new field, the advanced or systematic technological development may be required, which needs to combines the particular technologies to ports and harbours, computer, new materials, biotechnology and other related technologies. Thus, for technological development in the field where the comprehensive technical faculties are required, close cooperation among the technological development entities which have the common object may bring the satisfactory results efficiently, economically and in a short period. In such a case, the Ministry of Transport will utilize the public service corporations, as required, and call extensively at home and abroad not only to the private, academic and governmental circles related to the ports and harbours but also to the other fields, and thus promote the joint research and technological development.

3. Technological Development Promotion Measures

The Ministry of Transport will promote the following measures for expediting technological development on the newly selected subjects.

(1) General Measures

The Ministry of Transport will have positive public relations on ports and harbours and port technologies for securing the necessary human resources and fund and for obtaining the understanding of the people for technological development. Also, for furtherance of the technological development in boundary fields among studies or industries, it will promote the information disclosure on ports and harbours, exert the efforts for use and spread of the information, activate the exchange of researchers and promote the exchange of information at the international conferences.

The results of technological development will be quickly standardized with consideration for their flexible application, and the efforts will be made to realize the measures so that the information and software would duly evaluated and the cost or development expense should be incorporated into the contract.

(2) Supports to Private Enterprises

Recently, the technological development about ports and harbours has become large in scale, and has required a large amount of development fund.

The Ministry of Transport will give conveniences for the technological development and study an appropriate cost estimation method and take measures for popularization and utilization of the developed technology.

Summary

The Ports and Harbours Bureau of the Ministry of Transport hopes that this long-term policy is helpful in the port and harbour technological development for the respective development bodies.

The world continues to change rapidly, and the situation surrounding ports and harbours will also be anticipated to change. Therefore, the subjects of technological development of ports and harbours and the measures for proceeding them, shown here, will have to be reviewed, as required, in flexible response to the changing situations and the result of the development.

18TH MEETING OF THE
U.S./JAPAN MARINE FACILITIES PANEL OF UJNR

COASTAL AND OCEAN SPACE UTILIZATION

ENVIRONMENTAL MANAGEMENT OF PORT DEVELOPMENT

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Abstract

The role of ports has undergone a radical change in terms of their intermodal transport function, location, technology, and management. Many ports are moving their major facilities offshore and use commercial type management. Similarly, these operations will involve many new activities with potentials for major environmental impacts. In this paper, the changes in the port industry with possible environmental effects are discussed and guidelines for their effective management are presented. While port development and consequent dredging, reclamation, and construction still impose the major environmental hazard, port operations management increasingly imposes additional and often dominating environmental impact.

Introduction

The environmental impact of port development used to be mainly connected with the effects of dredging and resulting spoil disposal and, to a lesser extent, with actual port structures and port operational impacts. The changing role of ports, the extension of their services, the increasing use of offshore sites for port development, the large increase in the types and forms of cargo handled in ports, and the responsibility of ports to take care of ship generated wastes and other matter has imposed many new factors and has made the environmental management of ports more complex and demanding.

Ports are increasingly not only responsible for their own environmental management, but also for that of their users, at least as far as control of user operations and the accommodation or reception of port user generated wastes is concerned. In various parts of the world, port-state control is used, by which ports act on behalf of national and international regulators in inspecting vessels for safety and environmental conditions. They are also empowered to enforce requirements and arrest ships for contraventions. Similarly, many ports today are engaged in industrial or cargo form change activities which may have environmental implications.

Another issue of environmental concern is the handling and storage of hazardous substances. Ports must also be prepared for various types of accidents and other types of emergency situations, most of which may cause environmental impacts directly or indirectly.

Environmental management of port development is of increasing concern. In this paper. a strategy for the effective environmental management of port development and operation is proposed in the light of rapidly changing port and port user technology, port functions, environmental regulation, public concern, and political pressure.

Port environmental management varies between perfunctory concern or utter neglect of safe environmental impositions to correct for a unique or temporary environmental danger. A case in point is the U.S. response to the Exxon Valdez disaster, the result of apparent human error. Instead of considering stringent rules of navigation, mandatory traffic control and effective navigational aid to prevent groundings or collisions of ships in port approaches, the OPA of 1990 mandates introduction of double hull tankers designed to reduce damage and resulting outflow of oil from grounded tankers. In fact, environmental controls more often than not attempt to reduce the spread or impact and not the occurrence of environmental accidents. In other words, we are more concerned with containment than prevention.

This philosophy is used in other aspects of environmental management in ports and shipping as well, notwithstanding the fact that we cannot build ships which are completely spill proof, and that the costs of reducing the spill potentials from damaged ships is much greater than the cost of an effective world (or nation) wide ship traffic control and navigational guidance system, designed to reduce the risk of ship accidents.

There are at least 10 times as many commercial aircraft takeoffs and landings in the U.S. than ship arrivals and departures, and all of these are performed under the rigid control of air traffic controllers which assure that planes do not deviate from their assigned approach or departure path. Yet, we hesitate enforcement of similar requirements on ships, though over 84% of all ship accidents occur in port approaches, and most of these could be prevented by effective vessel traffic control and improved navigational aid systems which could be introduced at a fraction of the cost of making tankers less spill prone by design.

Similarly, waste disposal rules are not effectively imposed and we devote more resources to clean up than to prevent waste disposal damage. This paper is an attempt to identify opportunities for improved prevention of environmental impacts in ports and port-related activities.

Link Between Environmental Management and Port Productivity

The environmental management versus productivity trade off has been a subject of controversy and bias for many years and port environmental management was no exception. The problem is usually that productivity measures only reflect costs and environmental improvements or benefits do not show up as increased output. Yet, in many cases, the output increases because the quality of the output has improved and environment-spurred modernization boosts productivity by eliminating direct and indirect waste.

Relating port environmental spending to port productivity requires consideration of indirect port costs and benefits, a method often used by ports to justify major expansions or new investments. Ports traditionally identify regional spin off benefits to show the impact of new port developments. Environmental investments similarly constitute port developments with regional and spin off benefits.

One of the problems often cited is the difference in the environmental standards and therefore costs faced by various ports and the effect of these differences on port competitiveness. Many ports are delaying environmental actions for fear of loosing their competitive advantage although evidence abounds that well managed environmental controls will in general enhance a ports' competitiveness. There are many examples of cost effective safe dredging and spoil disposal projects, profitable reception of oil residues or wastes, efficient waste disposal systems, reduction of air pollution, and containment of hazardous materials. Effective port environmental management can provide impetus to port productivity and competitiveness not only by making the port safer and more productive, but also by facilitating port user compliance with environmental regulations or requirements in a <u>user</u> cost effective manner. This, in fact, may become one of the most important attractions of a port. For example, oil loading ports with efficient facilities for the reception of oil residues have attracted significant new business and provided new income for ports.

Port Environmental Management

Port environmental management consists of environmental impact prevention, environmental facility provision, and environmental impact clean up and damage mitigation. Ports must be involved in all these aspects to be effective. Similarly, they must consider that regulatory requirements are only guidelines or minimum standards and not a sign of effective port environmental management.

Emphasis must increasingly placed on environmentally safe port operations and therefore effective environmental damage prevention (Table 1). Port access and in port movement traffic controls are not only important to prevent environmental damage, but also improve port operational efficiency and increase port facility capacity.

TABLE 1 - Preventative Measures

1. Collision and Grounding Prevention
   - Vessel Traffic Control Systems
   - Navigational Aids
   - Communication Systems
   - Intelligent Ship Guidance Systems

- Pilotage
- Traffic Regulations
- Ship Docking Control/Management Systems
- Port Traffic Management Systems
- Establishment of Maneuvering Standards

2. Reception Facilities
   - Oily Waste
   - Residues and Mixtures Containing Noxious Liquid Substances
   - Solid Waste Disposal Facilities
   - Organic Waste
   - Hazardous Material Storage

3. Port Security
   - Terminal Security and Access
   - Cargo Security, Containment, and Storage
   - Vessel Port Operations Safety and Security
   - Computer and Data Security

4. Crisis Management Systems
   - Emergency Plans
   - Situation Audit and Evaluations
   - Crisis Management and Controls

Studies of navigational channel operations, for example, have shown that channel capacity can be increased by a factor of 2-3 and the safety of ship passage significantly increased if entry into and traffic through the channel is strictly controlled in terms of (1) sequence of ship admission, (2) ship separation distance as a function of ship size and stopping distance, (3) ship speed, and (4) ship movement and rudder control during passage.

The channel capacity increase achieved is a function of the length of the channel, the mix of ship traffic in terms of ship size, speed, etc. Similarly port maneuvering and docking operations can be greatly improved both in terms of their safety as well as time and space occupied by effective navigational control.

The same type of technology considered for intelligent highway or road vehicle traffic systems can be used for the management of intelligent port development and operations.

Port environmental management has, in the past, been largely reactive, mainly concerned with spill containment and clean up, hazardous cargo separation, and provision of waste reception facilities. Development of environmentally safe, intelligent proactive port facilities, services, and management systems are not only feasible, but economically attractive now. This is true for both port development and operations.

Environmental Impacts of Port Development

The most significant port development impact is usually the result of dredging and dredge spill disposal, but, as shown in Table 2, these are only some of many potential contributors.

TABLE 2 - Port Development Environmental Impacts

Channel/Basin Dredging

- Capital and Maintenance Dredging

Removal - Change in recharge aquifers. Change in topography, removal of polluted sediment, shellfish beds, benthic plants and suspension of dredged materials, saline intrusion into aquifers.

Disposal - Change in topography, recirculation, destruction of wetlands, runoff, noxious or pollutant disposal, bottom organisms buried, chemical composition change, water quality.

Port Structures

- Coastal

Topographic change, disturbing stable bottom environment, covering of breeding grounds, erosion, corrosion, hydraulic effects, subsurface motion, salutive and coagulating effects affecting water chemistry, hydrodynamic, and wave, water (current) motion effects, chemical effects of structural coating, and treatments, interface corrosion, leakage of pollutants from structure, effects of subsurface water motion, from changes in viscosity and surface tension, etc.

- On-Shore

Excavation/disposal, saline intrusion, from excavation, reduction in wetlands, change in coastal drainage, structural compacting, and more.

- Above Surface

Aerial Interference, vibration, noise, smell, aesthetics, visual interference, elimination of alternate use, access restriction, microwaves, light waves, other radiations, etc.

Strategy for Environmental Management of Port Development and Operations

The environmental impact of port development and operations is usually negative because ports do not effectively integrate environmental benefits and costs. They concentrate on reducing environmental damage, but pay less attention to damage prevention, and seldom perform analysis of the interaction of development and operational impacts or establish a rational policy approach based on a formal cause and effect analysis and assessment of environmental impacts and risks. Most importantly, cost and benefits are usually not traded off nor are major physical (engineering) and operational alternatives. As a result, we do not establish effective environmental balance sheets, an essential prerequisite for setting strategy for effective environmental management. The reasons are usually given that

a. environmental impact causes and effects are inadequately known or studied,

b. the impacts and their causes and effects are only known under uncertainty,

c. impacts are usually highly interdependent as well as conditioned, and

d. impact costs and benefits may be qualitative as well as quantitative, and it is difficult to relate one to the other.

The use of conditional stochastic hierarchical decision models is proposed for the establishment of an effective strategy for environmental management of port development and operations. The approach permits strategy formulation based on the integration of all factors, in terms of the estimated statistical or qualitative effects. Similarly, it permits consideration of interdependency.

Taking as an example the deepening of a navigational channel, there are a number of interdependent environmental causes, such as: capital dredging method and depth, slope, soil conditions, etc.; underkeel clearance, ship speed, and aspect ratio; and, maintenance dredging frequency, method, and depth.

These in turn are affected by sediment in suspension, boundary layer conditions, ocean current, and waves.

Some environmental effects are temporary during capital dredging when bottom conditions and material in suspension is affected, as well as permanent when ship passage as well as periodic or continuous maintenance dredging affects suspended material, bottom flow, and biological conditions.

All the causes and effects should be considered in one analysis and traded off in terms of economic and environmental costs and benefits simultaneously. There are numerous examples when we economically and/or environmentally optimize capital dredging only to find that channel operations (ship traffic) and maintenance are economically and environmentally sub-optimum or outright unattractive.

The problem is even more serious in major port construction development, when we optimize individual structural design subject to compliance with environmental limit standards, only to find that when all the port development components are in place, the port is neither economically or environmental attractive. Similarly, while environmental requirements are usually included in the development and operational design of port systems, such studies must include development of environmental management plans to be effective.

Unfortunately this is seldom done and environmental management is assumed to be satisfied by meeting particular development standards. In other words, there is no feedback or follow-up and major deviations from assumed environmental conditions are not taken care of. Neither is the fact that interdependence of the effects of several developments may result in exceeding safe standards, even though each development is well within permissible standards. Similarly, environmental benefits are often affected by interdependence of the effects of different developments.

Analytic Hierarchical Decision Models in Environmental Management

Port development environmental management involves, among others, decisions such as choice of methods, designs, and processes to be used.

Such decision processes usually involve one or more decision makers, several often conflicting or even contradictory objectives, multiple standards or performance measures, and various choices. Choices may be unique and independent or time variant in terms of their availability, performance, and environmental benefits or costs. Similarly, certain risks may be associated with each choice and the weight decision makers place on different economic and environmental objectives may also be uncertain within defined limits. Similarly, the performance of various decisions may be dependent on other choices and on time. Furthermore, the benefits or costs may be uncertain, qualitative, or quantitative.

Assume a hierarchy as defined in Figure 1, consisting of 4 levels with a single objective who has to rank several different combinations of port developments.

Objectives can be minimum or acceptable environmental impact or cost or maximum difference between environmental benefits and costs. Each factor at one level is related to each of the factors at the next higher level in turn, using the comparative weight or contribution it makes to the factor at the next higher level in qualitative and quantitative terms.

There may be some inconsistency in such comparative weighing. This though is easily determined by consistency analysis as shown later. Similar comparison matrices can be drawn up with respect to the factors at the next level (performance measure).

Then, each of the performance measures is related to each of the objectives in turn, and finally assumes the relative weight, or importance, or its relative contribution to the objective(s).

To obtain the weights of each alternative with respect to a performance measure, a logarithmic least square or eigenvector method is used. The latter computes the principal right eigenvector of each matrix which can be shown to represent the weight of each alternative with respect to the performance measure considered, and is usually preferred.

The weights are usually obtained as pairwise comparative weights by judgement or from actual data.

Deterministic Analytic Model Solution Methods

If A is a matrix of the form

$$A = \begin{bmatrix} 1 & a_{12} & a_{13} \\ 1/a_{12} & 1 & a_{23} \\ 1/a_{13} & 1/a_{23} & 1 \end{bmatrix} \qquad \mathbf{(1)}$$

where a_{ij} is the comparative weight of i compared to j with respect to the factor against which their performance is measured, and w_i and w_j are the priority weights of i and j, then $w_i/w_j = a_{ij}$ for all pairs i, j.

In the ideal case with complete consistency, all $a_{ij} = w_i/w_j = a_{ir}a_{rj} = w_i w_r = w_i w_r / w_r w_j$ and $a_{ji} = 1/a_{ij} = w_j/w_i$ and $w_i = a_{ij}w$ (i,j=1,2,...n) as well as

$$w_1 = \frac{1}{n}\sum_{j=1}^{n} a_{ij}w_j(i,j=1,2...n) \qquad (2)$$

The purpose is to obtain an unbiased vector of the weights of the alternatives i=1...n with respect to each of the factors at the next higher level. Usually $a_{ij} \rightarrow w_j/w_j$ but perturbations of this rate will usually occur. If λ_{max} = maximum eigenvalue of the matrix A, then

$$\lambda_{max} = (\sum_{j=1}^{n} a_{ij}w_j)/w_i\ (all\ i) \qquad (3)$$

The eigenvalue of A can be obtained in different ways, to determine the weights of the ith with respect to the factor at the next level. An approximate, yet simple, way is to sum the entries a_{ij} in each row and divide by the sum of the rows, or for

$$A = \begin{bmatrix} 1 & a_{12} \\ a_{21} & 1 \end{bmatrix} = \begin{bmatrix} (1+a_{12})/S \\ (1+a_{21}/S \end{bmatrix} \qquad (4)$$

where $S = (2 + a_{12} + a_{21})$

As the $a_{ij} \rightarrow 1/a_{ji}$, it is necessary to measure if the values a_{ij} and a_{ji} (all i) are consistent. This can be performed by using the eigenvector (or the maximum eigenvalue λ_{max} to measure the consistency of the matrix A. $(\lambda_{max}-n)/(n-1)$ = "consistency index" is a useful measure of consistency. Using a Random Inconsistency Index (R.I.I.) developed by Saaty [1] computed by random tests where R.I. is found to be

n	RI
1	0
2	0
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41

We can now determine the consistency ratio C.R. = C.R./R.I. which should have a value of C.R. $\leq$ 0.1 for acceptable consistency. The C.R. > 0.1 judgements on comparative weights may have to be revised.

A more accurate way to compute the priority or eigenvector $[w_i]$ is to raise A to increasing powers of K and then normalizing the result:

$$P^K = \lim_{K \rightarrow \infty} A^K e / e^T A^K e$$

where e = (1,...1) and for K = 1

$$p^1 = Ae/e^TAe$$

and second estimate

$$P^2 = A^2e/e^TA^2e$$

This is continued until iteration K when the process converges and the normalized weights of w_i remain constant from iteration to iteration.

Stochastic Expert Choice Decision Making in Port Environmental Management

In environmental management, the pairwise comparative weights are often quite uncertain and, instead of unique pairwise comparative weights, one can often obtain only probabilistic or conditional probabilistic pairwise weight comparisons. In the simplest case we are given a range of pairwise comparison weights, $a_{ij_{max}}$ and $a_{ij_{min}}$, and must then obtain the consistent range of $a_{ij_{max}}$ and $a_{ij_{min}}$.

Conversely, the a_{ij} may be conditioned on some weight a_{ke}. If a range ($a_{ij_{max}} - a_{ij_{max}}$) is given, it is usually possible to determine the consistent range of (a_{ij} max - a_{ij} min) or vice versa. Using the resulting extreme consistent values, the range of values of the priority weights $w_{i_{max}} = w_{i_{min}}$ $(i=1...n)$ for all the matrices in the hierarchy can be determined, and ultimately the range of the priority weights of the alternatives is a function of the characteristics of the hierarchy.

After checking the consistency, one could now determine the range of comparative weights of the decision alternatives between the extreme values obtained. Using standard statistical techniques, one could also determine the expected comparative weight.

The same method can be used when there are ranges in comparative weights at more than one level in the hierarchy,

Conclusion

Expert choice or hierarchical decision models are useful tools for the solution of complex multi-criteria, multi-level decision problems which abound in port environmental management.

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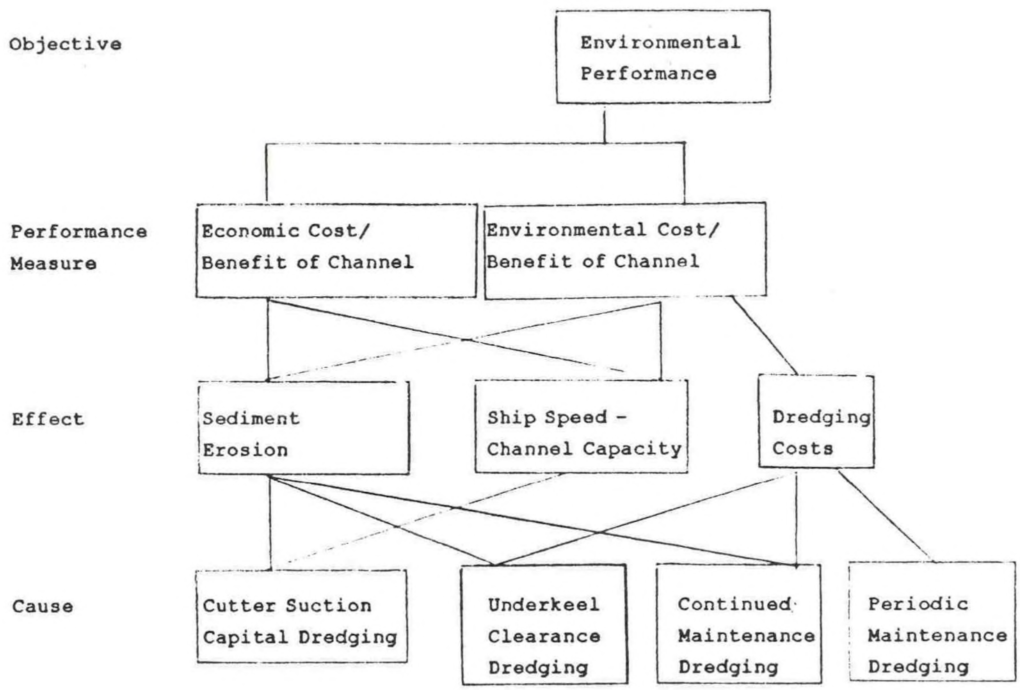
Figure 1 - Simple Hierarchical Decision and Comparative Weight Example



CHALLENGES FOR HUGE FLOATING PLATFORM : RESULTS OF FIELD TEST OF PROTOTYPE FLOATING PLATFORM

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1. ABSTRACT

Many kinds of conceptual plans of huge floating platform have been presented for the effective utilization of the ocean space.

Though a floating type of structure has a lot of merits in comparison with a reclamation type and is technically possible enough to construct, a huge floating platform has not yet been realized.

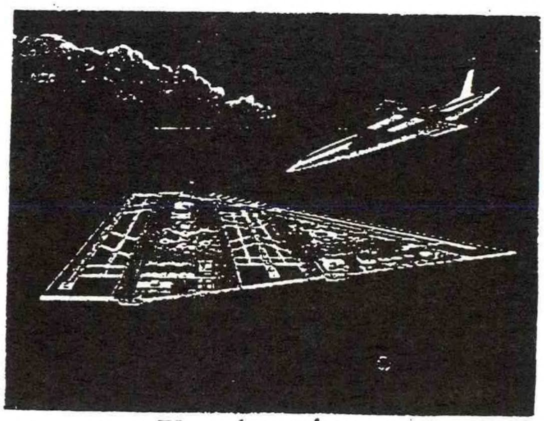
The research activities on the huge floating platform in Ship Research Institute began in 1977. In the first research activities, it has been investigated for about two years whether the construction of the Kansai international airport of floating type is technically possible or not [1].

After this feasibility study on the floating airport, the fundamental investigations on the technical problems concerning a huge floating platform were continued from 1982 to 1986 in order to ensure the construction of a huge floating platform[2],[3].

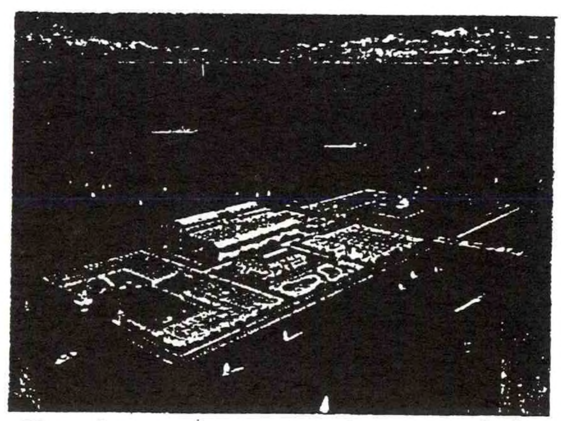
The technology of the basic elements to realize the construction of a huge floating platform had been established by these fundamental and applied researches in various fields. After that, in order to verify the element technology and confirm the safety and reliability of huge floating platform, the at-sea experiment was carried out at 3km offshore of Yura port, Yamagata prefecture in the Japan Sea from 1986 to 1990[4].

2. FEASIBILITY STUDY ON THE FLOATING AIRPORT

The technical feasibility of the floating type Kansai airport model as shown in Fig.1 which had been proposed by Japan Ship Building Industrial Association was investigated in both 1977 and 1978. This floating platform model was 5,000 m in length and 840 m in breadth and supported by a lot of floating bodies of a column type. In this project, the following technical items concerned with the construction



Floating airport



Floating sport and leisure facility

Photo 1 Examples of conceptual plans of huge floating platform (from the report of the Floating Structures Association of Japan) of the floating airport were investigated.

1) Determination of the environmental condition in the area
2) Estimation of the exciting forces acting on the floating bodies
3) Estimation of the mooring forces and behavior of floating bodies
4) Investigation of the structural strength of floating airport

The unsolved problems were clarified through the works of model test and computer simulation .

As the results of the studies, it was concluded that the construction of the floating airport will be technically possible with the present techniques. In addition to the above-mentioned technical feasibility studies, the synthetic investigations on the floating airport, the safety under disasters, the relations between constructing methods and terms, the maintenance techniques and the constructing cost,were also performed.

3. STUDY ON THE FUNDAMENTAL TECHNOLOGY OF A HUGE FLOATING PLATFORM

After the feasibility study on the floating airport, some technical and fundamental problems remained to be solved in order to construct a huge floating platform in the severe sea conditions. This fundamental study was performed about the following themes :

1) Hydrodynamic force of added mass and damping force
2) Wave exciting force and current force
3) Motion and stress distribution of huge platform as flexible structure
4) Structural strength analysis of main deck structure
5) Mooring force acting on the multi-anchoring system

The series of model experiments were carried out by using the models consisted of various combinations of the element floating bodies as shown in Fig.2. These models were used to measure the flexure responses as well as mooring force distribution of the multi-anchoring systems.

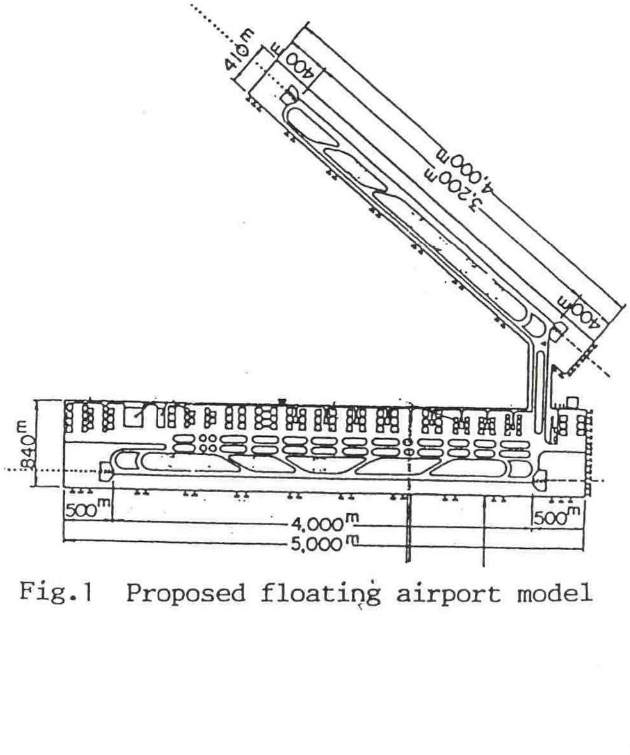


Fig.1 Proposed floating airport model

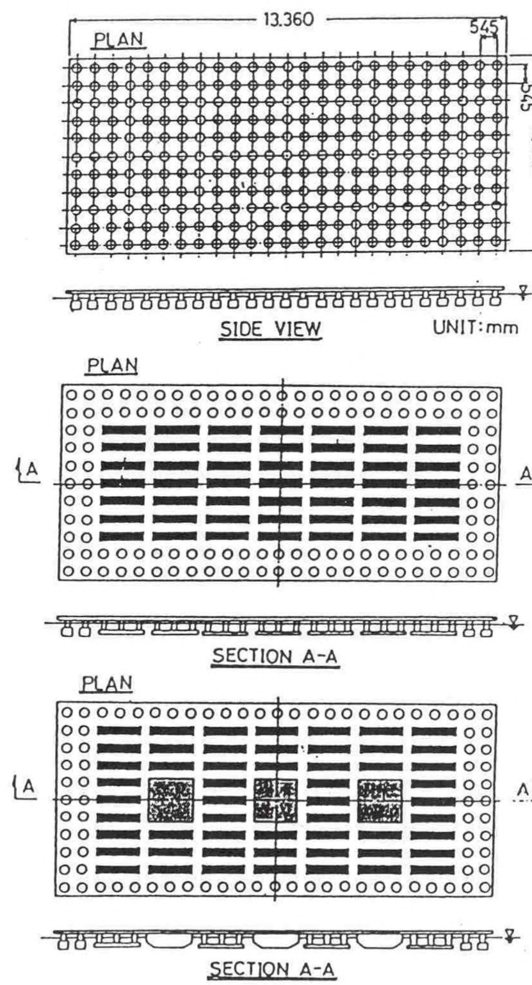


Fig.2 Large-sized models

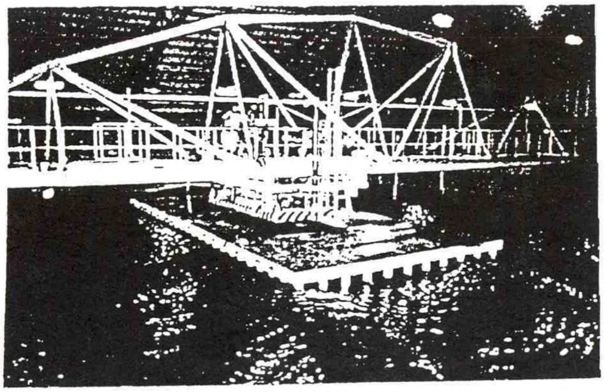


Photo 2 Model test

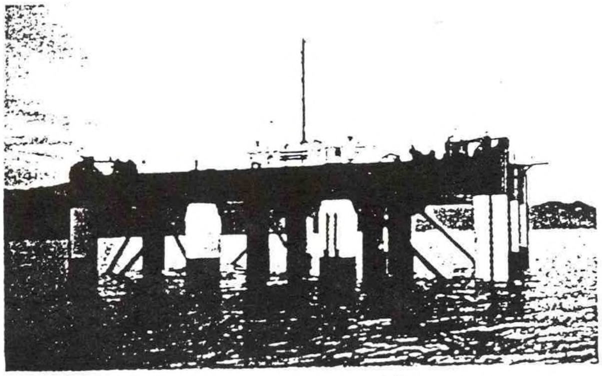


Photo 3 POSEIDON

4. RESULTS OF THE AT-SEA EXPERIMENT OF FLOATING PLATFORM "POSEIDON"

The fundamental and applied researches have been carried out using basin tests and theoretical calculations in order to realized a huge floating platform. An at-sea experiment using a proto-type floating structure named POSEIDON was planned, in the course of the researches. The main purpose of this field measurement was to validate the element technologies which had been developed so far as well as to evaluate the reliability of the floating platform in the real ocean environment.

(1) OUTLINE OF AT-SEA EXPERIMENT

The test area is 3 km offshore from Yura port at the Japan Sea, north-western coast of Honshu, which has been chosen by considering the meteorological data of the test area in the past, The sea floor of the test area is almost flat and thus suitable for mooring the structure. The water depth is about 41 m . POSEIDON was slackly moored by 6 chain lines. POSEIDON is shown in Fig.3 .

The measuring items are classified as follows;

1) Environmental conditions,
2) High and low frequency motions of structure
3) Strength of structure
4) Mooring line tensions
5) Corrosion of paint

The outline of this experiment has been described in the previous UJNR /MFP report [4].

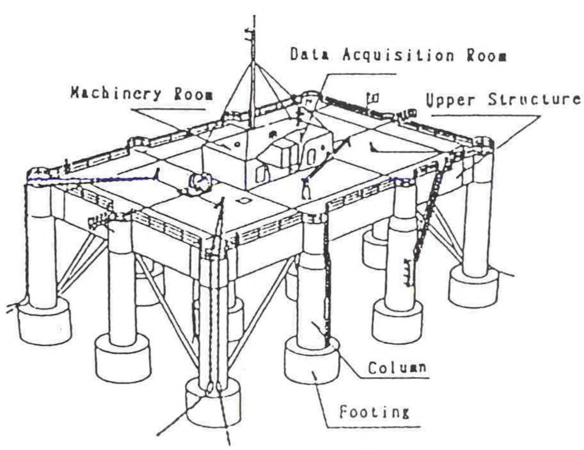


Fig.3 Structure of POSEIDON

Table 1 Principal dimensions

ITEMS	DIMENSIONS
Length overall	34.0 m
Breadth overall	24.0 m
Height of main structure	13.5 m
Draft	5.5 m
Distace betwoen columns	10.0 m
Column diameter	2.0 m (partially 2.5 m)
Column height	8.5 m
Footing diamter	4.0 m
Footing height	2.5 m
Displacement (△)	530.805 ton

(2) MAIN RESULTS

The field measurement was carried out from September 1986 to July 1990. The analyses of vast data are still going on . Some of these experimental results were presented in the previous reports. Here the summary of the already obtained results and new analyzed results were presented .

WIND SPECTRUM[6]

The characteristics of wind fluctuation were investigated using data measured at 19.5m above water level. Then a new formula of representing wind spectrum on the sea was proposed as follows;

$$f\,S_u(f)/\sigma_u = 0.4751\ X(1+X)^{-5/6}$$

here $X = f/\alpha$ $\quad \alpha = 0.0623\ (u^*/\sigma_u)^3\ a^{3/2}\ U_{19.5}$

$\qquad\qquad\qquad = 0.0623\ (\sqrt{C_D}/I)^3\ a^{3/2}\ U_{19.5}$

u^* ; friction velocity $\quad C_D$; friction coefficient

I ; turbulence intensity($=\sigma_u/U_{19.5}$)

a ; Kolmogorov const.

The wind spectrum and contour map of gust factor was obtained as shown in Fig.4 and 5 .

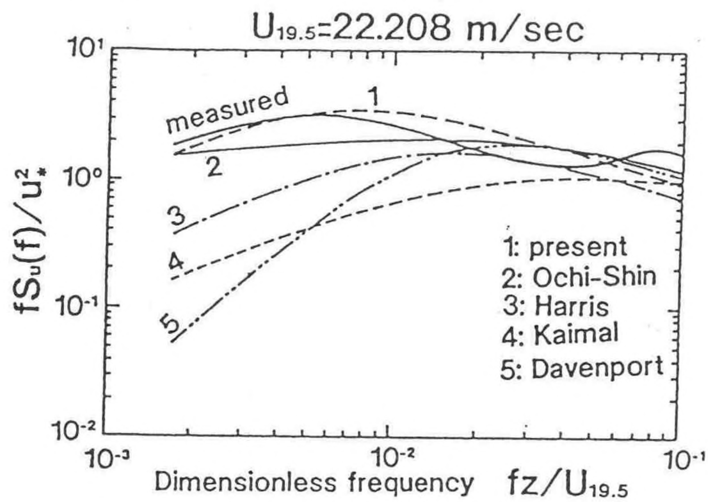


Fig.4 Wind spectrum at test field

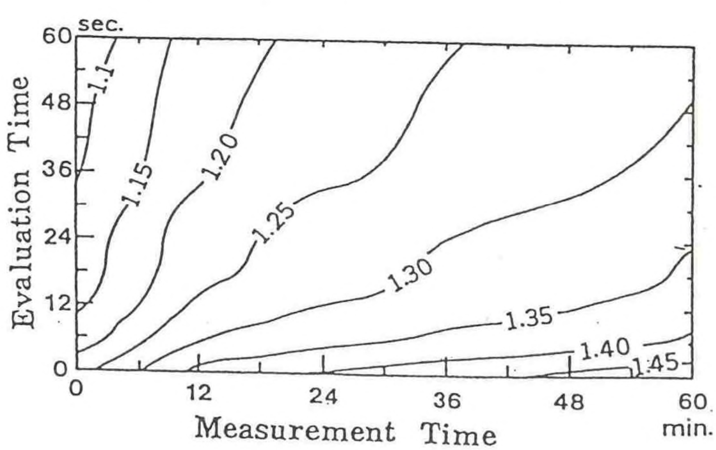


Fig.5 Contour map of gust factor

DIRECTIONAL WAVE SPECTRUM[7]

Three wave height meters of ultrasonic type were installed as a line array at the sea bottom of 180 m ahead of POSEIDON . The line array was adopted to detect the wave directionality with high accuracy for the waves from coming WNW direction.

The characteristics of frequency spectrum and directional functions were investigated using the maximum likelihood method(MLM)

- The shape of frequency spectrum in the high frequency range is not proportional to f^{-5} but f^{-4} , and the JONSWAP spectrum was modified to satisfy f^{-4} rule.
- The measured directional functions can be approximated by Mitsuyasu-Type function. The spreading parameters show the tendency of frequency dependency and they take peak values at the peak frequency as suggested by Mitsuyasu. The change rate of measured spreading parameters with respect to frequency is not so rapid as the formula given by Mitsuyasu.

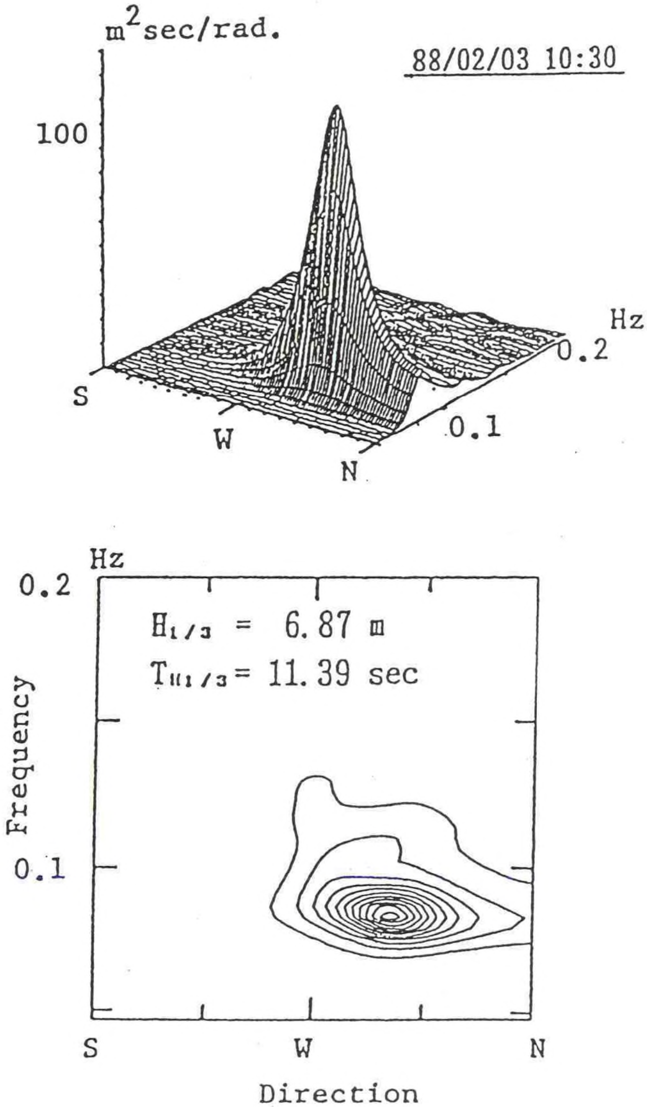


Fig.6 Directional wave spectrum

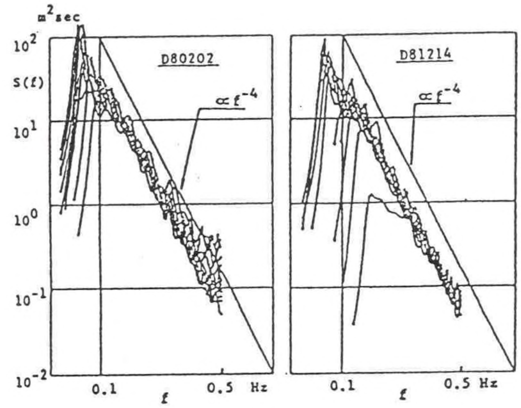


Fig.7 Frequency spectra for 2 hours

Mitsuyasu

$S=S_{max}(f/f_p)^5$ .... $f \leq f_p$

$S=S_{max}(f/f_p)^{-2.6}$ .... $f > f_p$

Izumimiya

$S=S_{max}/[1+10(\log_e(f/f_p))^2]$

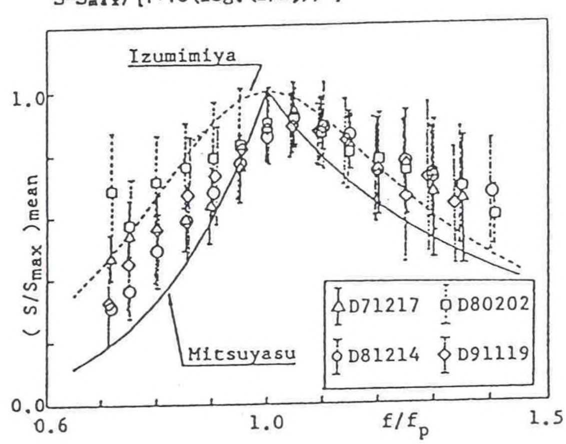


Fig.8 Spreading parameter S

MOTION RESPONSE IN DIRECTIONAL WAVES [8]

The estimation of response amplitude operator of motions of floating structure in waves is very important to predict its behavior in actual seas.

The directional wave spectra were analyzed using measured data. The 6 degree of motions of POSEIDON were measured by accelerometers and vertical/directional gyroscopes. Then we tried to estimate the directional frequency response functions in the wave frequency range. The results estimated by the present method were compared with the theoretical response amplitude operator and it was found that we need many experimental runs of various wave directions for obtaining fairly good response amplitude operator.

$$S_i(\omega) = S_\eta(\omega)\int_{-\pi}^{\pi} |H_i(\omega,\chi)|^2\, D(\omega,\chi)\, d\chi$$

here $S_i(\omega)$; response spectrum of i-mode motion
$S_\eta(\omega)$; wave spectrum $D(\omega,\chi)$; directional function
$H_i(\omega,\chi)$; directional frequency response function

The low frequency motion with the period from 60 to 90 seconds due to waves occurred surely. The extreme values in N peaks of surge motion is shown in Fig.12 . The measured data are scattered between the lines of the result calculated by linear theory of Longuet-Higgis [9] and non-linear theory of Kato[10]. The latter gives the upper limit to the measured data. Therefore, the maximum expected values of low frequency motion due to waves can be estimated using this method.

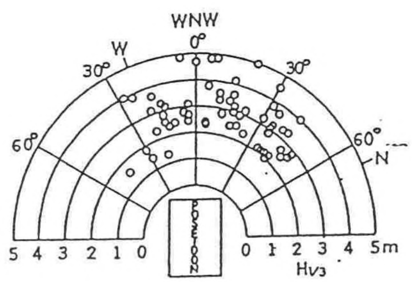


Fig.9 Principal directions and significant wave heights

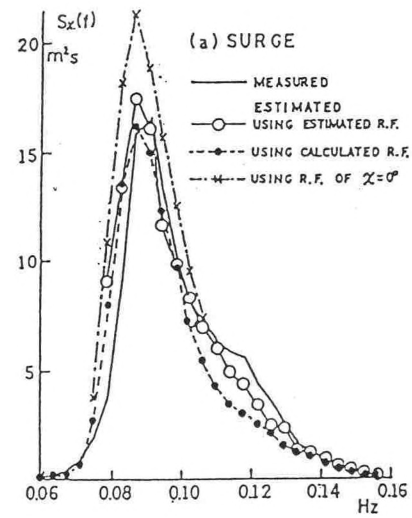


Fig.11 Response spectra of surge

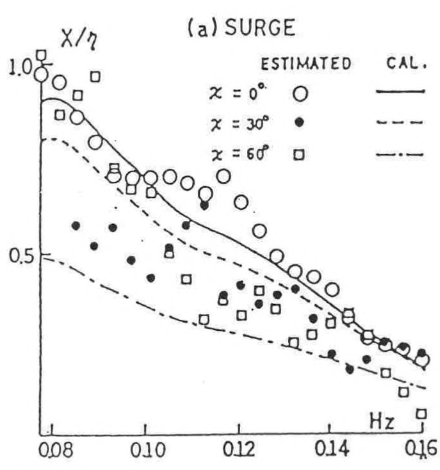


Fig.10 Directional frequency response functions

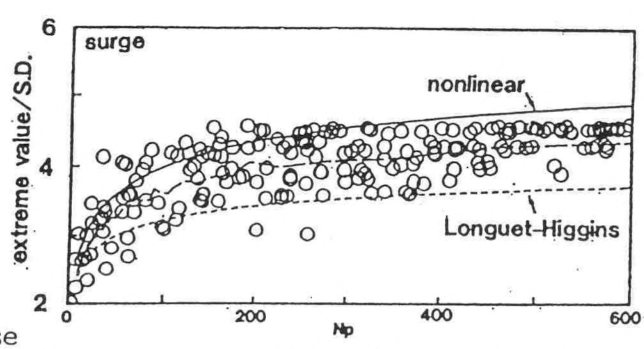


Fig.12 Extreme value/S.D.in N peakes

STRENGTH OF STRUCTURE AND FATIGUE ANALYSIS [11]

The structural strains induced by waves were measured at 12 locations of main structural members over a total of 4 years. The fatigue damage of the structure was estimated from the measured stress range distributions applying Miner's law. The results were also compared with the existing design values.

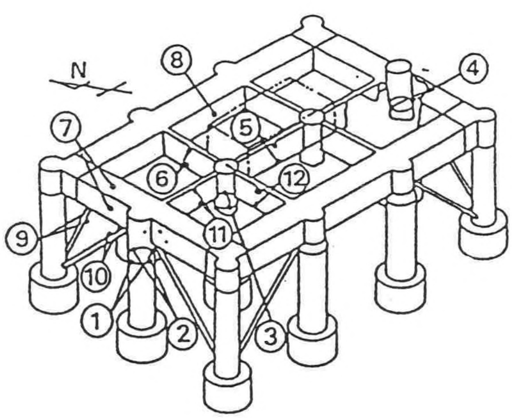


Fig.13 Measured locations of strain

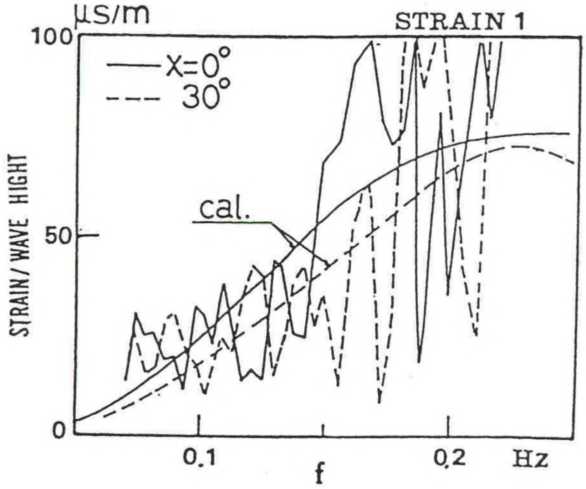


Fig.14 Response amplitude operator

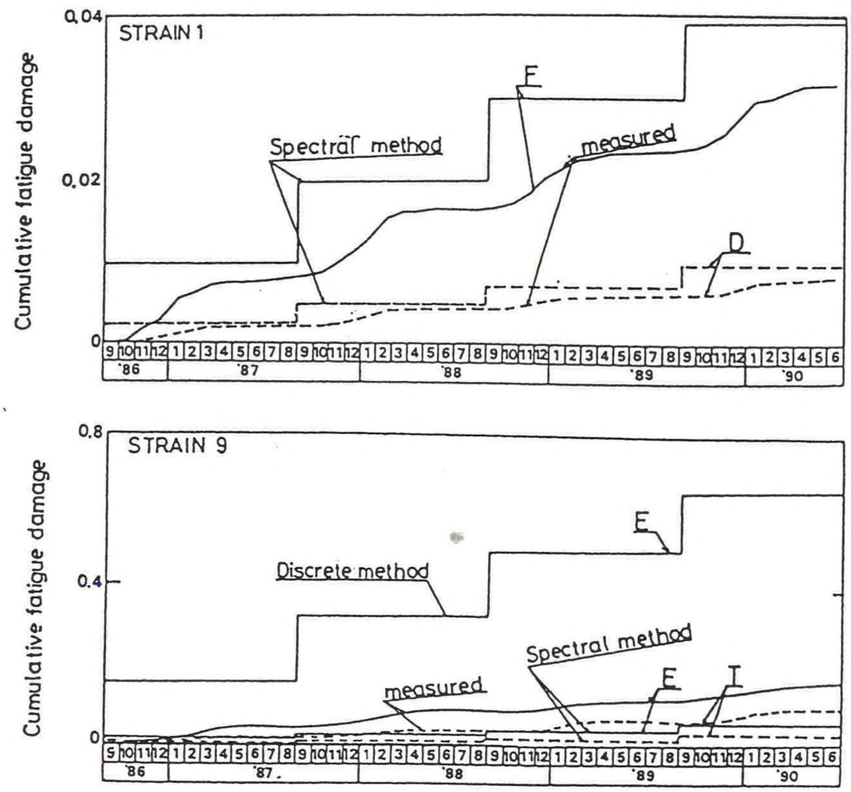


Fig.15 Cumulative fatigue damage in during field test

TENSIONS OF MOORING LINES [12][13]

POSEIDON was moored by six chain lines, and tensions of two lines among them were measured by under water force transducers. The low frequency motions of structure were measured by underwater ultrasonic device, while high frequency motions were measured by accelerometers and vertical/ directional gyroscopes.

The numerical simulation method and statistical characteristics of mooring line tensions were investigated using the field measured data.

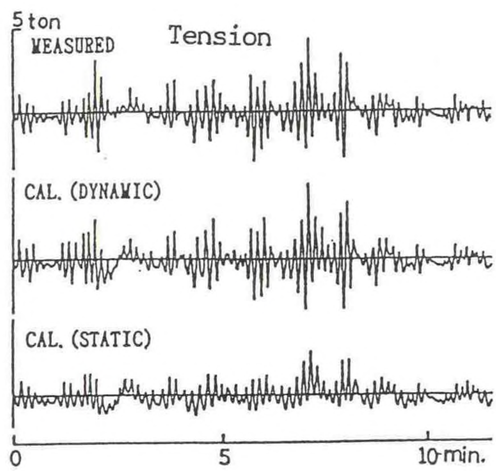


Fig.16 Time series of measured and simulated tensions

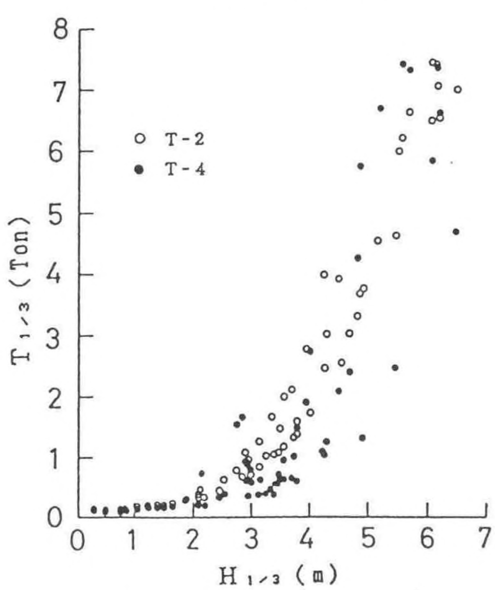


Fig.17 T1/3 vs. H1/3

• A new numerical simuration method of time series of mooring line tension was proposed taking account of the effect of low frequency motions.

• The strong non-linearity of the mooring line tension was clarified, and it was found that the statistical distributions of tension coincide well with the Hermite statistical moment model proposed recently.

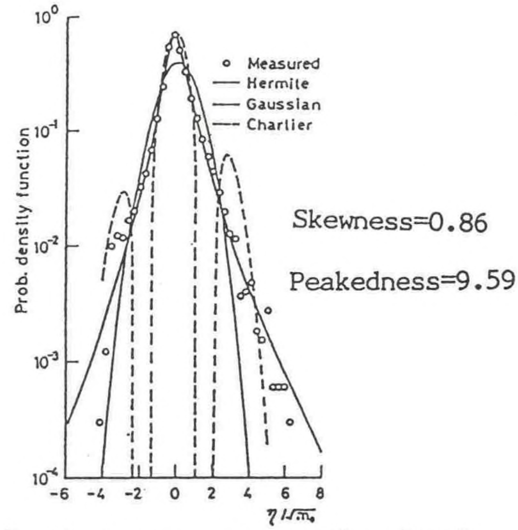


Fig.18 Instantaneous distribution of measured tensions

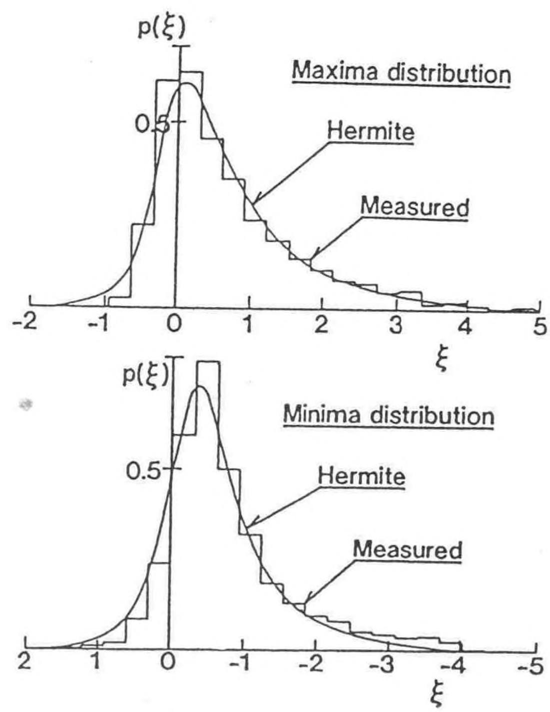


Fig.19 Minima and maxima distribution of measured tensions

DEFORMATION AND STRESS DUE TO SOLAR RADIATION [14]

In order to realize the construction of a huge platform, the investigations of structure deformation and stress distribution caused by the non-uniform thermal distribution due to solar radiation are indispensable.

The long continuous data of solar radiation, temperature and strains of steel at various points were obtained in this experiment. Using those field data, the estimation methods of solar radiation, thermal distribution and stress distribution were investigated, and thus validity of those methods was confirmed.

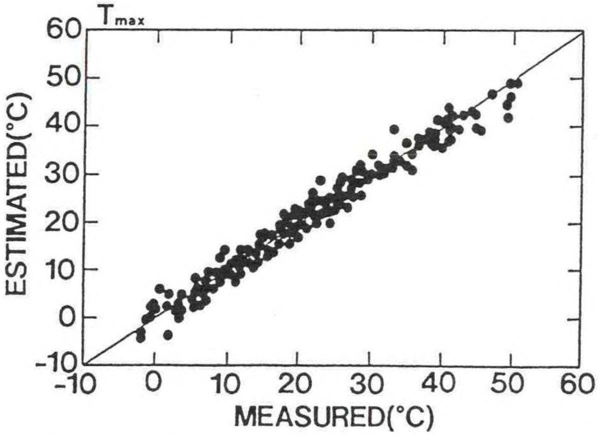


Fig.20 Comparison of Tmax between estimated and measured

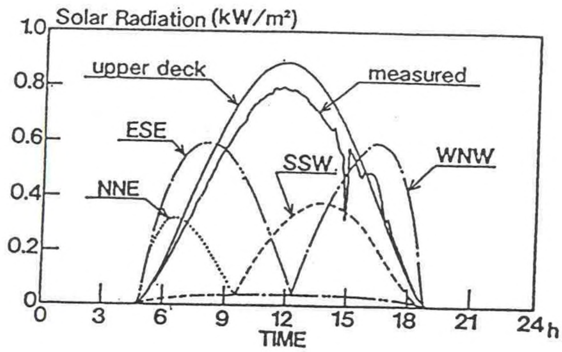


Fig.21 Total solar radiation for each surface wall

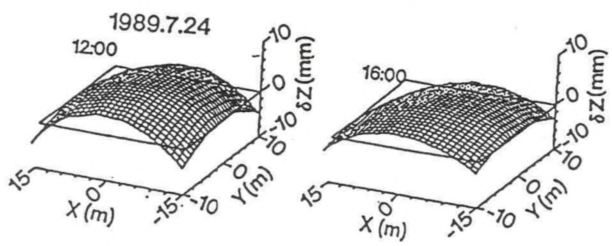


Fig.22 Deflection of upper deck

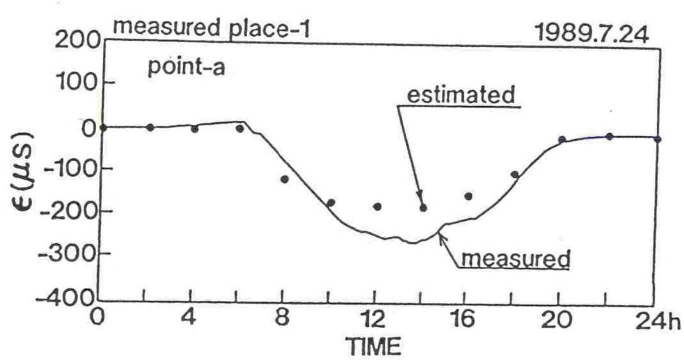


Fig.23 Comparison of strain between estimated and measured

5. FUTURE RESEARCH ACTIVITIES

It will be technically possible enough to construct a huge floating platform with present techniques. However, we are challenging to the research activities for developing more advanced floating platforms.

(1) DEVELOPMENT OF ADVANCED FLOATING PLATFORM

The research themes are as follows;

- More accurate estimation of the external forces acting on floating bodies,
- Active control of the motions of floating platform by oil pressure devices,
- Passive control of the motions of floating platform by changing shapes or arrangements of floating bodies.

(2) INVESTIGATIONS ON THE INFLUENCE OF THE HUGE FLOATING PLATFORM ON THE MARINE ENVIRONMENT

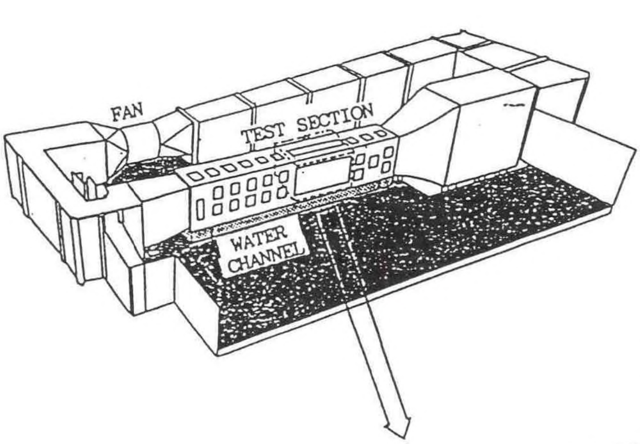
The variation of marine environment caused by a huge floating platform should be assessed on the stage of planning. In this studies, the assessment on the physical influences of the huge floating platform on the marine environment will be mainly investigated.

(3) CONSTRUCTION OF PULSATION WIND TUNNEL WITH WATER CHANNEL

A water channel is installed under the test section of the wind tunnel, and wave and current can be generated in it. So we can perform the experiments on a floating platform under the combined external forces of wind, wave and current. This wind tunnel will be accomplished in 1993. A schematic view and principal dimensions are shown in Fig.24.

Pulsation Wind Tunnel with Water Channel

(Under construction)



Principal Dimensions

1.Wind Tunnel

Type

Götingen circulating flow type

Test Section

Closed Section

breadth × depth × length	3m × 2m × 15m

One part (3m length) can be used as open section.

Performance

Steady Wind

Maximum wind speed	30m/s
Velocity uniformity	±1%
Turbulence intensity	0.5%

Pulsation Wind

Sinusoidal pulsation	13m/s±50%(period 50sec)
Irregular pulsation	by external signal

2.Water Channel

Test Section

breadth × depth × length	3m × 1.5m × 10m

Performance:

Wave Generator

Maximum wave hight	20cm
Wave period	0.6~4.0sec

Current Generator

Maximum current speed	0.3m/s

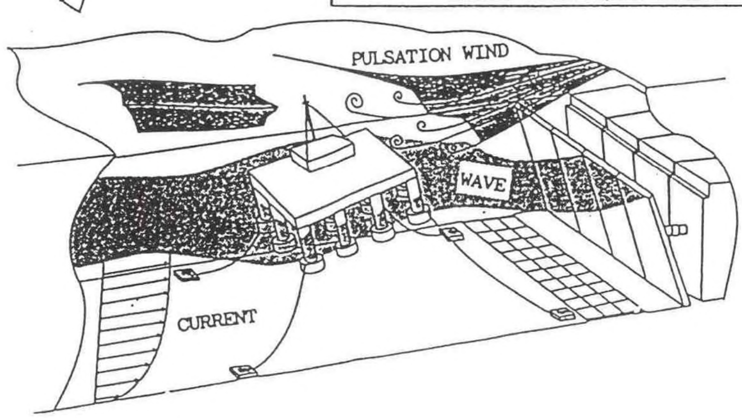


Fig.24 Schematic view of wind tunnel

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FIBER REINFORCED POLYMER HONEYCOMB MATERIALS FOR MARINE FLOATING STRUCTURES

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High strength, light weight fiber reinforces polymer honeycomb (FRPH) materials may provide an improved method for the fabrication of floating marine structures and systems. This paper discusses the state of the art and possible areas for marine applications of these materials.

The use of high strength, lightweight structural materials based on fiber reinforced polymers and having a honeycomb like core may significantly improve overall structural rigidity and strength and reduce the costs of floating marine structures. These materials can provide very high corrosion resistance and high strength to weight ratios for compression and bending stresses due to the high moment of inertia of their cross-sections and the efficient use of material. As opposed to honeycomb structures which use a separate bonded skin to the honeycomb core substructure, current technology now allows FRPH materials to be made in a single operation in which the bond of the core structure to the skin is integral with the fiber reinforced polymer material itself. This imparts significant strength to the core to skin bond and increases the ability of the material to withstand mechanical and thermal stresses as well as simplifying the production process.

Application Opportunities

The potential applications for floating platforms to a variety of ocean based activities will in most cases depend heavily on the economics of creating "real estate at sea" in comparison with traditional land coastal development and extension. Limited port areas and precipitous coastal slopes often make the choice of an ocean platform an attractive option for answering the need to expand port facilities. The use of floating systems is more environmentally benign, but will always be considered in comparison with the known engineering methods and costs of a traditional land extension through fill, or through the sacrifice of existing land space, giving up one land use for another. Further, consideration of floating platform "real estate" raises the issue of the lifetime of the floating system and the potential effects of motion on the functions which are to use the platform space. Materials cost and fabrication methods will be significant factors in determining the competitive economics between "floating real estate" systems and those using conventional barrier and fill techniques for real estate extension from the existing land. New materials which may significantly improve strength and lifetime costs can provide the key to the economic feasibility and practicality of "floating real estate" systems.

Similarly, the U.S. currently has no effective world market in shipbuilding, and other nations are beginning to feel the economic effects of increased world competition. New materials other than steel for at least the smaller sized vessels may offer new opportunities for competitiveness in ship construction as well as providing new methods for design and construction which in turn may make new ship designs possible.

In both of these application areas, the properties of FRPH materials may provide the technological basis for improved engineering and for design and construction methods leading to competitive acquisition and lifetime costs for marine systems.

Design Considerations

The basic design and application potential for honeycomb like lightweight materials has been recognized for many years. The simplest material is of course cardboard and its derivatives. Cardboard is currently used, in both its common pasted form and most recently as a fiber filled polymer, for a variety of container and construction material applications. These include doors, wall panels, and furniture, as well as joists and beams for basic house construction. In order to take advantage of the high strength and rigidity of these honeycomb cell materials, the aircraft industry, especially military aircraft, also use built up metallic or composite materials for aerodynamic control surfaces and some body applications. These materials are built up in a bonding or brazing (for metals) process which significantly increases their cost. However, for the limited aerospace applications in which their light weight, high strength properties are of great value, the higher cost is justified. For general application to large scale marine structures, however, low cost and ease of fabrication will be paramount design considerations.

The general structural characteristics of FRPH materials are illustrated in Figure 1. The general structural features are a closed cell honeycomb like core sandwiched between two skins. In the current state-of-the-art manufacturing techniques, it is possible to form the cellular core and the two skins together in one continuous bonding operation such that the polymer agent provides a bond between the core and skin which is a continuous part of the polymer fiber bonding. Thus the core and skin materials form a single homogeneous structure. Of course, for particular requirements, different thickness and different reinforcing materials can be incorporated in the two skins and in the core materials. This provides a wide range of FRPH material properties which can be engineered to suit the particular application needs for the material.

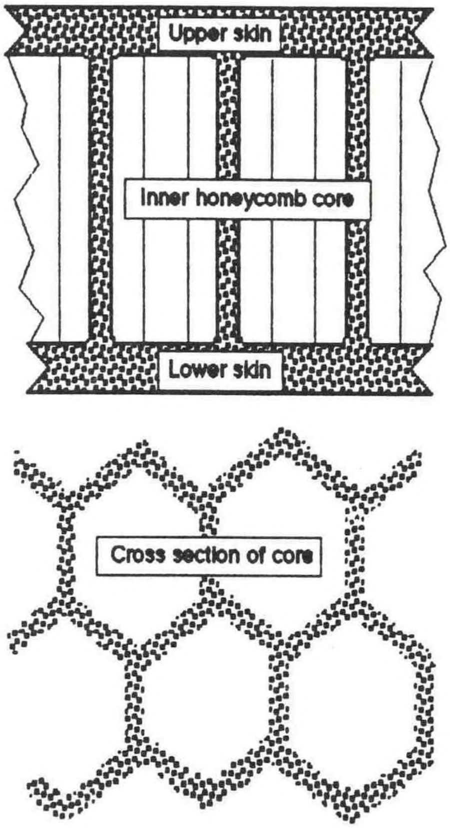

Figure 1. FRPH Configuration

FRPH can be produced over a very wide range of sizes. Using proprietary fabrication techniques developed by Core Craft Technologies, Inc., FRPH materials of very large (1 meter and larger) cross section have been produced and have already been used for large building structure applications. The operating strengths of these large scale materials are suitable for such applications as highway bridges and causeways. At the same time, very strong wallboard structures are now being produced using a cardboard type fiber material which are on the order of

1-2 cm in thickness. Large tank and circular buidling covers using the FRPH materials have also been fabricated and successfully installed within the past 20 years and are still showing no signs of deterioration

A very important element in the fabrication and application of FRPH materials, particularly for marine applications, is the ability to fabricate such materials in a <u>conformal</u> manner. Until recently, most manufacturing methods for these materials produced planar configurations only. However, recent fabrication advances have made it possible to produce curved and cylindrical configurations with the internal honeycomb like core elements lying along radials from the center of curvature of the local surface (or from the axis of the cylindrical form). This type of construction is extremely important if the high strength and rigidity of the FRPH material is to be obtained in these forms. The geometry of the internal core must be appropriately aligned with the major stress vectors which will be encountered in its intended application.

Potential strengths of the various possible FRPH materials can be tailored on the basis of the dimensions of the material elements (inner and outer skin and core) and the types of reinforcing fiber used. Typical compressive working strengths of the basic FRPH materials will range from 100 to 1000 psi. depending on the fiber and the construction. The upper figure is significantly better than typical concrete. Basic solid fiberglass reinforced G-10 phenolic has an ultimate compressive strength on the order of 40,000 psi. These materials are generally competitive with steel on a comparable weight basis.

There are some potential problems with these materials. The reinforced polymers can deteriorate over time through exposure to sunlight and deterioration can also occur due to seawater exposure. Of course both of these concerns have been successfully met in the use of solid fiberglass polymer hulls for small to medium sized boats for many years. The use of appropriate light reflecting and absorbing materials in the outer skin, combined with surface sealants and treatments, can be expected to provide an adequate life expectancy to FRPH marine systems. Nevertheless, for specific proposed applications, the potential lifetime of the material will need to be verified through an appropriate evaluation program.

Material failure modes are another important consideration. Although very strong and rigid, the RFPH materials will have different yield characteristics due to fatigue or to overload. The plastic deformation of steel, for example, will allow a ship hull to be significantly bend without necessarily incurring a hull penetration. The Fiber reinforced polymer materials, however, are likely to incur a brittle separation or fracture if pressed beyond ultimate strength. On the other hand, their range of elastic deformation is generally greater than that for steel. When used for a hull, the FRPH may fend off bumps better than steel, but when stressed beyond ultimate strength, might fracture when steel would only incur a permanent bend. However, it is also true that the basic FRPH structure is, in effect, a double hull with multiple small closed compartmentation. Therefore, even if the outer skin is penetrated, the FRPH hull structure would only take on a small amount of water from a single break in the outer hull skin. All of these design factors can be examined and the design risk level determined by straightforward means. For floating platforms, the question of hull collisions will likely be of less import than the overall lifetime and the cost of the material.

Potential Applications

Two principal application areas are suggested: floating platforms (including the construction of major "floating real estate" systems) and ship construction. Applications to the floating platform are illustrated in Figure 2. In this case, the major structural elements are the floatation itself and the overbridging upper working surface or decking of the platform. The FRPH materials are appropriate for both elements.

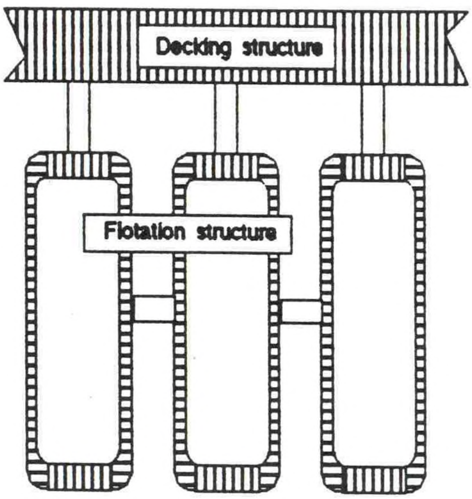

Figure 2. Floating Platform Application

In the case of the floatation element, the primary functional consideration will be twofold: 1) the floatation efficiency (net buoyancy) and 2) the lifetime of the element. Its clear that a requirement to replace the platform floatation before the amortized lifetime of the decking or the systems which the platform is supporting would be very undesirable. These usages may be very long lived. Therefore the platform floatation system must have a very long life expectancy, on the order of several decades at a minimum. Under many conditions of exposure, polymers have already demonstrated such lifetime capability. Indeed, one of the primary concerns of environmentalists is the indestructibility of plastic trash. Although the potential for long service seems inherent in the use of RFPH materials, lifetime and cost will be the primary concerns in FRPH applications to "floating real estate" platforms.

As to floatation efficiency, the strength to weight ratio of the RFPH materials will make them a clear winner against all other systems in the same cost range. Steel and concrete structures will be much heavier in proportion to their net buoyancy. In terms of cost per pound, this will increase the potential relative cost of steel and concrete floatation. Cost per pound of the FRPH material based on current manufacturing methods has been estimated to lie in the range of $5 to $10.

Another potential benefit is the inherent safety factor of the effective double hull provided by the RFPH material. Formed into floatation cylinders, with appropriate end terminations, the RFPH would provide a very secure closed cell containment of any outer skin leakage. Also interesting is the likelihood that such outer skin breaks could be repaired in situ before the inner skin suffers any deterioration, making repairs much simpler than in the case of steel or concrete systems.

For the decking applications, the large scale FRPH planar forms which have already been commercially produced could be adapted directly to provide the operating surface of the platform. To meet flexure concerns, these forms have very high rigidity and can be conformed to offer a variety of attachment interfaces. Another potentially useful characteristic is the low heat transfer of these materials, combined with the natural insulating properties of the closed cell inner structure.

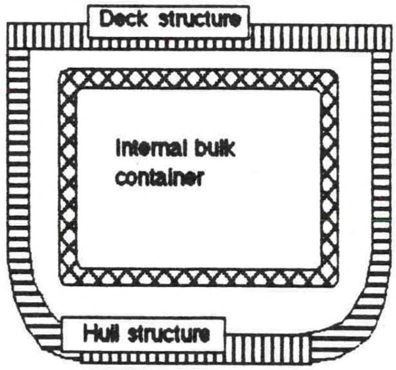

Figure 3. Shipbuilding Applications

In the second suggested application area of shipbuilding, the RFPH materials offer interesting alternatives to convention construction of the hull itself (including the main decking) and to the fabrication of bulk storage elements within the hull, if separate from the hull (see figure 3). In addition to the inherent effective double hull nature of the FRPH material configuration, the polymer based materials will be much less reactive than metal for many bulk products and will not suffer the normal corrosion problems of steel. The use of custom FRPH materials can also accommodate built in load transfer and attachment interface elements which are integral with the basic FRPH structure (Figure 4).

These opportunities for custom materials design, combined with fabrication methods which allow specific conformal shape requirements to be met in the FRPH fabrication process, would contribute significantly to cost reduction in the shipbuilding process itself. Further, the FRPH structural elements could be designed in modular form for the flexible construction of ships of various sizes and configurations within a class, further reducing the cost of meeting specific customer needs.

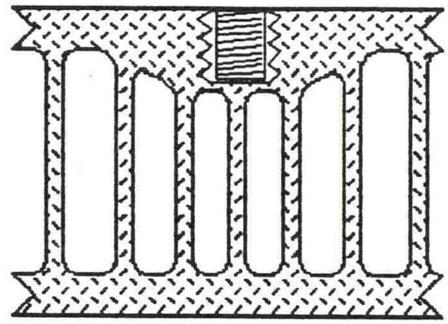

Figure 4. Proposed Load Transfer Design

An appropriate initial study examining the potential for an all FRPH hull, and for FRPH based internal bulk storage could examine these issues in the context of current state-of-the-art manufacturing capability which already exists. Similar FRPH materials have already been used in major land based construction in climates ranging from semi arctic (Alaska) to tropical and have already demonstrated useful lifetimes in these structures of up to 20 years with no effective deterioration.

In conclusion, FRPH materials offer a new opportunity to design marine structural systems for both floating platforms and shipping which will improve efficiency and cost competitiveness of these systems as compared with standard materials and construction techniques. The FRPH materials may well provide a path to practical and economical solutions to the problem of dwindling coastal space resources. The adaption of these materials to the marine construction industry may offer an opportunity to regain a competitive edge in the world marketplace for shipping and floating platforms.

DEVELOPMENT OF SUBMERGING/SURFACING TYPE ARTIFICIAL SEA FLOOR "MARINE-AYA NO. 1"

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ABSTRUCT

To make use of bays in a Rias coast, which are less useful for fishery, a semi-submersible floating fishery cultivation facility with function of submersing and surfacing, "ARTIFICIAL SEA FLOOR", was developed and placed at a trial sea, and for developing know-how to make use of marine space in three demensions, test cultivation of shell (abalones) and fish (black rockfish) was carried out.

1) The facility, the artificial sea floor, was placed in a bay in Iwate Prefecture facing the North Pacific Ocean in December 1990.

2) The facility has a shelf structure of 20m x 20m submerged 4m depth layer and an operation hut standing to the sea surface from the center of the shelf.

3) Abalones were cultivated at a level of the shelf, and black rockfish, below the shelf. The facility was also used as a floating fishing reef.

4) When feeding kelp to abalones, the facility was surfaced. Fish were fed automatically by feeding machine from the surface in the submersing condition.

The at-sea-test made it clear that the submersing/surfacing type artifitial seafloor provides easy operation, safe working and low operation cost. Also it was verified that the facility would be useful for mariculture not affected waves and rains, and would make use of marine space in three dimensions.

1. INTRODUCTION

In the bay of the rias coast the sea floor is steep and deep. Therefore sunny rocky area suitable to growth of shells and sea weeds and the proper area for a mariculture of fishes are narrow. And also the deep sandy or muddy bottom is not so useful for a fishing ground. In Iwate Prefecture, coastal area is rich with rias bays, the abalone is one of the important resources for the coastal fishery and its propagation business has been practiced for long years. However, its yield keeps on decreasing year by year. Therefore, practical and effective countermeasure to stop the decreasing of abalone resources have been requested, and one possible measure was thougt to utilize the underwater space in the rias bay by constructing artificial sea floor.

As a link in the chain of "Aqua-Marine Plan" of Science and Technology Agency, Japan Marine Science and Technology Center (JAMSTEC) and Iwate Prefectural Government started studying the artificial sea floor, and undertook the Project "Development of Marine Space Expansion Technology Employing Submerging/Surfacing Type Artificial Sea Floor" as a three-year plan starting in 1989.

The experimental facility named "Marine-Aya No.1" was constructed and deployed at a depth of 16m in Ryohri-Minato Bay of Sanriku Town, Iwate Prefecture, in December 1990. After the pre-operation test of about 5 months, its at-sea-demonstration test including the cultivation of abalones and black rockfish was carried out for about one year from May 1991 and its high evaluation as a cultivation facility could be obtained.

This paper reports the concept of the artificial sea floor, the construction of the facility and the at-sea test results of it.

2. CONCEPT OF ARTIFICIAL SEA FLOOR

The word "Artificial Sea Floor" has been recognized as a considerably popular one in Japanese fisheries reserchers. In the conventional concept, this means a flat surface made of a concrete structure, steel one or the like and placed in the middle sea layer by means of a mooring system or support system. Such a structure provides only a surface of one layer in the sea and any light cannot reach the layer beneath this, also disturbs the vertical sea water motion. Therefore, this type of the artificial sea floor has a utility value, but has a minus value for the water space and sea floor beneath it. In addition, as for the utilization method of the artificial sea floor installed, it is thought only to offer a propagation space and fishing bank for marine biological resources and natural producing power is expected.

On the other hand a high cost is estimated necessary in building the artificial sea floor, and so it is unprofitable clearly when this utilization relies the natural producing power only. Therefore, it is considered necessary that the artificial sea floor can make the most of the underwater space three-dimensionally, can be used for not only propagation but also culture, does not disturb the ecosystem of the installed sea area, and the facility is sufficiently rigid and requires a low maintenance and management cost. (Note; "Propagation" is to plan increasing of resources such as recapturing of young abalones in the sea, and "culture" is to breed and feed fishes for their artificial growth.)

In order to meet these requirements various concepts have been studied. Finally, a fundamental plan has been prepared and determined. The plan is to built such a structure that the underwater space can be utilized in multi-stage conditions, to float and moor it in the middle layer of a sandy bottom area in a rias bay, and to utilize it for culture of abalomes and fish, and also to give it the functions of a floating fishing reef, and further to utilize it as a oceanographic phenomenon monitoring station.

In this point the control method of cultivated abalones and fish becomes a problem. For example in cultivating abalones it is necessary to feed food (kelps are common in Iwate Prefecture) of the nearly same weight as that of the fed abalones every 10 to 15 days and then to remove remaining food completely. The maximum density for abalone culture is said to be about 10kg per m^2. If an area of $100m^2$ is us, about 1 ton of abalones can be bred and so about 1 ton of food should be supplied. In the warm southern sea this work can be carried out by diving. However, it is almost unrealistic in cold North Japan during winter time. As for fish normal feeding is possible with an automatic feeding machine, but removal of dead individuals, selection in case of difference in growth, catching work, etc. are difficult to be carried out underwater. As the means to solve these problems it is planned "to surface the artificial sea floor to the sea surface when necessary".

3. GENERAL PLAN OF RESEARCH AND DEVELOPMENT

It was decided that the research term is three years starting in Fiscal Year 1989 (Table 1), the artificial sea floor facility is to be designed and manufactured during the first two years, and the demonstration test in the actual sea area is to be carried out in the third year.

For the experiment site a 16m deep area inside the break-water at the mouth of Ryohri-Minato Bay of Sanriku Town, Iwate Prefecture was selected.(Fig.1) The concept design of the facility was started considering the sea conditions of the above sea area. To determine the depth layer of the artificial sea floor, habitat of natural abalones around the experiment site was previously examined by diving survey. As the result, majour habitat depth was proved between 3 to 5m, then the layer of the artificial sea floor was decided to 4m. And it was decided that the artificial sea floor is to be 20m long and 20m wide and to be anchored in the sandy sea bottom with anchors and chains in the catenary type.

The artificial sea floor was built in Shiogama City, about 85nm away from the test sea area, by Kawasaki Heavy Industries, Ltd. After completion it was towed to Ryohri-Minato Bay and its mooring work was finished in December 1990. Up to April 1991 the pre-operation test was carried out, such as the submerging/ surfacing test, ageing of the facility, study of manufacturing/fitting method of culture baskets and culture preserve nets, etc. In May 1991 the at-sea-demonstration test was started, including the culture test of abalones and black rockfish.

The following eight items have been determined for the at-sea-test themes :

1) Abalone culture test
2) Black rockfish culture test
3) Study of maintenance/management technique
4) Monitoring of sea conditions and atmospheric phenomena
5) Study of floating fishing reef functions
6) Fishing gear technology evaluation of facility and study of its adaptability to open sea
7) Physical study of artificial sea floor boundary layer
8) System evaluation

Table 1 General Schedule of Reserch Program

Item	1989	1990	1991
1. Investigate the Test Sea Area	–		
2. Design/Construct the Facility	———	———	
3. Anchor the Facility in the Sea		–	
4. Pre-Operation Test		–	–
5. At Sea Demonstration Test			———
6. System Evaluation			—

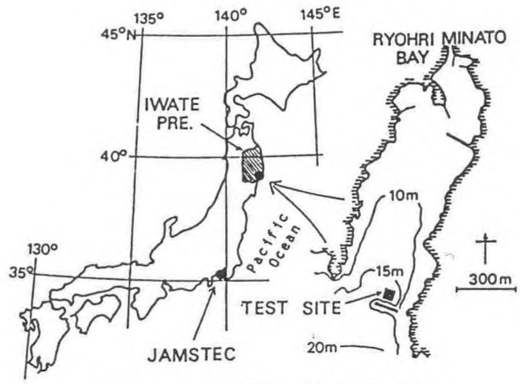


Fig.1 Location of Test Site

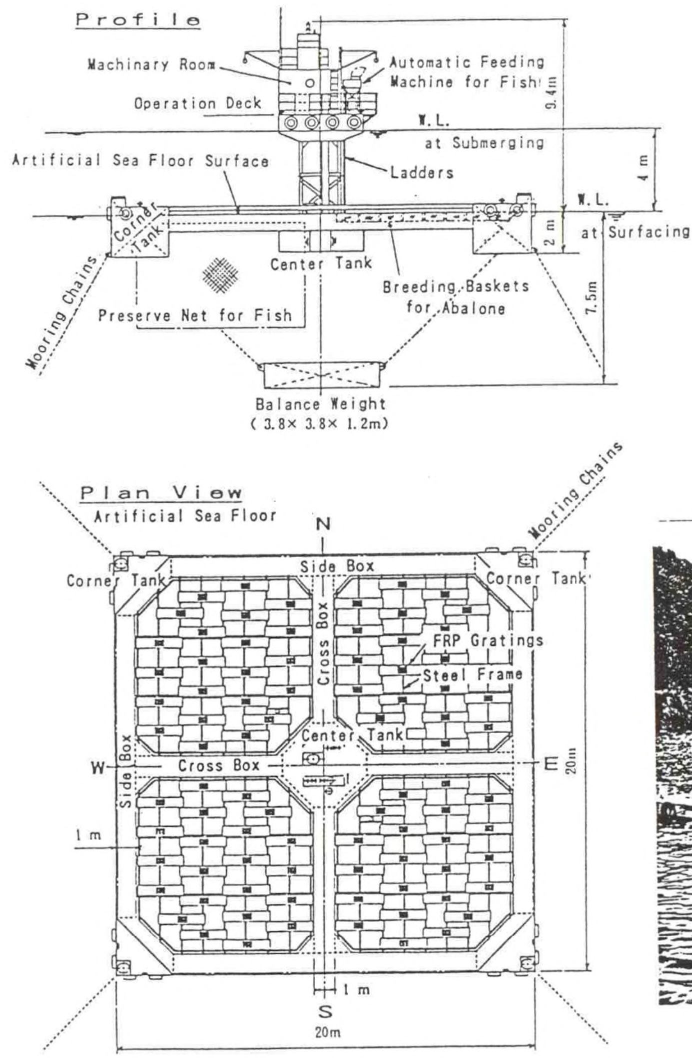
4. SUBMERGING/SURFACING TYPE ARTIFICIAL SEA FLOOR

4.1. Outline of Facility

General arrangement of the artificial sea floor facility is shown in Fig.2. The facility is a welded steel structure composed of the artificial sea floor section (20m wide x 20m long x 2m deep) and an operation machinery room (about 9.4m high) supported above the sea surface with struts just above the center of the sea floor section, and is anchored to the sea floor at 4 points with anchors and chains.

The upper face of the artificial sea floor section is a steel frame structure divided equally into four square parts and can load various experiment devices of up to about 30 tons. The artificial sea floor section and the space beneath this section are used for abalone culture and fish breeding respectively, and the facility itself is utilized as a sea condition/atmospheric phenomena monitoring station and floating fishing reef. The artificial sea floor surface is normally submerged (Photo.1) in the layer 4m below the sea surface, and, if necessary, can be surfaced (Photo.2) above the sea surface by discharging water from a main ballast water tank.

Abalones are cultivated with covered breeding baskets fixed to the steel frames of the artificial sea floor surface. They are fixed in such positions that their covers are slightly above the water surface when the facility have surfaced. Sea weeds such as kelps are fed every 10 to 15 days, and the artificial sea floor is surfaced in advance to carry out this work on the sea surface. Fish is cultivated in the preserve nets fitted in the space below the artificial sea floor. Formula feed is used and is supplied to the preserve nets through pipes by an automatic feeding machine provided in the machinery room above the sea surface.



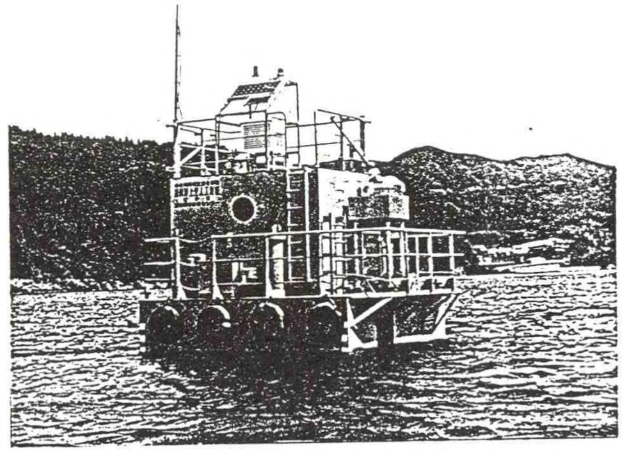


Photo.1 The Facility at Submerging

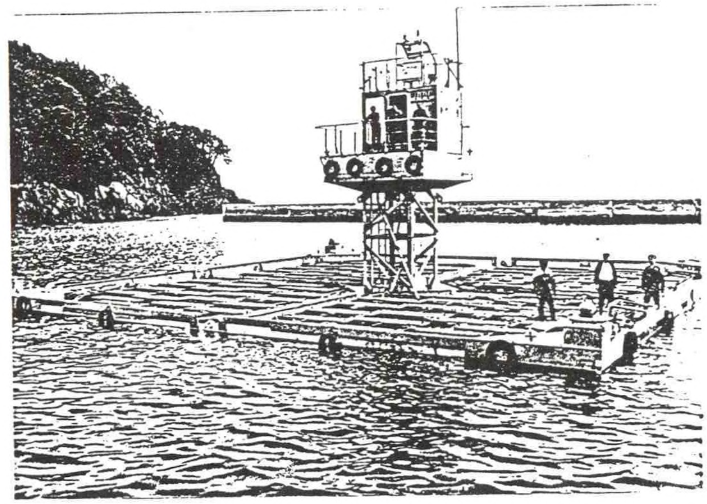


Photo.2 The Facility at Surfacing

Fig.2 General Arrangement of the Facility

4.2 Principal Paticulars
- Length x Width x Height (overall) : 20 m x 20 m x 11.4 m
- Draft : Surfacing abt. 2.0 m
  Submerging abt. 6.0 m
- Height of superstructure : Surfacing abt. 9.4 m
- Draft adjusting capacity : Loading weight of up to abt. 30 tons
- Time required for submerging : abt. 10 min.
- Time required for surfacing : abt. 60 min.

4.3. Design Conditions

The themes in designing the artificial sea floor were to make the operation as simple as possible, to decrease the operation cost as low as possible, and to give such a long life on the sea that no special maintenance and inspection are necessary, cosidering the usefullness and cost-efficiency as a culturing facility.

(1) Applied Rules

In designing the facility, the following rules were referred to:
- Nihon Kouwan Kyoukai : Technical criteria for harbor facilities and their comments
- Coastal Fishery Promote and Developement Society : Coastal fishery arrangement/development project structure design guideline
- Nippon Kaiji Kyoukai : Rules and regulations for the construction and classification of ships, Part C Hull construction and equipment.

(2) Placed Sea Area
- Placed sea area : North side (inside) of east break-water in Ryohri-Minato Bay
- Depth of water : Load water line abt. 16 m (Tide level change 1.5 m)
- Sea floor soil condition : Sandy soil, nearly flat

(3) Sea Conditions and Durability

The design conditions for the break-water in the mouth of Ryohri-Minato Bay were reffered to. For waves the diffracted waves and surpassed waves caused by the break-water are calculated to determine the design values.
- Waves (at the Break-water) : $H_{1/3}$ height 5.2 m (period 16.1 sec)
- Tide speed : 0.5 knot
- Wind speed : 40 m/sec
- Designed life of the facility : 5 years (to give such strength and durability that no special maintenance and inspection are necessary while placed on the sea)

4.4. Facility Construction

The bird's-eye view of the artificial sea floor facility is shown in Fig.3. The facility is composed of the artificial sea floor section, superstructure, balance weight, mooring equipment, etc.

(1) Artificial Sea Floor Section

This section is a box structure having four equally-provided square openings in the plan view. The main ballast water tank (hereinafter called the center tank) is provided in the center of it, and at four corners of its periphery part the auxiliary ballast water tanks (hereinafter called the corner tanks) are arranged. And the hollow side boxes and cross boxes are connecting these tanks. The center tank and corner tanks are two times deeper than the side and cross boxes. All these tanks and boxes are connected with each other with their upper surfaces arranged flush to form the artificial sea floor surface. This surface is in the 4m depth layer during submerging and is only several centimeters above the sea surface during surfacing. Upper faces of all boxes becomes traffic passages during surfacing.

The size of the four openings is about 8m x 8m each. These are such shelf structures that steel frames are arranged on their upper face level at intervals of 1m to form an artificial sea floor surface that does not prevent the movement of sea water in the vertical direction. The steel frames are slightly above the sea surface during surfacing of the facility and are used to fix the abalone breeding baskets and to hang the fish preserve nets. In addition, on the upper face of the steel frames, optionally-movable FRP gratings are laid over 1/3 in area as scaffoldings.

The center tank governs submerging and surfacing of the facility. By charging or discharging sea water of about 20 tons the position of the artificial sea floor surface is switched between the submerged one in the 4m depth layer and surfaced one slightly above the sea surface.

The corner tanks govern draft adjustment and attitude adjustment at the surfacing position. When the facility is built and just placed in the site, these four tanks are in nearly-full condition with ballst water. However, by the time when any unbalanced load change occured due to loading of the culture equipment and experiment devices, growth of bred fish and shells or adhesive creatures, the draft and attitude of the facility can be adjusted easily by adjusting the water contents of these tanks.

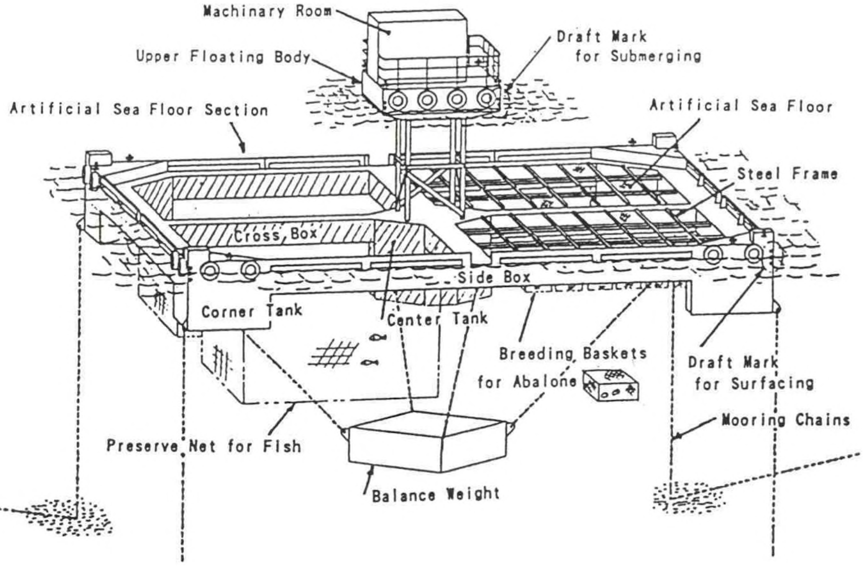


Fig.3 Bird's-eye View of the Facility

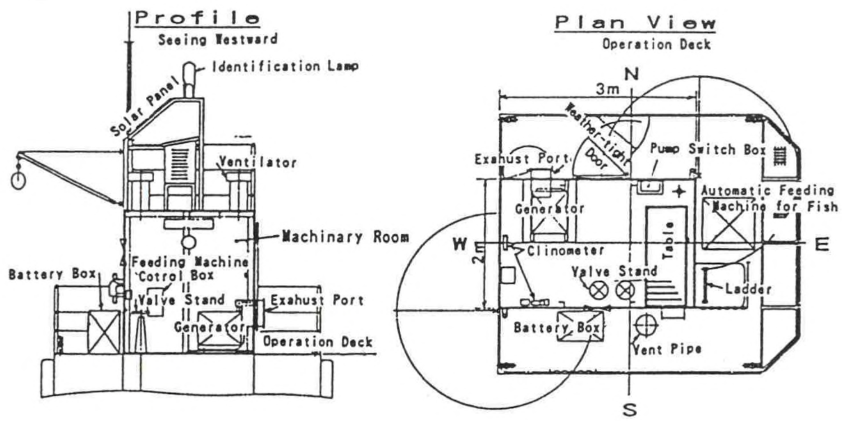


Fig.4 Arrangement of the Macinary Room

(2) Superstructure

The superstructure is supported with four struts provided on the deck of the center tank so that it will be above the sea surface during submerging. The struts are designed to be frame-work structures made of shape steel members which generating least buoyancy in order to reduce the ballast water tank volume.

The upper floating body, composed of a hollow rectangular box, is designed to keep most of the body above the sea surface during facility is submerging, and have a reserve buoyancy of about 10 tons preparing when a part of buoyancy had lost in any underwater section. A buoyant material is poured into the inside of the floating body so that the necessary least buoyancy will be secured even in case of structure had damaged due to collision of a fishing boat or the like.

Arrangement of the machinery room is shown in Fig.4. This room is arranged on the deck of the upper floating body (hereinafter called the operation deck). In its north side a weather-tight door is provided and in its south side a water-tight window.

Inside the room an electric generator set and the water charging valve operation stand, water discharging pump operation board, etc. for the center tank ballasting system are installed. For the traffic purpose vertical ladders are provided respectively between the artificial sea floor surface and the operating deck and between the operation deck and the roof of the machinery room. In addition handrails are provided around the operation deck and the roof of the machinery room from the safety point of view, since these becomes high places during surfacing.

(3) Balance Weight

In order to improve stability by lowering the center of gravity of the facility, a balance weight of about 25 tons in underwater weight is hung beneath the artificial sea floor section. The balance weight is a steel box filled with concrete and is connected to the central parts of the peripheral side boxes with four chains respectively. The inclined angles of the respective chains are set larger than the maximum facility inclination caused by waves in order to keep 4 chains always in tension states and to maintain the initial stability without changing the relative position of the balance weight to the facility even when waves oscillate the facility. Besides, since all chains are arranged under the cross-boxes, they do not interfere the preserve nets for fish.

(4) Mooring Equipment

This facility is loosely moored with four mooring lines extended diagonally. Considering the coming direction of waves, heavy lines are used for two mooring lines of the break-water side (south side) and light lines for two lines of the bay interior side (north side).

These specifications are as follows :

- South side :
  4.5t Dunforth type anchor x 1 set
  + ϕ 76(Gr.2) chain x 13.5m
  + ϕ 40(Gr.2) chain x 41m
- North side :
  1.4t Dunforth type anchor x 1 set
  + ϕ 64(Gr.2) chain x 13.5m
  + ϕ 40(Gr.2) chain x 27.5m

(5) Cathodic Protection System

Aluminum alloy anodes are fitted on the underwater section of the facility. The anodes have 5 year designed life.

(6) Draft Marking

In order to make checking easy for the draft and attitude angle of the facility during submerging and surfacing, the draft markings are placed on the side faces at four corners each of the upper floating body and the artificial sea floor section. For the draft marking three flat plates of 10cm square are arranged at upper and lower sides of the designed draft line at 10 cm interval.

4.5. Equipments

(1) Ballasting System (Fig.5)

A set of ϕ 125mm pipes is provided as the fooding line for the center tank. The line is connected to a sea water intake pipe of ϕ 300mm having openings at the top and bottom walls of the center tank respectively, and the other end is opened at the inside of the center tank via two sets of sluice valves (hereinafter called the flooding valves). Since the flooding valves are to be opened to the sea directly, a double valves are arranged in siries to secure water-tightness at the closed position, and the handle shafts are extended upward so that the valve can be operated in the machinery room . In order that the center tank can be filled fully with sea water by natural flooding even during facility surfacing, a well is provided at the upper part of the tank and the flooding line is led under the waterline at the afloat condition.

A water pump (120/240ℓ /min x 10/7m total head) is installed bottom of the center tank to discharge water through the discharging pipe of ϕ 80mm. The discharging pipe is once raised upward through the tank top wall and provided with a non-return valve. And to prevent the sea water from reversing due to siphonage at the afloat condition, an air leading pipe is provided in the downstream side of the non-return valve. Inside the center tank is provided a float switch that becomes "Off" when sea water is discharged fully and stops the water pump automatically.

The air vent pipe of the center tank is 300mm in diameter. This size is determined so that a portable submergible pump can be lowered through it into the tank for water discharging as a back up measure incase of the water pump failure at the facility submerged condition.

The corner tanks are used for draft and attitude adjustment during surfacing of the facility. For the purpose of system simplification, any fixed ballasting line is not provided and, if required, the manhole is opened and a portable submergible pump is used for charging and discharging.

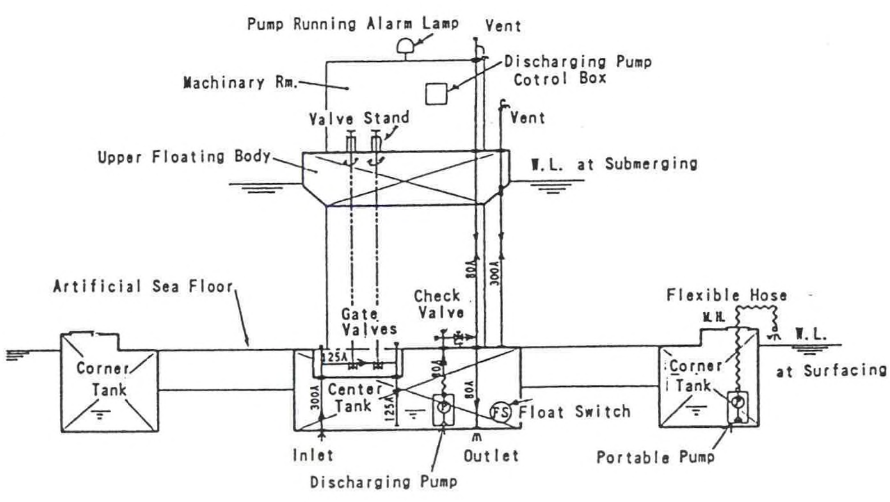


Fig.5 Piping Diagram of the Ballasting System

(2) Electric Generating Set

As the power source of the water pump a set of the soundproof package type Diesel generator (3.8 kVA in output) is installed in the machinery room. The generator supplys AC 100V for the illumination in the machinery room and to the socket outlet for miscellaneous uses in addition to AC 200V for pumps.

(3) Water Pump Operation Board

An operation board for the center tank discharging water pump is installed in the machinery room. On the board are provided state indications and push-buttons for pump and power source.

(4) Automatic Fish Feeding Machine

An automatic feeding machine powered by solar cells and storage batteries is installed on the operation deck. Two feeding pipes are branched from a feeding hopper and led from the superstructure to feeding ports on the artificial sea floor. Thanks to this machine, cultivated fish in the sea can be fed even during facility submerging and also even without human power.

(5) Miscellaneous

Such components are fitted as an alarm lamp to show running of the discharging water pump to the outside, simplified identification lamp to be "On" in the night, instrument shelter, inclinometer, small derrick, lightning conductor, etc.

4.6. Submerging/Surfacing Operation Procedures

Submerging/surfacing operation procedures of the facility are very simple. For surfacing an operator boards the facility, starts the generator, confirms the safety around the facility, and then starts the center tank discharging water pump. About one hour after starting the surfacing operation, the pump stops automatically. In this waiting time the operator can collect kelps for abalone feeding, and so this one-houris not long at all.

After completion of surfacing, he stops the generator and feeds abalones and others. After feeding is over, he confirms the safety on the artificial sea floor before submerging the facility, and then opens the double flooding valves. The facility will complete submerging through natural flooding in about 10 minutes.

The above operations were carried out by two men, i.e. an experiment member and a support boat captain, during the at-sea-test, but can be carried out safely even by one man.

5. RESULTS OF AT-SEA-TEST

5.1. Abalone Culture Test

In order to confirm the effect of abalone culture in the artificial sea floor facility, we bred about 5,000 young shells in total of northern abalones *Haliotis discus hannai* in three different divisions, i.e. culture baskets on the artificial sea floor, suspended cages placed in the sea area near the artificial sea floor, and breeding water tank on the shore, and studied comparison of their growth degrees.

Bait was basically kelps which abalones like most. On the artificial sea floor formula feed (artificial bait) which can be obtained easily in large quantities was also used to study effectiveness of the formula feed for future mass culture and in case of kelp shortage. Formula feed was fed every 3 to 5 days and kelps were every 10 to 15 days after the artificial sea floor was surfaced. The test period was from May 1991 to November 1991 during the sea water temperature was high. (However, abalones were bred till March 1992.)

Average values of abalone shell length and weight measured every month are shown in Fig.6. (Falling trends seen in November are due to stop of feeding in one week for the last measurement.) Average increases of the shell length and weight in half a year are as follows :

Abarone Class	May 1991 Shell length	Weight	Nov.1991 Sehll length	Weight
· 30mm size	33.5mm	5.5g	51.0mm	17.5g
· 45mm size	46.5	18.2	66.5	38.0
· 60mm size	63.0	35.5	78.7	62.5

Till early summer, increase of the shell length was high in the shore water tank division where the water temperature became higher than that of sea water. After midsummer when the temperature of sea water rose, increase was rapid in the artificial sea floor and the suspended cage divisions. In November there scarcely was differences in shell length due to the place and the bait for the 60 and 45 mm sizes. However, for the 30mm size the growth degree of the artificial sea floor formula feed division was remarkable.

The increase of weight was the highest in the formula feed division. For the kelps feeding abalones, the results in November show that in all three divisions (i.e. the artificial sea floor, the suspended cage and the shore water tank) weight increased similarly and there scarcely was differences between these divisions.

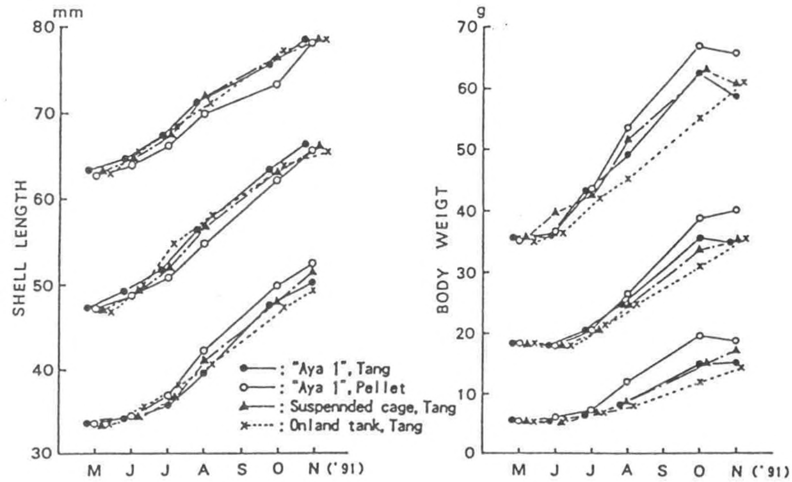


Fig.6 Grouth of the Abalones

The survival rates of the abalone seeds during the breeding period are 97.0, 96.7 and 94.3 % in the artificial sea floor, the suspended cage and the shore water tank divisions respectively. Namely, the rate in the artificial sea floor was the highest.

5.2. Fish (Black Rock Fish) Culture Test

The utilization of the artificial sea floor was considered to be mainly for abalone culture from the economical point of view. However, abalone feeding utilizes the artificial sea floor surface only, and so the extensive sea space beneath it is not utilized at all. Then, it was determined to utilize the space three-dimensionally by carrying out abalone culture on the artificial sea floor surface and fish culture in the space beneath it. The kind of fish selected was black rockfish *Seabstes schlegeli* which is made much of in Iwate.

1,000 individuals of the 20cm total length size young fish were cultivated in a preserve net (5m x 5m x 5m large) fitted beneath the artificial sea floor. The test period was May 1991 to November 1991, similarly to abalones.(However, breeding was carried out till March 1992 and the fish were tagged and recaptured.) Formula feed was used and was fed once a day in the evening twilight with the automatic feeding machine. The growth rates were measured every month.

The black rockfish grew satisfactorily. That of 234mm in average total length and 208g in average weight in May grew to that of 290mm and 422g in November. In spite of such extensive management that fish is fed with the automatic feeding machine in preserve net placed in the sea, the fish grew satisfactorily.

5.3. Study of Maintenance/Management Technology

The artificial sea floor is a large offshore steel structure and has been designed and manufactured with such a sufficient margin that this can be used for 5 years without requiring special inspection and repair. The Ships Safety Act of Japanese Government is not applied to this facility, but since there were no precedent for the inspection method during long-term mooring, any standard had to be prepared. Therefore, the artificial seafloor maintenance/management standards were prepared, and the facility was inspected periodically on the basis of the standards and the initial data necessary for long-term follow-up data on durability were obtained.

(1) Preparation of Artificial Sea Floor Maintenance/Management Standards

Rules of classification societies (Nippon Kaiji Kyokai : NK and Det Norske Veritas : DnV) on underwater inspection were investigated and also the present condition of the offshore structure maintenance/ inspection technique was investigated from a number of literatures to prepare the maintenance/management standards. The standards are composed of the following items.

(a) Routine check (The checks on normal use of the fcility.)
· Daily check : Visual inspection on normal use of the facility. Fuel replenishment of the generator and so on are included.
· Monthly check : Confirmation of fundamental performances of the facility. Measurement of submerging/surfacing time, draft and inclination are included.
· Quarterly check : Confirmation of lamps and batteries, etc. and watertightness of hatches.

(b) Annual surveys (Confirmation of safety and durability of the facility)
· Cathodic protection system : Cathodic protection potential measurement and anode volume measurement.
· Mooring equipment : Appearance inspection, anchor position survey and chain diameter measurement.
· Ballance weight : Appearance inspection and chain diameter measurement.
· Artificial sea floor main body : Appearance inspection
· Sea Water Ballasting System : Open test of the ballasting system and manholes.

(2) Results of Monthly and Quarterly Check

More than a year and 4 months has passed since placing the submerging/surfacing type artificial sea floor "MARINE-AYA NO.1" and about 150 times of submerging/surfacing operations have been carried out, and there was neither damage nor anomaly of the facility. For a while in summer the submerging/surfacing time tended to became longer, but after opening and cleaning of the sea water piping in August the time became nearly equal to the initial values and constant. As for the draft and inclination, water ballast was adjusted by about 200kg in one of the corner tanks in May togather with loading of the abalone baskets and a black rockfish preserve net. Since then there was no change in drafts and ballast re-adjustment was unnecessary.

(3) Results of Periodical Survey

In August 1991 first periodical survey was carried out mainly through the diving work. The underwater work were monitored by an underwater TV on board the facility, and the inspector instructed the divers with an underwater conversation system. The underwater work was carried out by members of JAMSTEC. There was no anomaly in all survey items and it was confirmed that safety and durability of the facility was as good as designed. No trouble was estimated in coming long-term mooring.

5.4. Evaluation of Submerging/Surfacing Type Artificial Sea Floor

The submerging/surfacing type artificial sea floor is a special offshore structure unparalleled in the world, and the at-sea-test in Sanriku Town has been finished satisfactorily. Experiment members concerned held liaison conferences whenever considered necessary and repeated active discussions. The experiment has been carried out with such close cooperation and so high evaluation has been given by Ryori Fishery Cooperative Association, which will be a user of facilities of the same sort in future. From the test results the features of this facility are summarized as follows :

(a) The facility is strong against waves.

In the main body and mooring system any anomaly caused by strong winds and/or waves of typhoons or low atmospheric pressures was not recognized. The effect of normally-submerging of its main body in the sea could be confirmed.

(b) The operation cost is low.

Since the simplified identification lamp and automatic feeding machine are powered by solar cells, they require no operation cost. The facility submerging/surfacing cost is about 1 liter of light oil used by the generator for surfacing but none for submerging because of natural flooding. About 150 times of submerging/surfacing operations were carried out and the required operation cost was only about 10,000yen (about $80) for fuel in a year.

(c) The facility is suitable to mariculture in North Japan.

As a mariculture facility the artificial sea floor could be operated by few men (was operated by two men) and was rigid and stable in waves, therefore, work on the sea (breeding management) was very easy. Because of the low temperature and strong winds and waves in winter, work on the sea is severe in North Japan. However, by surfacing of the artificial sea floor, work can be carried out safely without wetting the worker's body with sea water.

(d) The underwater space can be utilized three-dimensionally.

Abalones and black rockfish were cultivated in one facility, but in addition various kinds of fish and shells, such as oysters and scallops can be bred simultaneously. By cultivating many kinds of fish and shells, the artificial sea floor surface and the space beneath it can be utilized multi-purposely and three-dimensionally.

(e) Water quality control for bred life is unnecessary.

Sea water control can be left to natural circulation, and so it needs no cost. When a typhoon brought a heavy rainfall, a lot of fresh water and soil flowed from the rivers into the bay and surface sea water in the whole bay decreased its salinity and was colored brown. However, since the artificial sea floor was submerged in the 4 meter depth layer, abalones and black rockfish were not affected at all.

(f) The facility has functions of a floating fishing reef.

Young jack mackerels *Trachurus japonica*, sand launces *Ammodytes personatu*, etc. crowded in large quantities around the facility in their respective seasons and also many other fishes were seen there. It has been found that the artificial sea floor manufactured mainly for cultivation has also functions of a floating fishing reef as an value added.

(g) Economy of the facility.

Even when the use is limited to middle period breeding of abalones, it is estimated that the facility can breed 3 to 4 tons/year (price is about 13,000 yen/kg : $100/kg) extensively only with submerging/surfacing once in 10 to 15 days for kelps feeding. The maintenance/management operation such as feeding can be carried out on the facility by far easily, safely and effectively, compared with the operation on a boat. It is also considered that the management cost is lower and profitability is good. Even when 5 to 6 sets are placed for one fishery cooperative association, mass-culture will be possible by managing them one set a day in order with two workers.

6. CONCLUSION

The at-sea-test made it clear that the submersing/surfacing type artifitial seafloor provides easy operation, safe working and low operation cost. Also it was verified that the facility would be useful for mariculture not affected waves and rains, and would make use of marine space in three dimensions. Regarding the economy of the facility it is estimated that 3 to 4 tons/year production may be possible, only one working day in two weeks for kelps feeding.

Since April 1992, the second phase three years study was started for putting the facility to practical use. JAMSTEC, Iwate Prifectural Government and Ryohri Fishery Cooperative Association are joinnig this study. The themes are as follows :

1) Durability demonstration of facility.
2) Study of abalone seed size selection and breeding period to increase econimical efficiency.
3) Evaluation of operability and economical efficiency of facility in breeding/managing abalones on a large nunber scale.

This study is going successfuly and the artificial sea floor is filled with abalone cultivated baskets. We wish to expect through development of such cooperative study that facilities like this will be placed at many places in Japan Coast and contribute effective utilization of the continental shelf spaces in future.

ACKNOWLEDGEMENT

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A Floating, Offshore Satellite Launching Facility

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Introduction

The objective of this paper is to propose a concept for a floating, offshore satellite launching facility that could meet present and future launching needs while providing for greater environmental acceptability, improved safety and economic competitiveness with coastal, land-based systems.

The information revolution has greatly increased the needs for satellites that are central to various types of information systems including various types of global and regional communications networks, earth observation and environmental monitoring systems, earth surveillance and control systems, scientific atmospheric and space probes, and many other such applications. Many developed nations are vigorously pursuing such satellites programs and all have their own testing and launching facilities and many of the common problems identified with each. Among these, is having adequate surrounding space to provide a buffer to populated coastal regions to minimize environmental problems and provide adequate safety. The proposed concept of a floating launching facility is applicable to all size space payloads, their launching platforms and their many supporting and control systems.

At first glance, it does not appear wise to have a single floating facility to handle the full spectrum of launch capabilities. A huge rocket launching systems and large payloads could tie up a facility for a long period of time denying use for the information/ communication-types smaller payloads.

For the purpose of this paper, only information/ communications-type satellite payloads and their attendant systems are considered for this facility. However, the floating facility concept can be scaled up and expanded to handle the largest of systems. This paper will be limited to discussing the floating facility concept as a suitable platform, and will not delve into the technology and systems of launching. That could easily be the subject of another paper. In order to better define the proposed concept, this paper covers general systems requirements, site selection considerations and facility configuration.

System Requirements

General system requirements are given to provide a basis for developing a system configuration. These include:

o A floating, offshore facility of adequate size to accommodate all basic launch and related support equipment and supplies, fuel storage, power and communication systems and instrumentation for monitoring and control.

o A separate floating facility and shore-based facility to provide for all command and control capabilities.

o A means to shuttle people, equipment and supplies from shore to the offshore facility.

o Floating launch facility to be designed for maximum platform stability in six degrees of freedom in platform motion.

o A propulsion systems to enable self-propulsion for transit from shore to site and for accurate positioning on site with the help of thrusters.

o Mooring system to further ensure long term station-keeping.

o Navigation systems to ensure accurate absolute positioning.

o Communications systems duplicating present launch facility requirements.

o Site selection to be influenced mainly by site and range safety, operating efficiency and environmental concerns.

Site Selection

Since Equatorial orbits are required for most communications-type satellites, it is describe to locate a launch facility reasonably close to the equator. In this way the desired equatorial orbit can be achieved quickly and efficiently requiring less fuel and fuel storage, allowing for a larger satellite payload. Good weather windows throughout the year is another important factor. There are many locations within about + 20 degrees that could provide uniformly good weather, except for an occasional tropical storm. Another important location consideration is easy access to transportation for people and large system components. This equates to improved efficiency and cost savings. Coastal real estate and the inshore coastal environment is growing in popularity for living and recreation, and is not popular for large noisy utilities. Also, the population density of these coastal regions is steadily increasing and the demand and cost of coastal real estate is similarly rising.

Environmental pollution, especially air and marine pollution including visual and noise pollution is also a very major concern to the growing population. An obvious consideration is the geo-political aspects i.e. who has jurisdictional ownerships and control of the land and adjacent waters. If this is to be a cooperative international venture, then the host country must enter into agreements for access and use of the facility.

Lastly, but most importantly safety is a prime consideration for any rocket launching facilities. For example, in August 1992 a rocket carrying a cable television satellite was blown up over the Atlantic Ocean when its booster failed after launch from Cape Canaveral. 18 months earlier an Atlas rocket carrying a Japanese broadcasting satellite was blown up shortly after lift off. In both cases, no damage was caused to people or property below. However, there is always a prevailing concern for safety.

In considering the aforementioned location requirements and special concerns, an offshore floating facility has considerable merit.
There are several candidates locations that can be considered in the Pacific, Atlantic and Indian Oceans. Whatever location that best meets the system requirement can be selected within the political jurisdiction of the facility's owner.

For the purpose of providing an example of a suitable location, the southern most offshore region off of the Big Island of Hawaii is suggested as a possibility. It is at about 16.5 degrees latitude and has generally favorable weather. See figure 1. It is at readily accessible via international air travel and large components can be shipped on regularly traveled shipping routes. Development of large components can be off-loaded at docking space adjacent to the facility. This offshore location can be easily supplied and serviced via existing facilities in the State of Hawaii. Ideally a shore-based station located in the southern part of Hawaii can serve as a staging and linkage for the offshore facility. The offshore facility can be located at varying distances offshore depending on the closest tolerable distance which would satisfy environmental and safety concerns. It is not the objective of this paper to propose a site but rather give this merely as an a example of a candidate site that may be able to meet location sensitive requirement. In order to propose a specific site federal and state controlled procedures would need to be followed and adhered to before any selection is made. Also, economic tradeoff studies would be essential before any development would start.

System Configuration

Based on the general system requirement and site location, the proposed configuration (illustrated in fig 2) is described below.

o Marine Launching Facility Based on previous studies, including the first workshop on Very Large Floating Platforms held in Hawaii April 1991, a semi submersible type platform is selected. Its platform size should be approximately 100 meters square or one hectare. This should be able to accommodate a land-based system used for launching payloads weighing up to a maximum of about one ton in size. If needed, additional space can be provided by coupling another 100 meter square module,or perhaps going to a 100 meter by 150 meter platform. Space requirements and size selection can be made after the sizes for the maximum launch capability needed are determined in separate design and tradeoff studies. The 100 M X 100M size is achievable, as presently being demonstrated by the HARMONY Platforms to be deployed off the coast of California. The proposed launch platform would include: the rocket launching system and all supporting and supply systems; fuel storage and power systems; and various maintenance and housekeeping facilities. Ship docking space would be provided adjacent to the platform, and a heliport on the edge of the platform near the docking space.

Propulsion and Stationkeeping

Self propulsion will be provided to enable the platform to move from shore to offshore site and also be part of a dynamic positioning system. The main self propulsion would be accomplished by a separate propulsion unit located in the semi-submergld pontoons. Two propulsion units would also provide the differential thrust for steering. Ducted thrusters would also be located in the semi-submerged pontoons so that there is a thruster oriented in each corner to provide a configuration that can be easily computer-controlled with position referenced to absolute geodetic coordinates in two dimensions on the water surface. To maintain vertical positioning, the semisubmerged design is least impervious to vertical movement, especially after it is ballasted down to minimize freeboard. To further ensure having the maximum stability, a tension leg mooring system is proposed.

The tension leg system could draw the platform down against the buoyant force, thus reducing any wave or swell induced motions. During any launch the dynamic positioning system would be activated with the tension leg mooring system. After the launch, dynamic positioning would not be necessary since the inherent semi-submersible design is stable enough.

Command and Control Facility

This facility would provide all the command and control functions before, during and after launch, as is currently done. This facility could be located on shore, perhaps near the dock space and shore-based logistics support building. Another option is to have the command and control facility located on a 5000 ton catamaran ship that could have a dual role to include ferrying large satellite and launch system components to the platform and also serve as a daily shuttle for people and supplies.

During launch the ship could be positioned safely near the floating launch platform to directly observe and monitor all aspects of the launch cycle.

Additional Options

There are several additional options that can be considered at the proposed site for additional economic benefit.

Electric Power: It is estimated that between 500 to 1000 KW of electric power is needed for the launching operations and housekeeping functions. An undersea electric power cable from the southern region of the Big Island to the launching facility several miles offshore can be incorporated. A cable of this type has already been installed between the islands of Oahu and Maui.

An OTEC plant co-located on the launching platform can provide a power source option with or without the undersea electric cable. In either case, a diesel electric power plant would be provided as a self-sufficient back up source.

OTEC: Co-locating am OTEC plant provides some additional economic benefits of being self sufficient for power, fresh water, air conditioning, hydrogen fuel and nutrients for offshore mariculture. A desalination system using OTEC power and cold water can be incorporated as a source of potable water. The deep cold water can be used for air conditioning after it passes through the OTEC condensers. After providing the air conditioning function, the water can be distributed to an adjacent offshore mariculture facility so that the nutrient-laden water can be used to feed the marine organisms. Through electrolysis, OTEC electric power can be used to convert sea water to hydrogen that can be stored and used as a fuel for launching rockets or as a means of energy storage for back up power. When launch platform electrical loads are low the OTEC power can be diverted for hydrogen production and storage.

Wave Energy Absorption: The stationary platform could be equipped with an outer ring of wave energy absorbers to provide calmer waters surrounding the launching platform as well as converting the wave energy into electric power. Since the platform is moored, pneumatic turbines or oscillating water column caissons can be used to extract energy from the air compressed by the rising crest of the wave cycle. The facility can serve as an at-sea evaluation facility for wave energy devices operating offshore in deep waters.

Offshore Mariculture: A separate floating facility constructed of linked cages can be co-located next to the launching facility and supplied power and nutrients from the OTEC system. The mariculture facility would be operated as a separate entity from the launching facility but would benefit from the stationkeeping ability of the facility as well as its housekeeping features while it is coupled to it.

Ocean Research and Technology Development: The stationary launching facility would also provide an ideal at-sea research laboratory for long term time series measurements of the deep ocean, surface-air interface, and adjacent atmosphere from water surface to high altitude can monitored to study the long term affects on weather and climate. The facility can also serve as a staging area for deep ocean research of marine life in the water column and on the sea floor, including hydrothermal vents . A hyperbaric laboratory can be used to accept in-situ transfers of deep ocean marine life while maintaining the pressure and temperature of the deep ocean environment. This facility could be used to study deep ocean marine biotechnology to develop new products including pharmaceuticals. The laboratory could also be used for test and evaluation of ocean technology for resource stock assessment, marine mineral sampling, assay and recovery and remote controlled and autonomous vehicle operations. Marine Recreation: The launch facility could become a tourist attraction to enable site visits by sight-seeing boats or cruisers. The boats could be safely positioned in a protected area to witness a scheduled launch activity or at other times to observe various research efforts in mariculture, ocean energy, and new technology developments.

Conclusions and Recommendations

Based upon the increasing needs for communications, television, weather and climate monitoring, and scientific research including space probes, there will be growing needs for suitable launch facilities. Coastal real estate is becoming less available and costly because of the population trends favoring coastal living. The coastal population is concerned about their adjacent environment and anything that would jeopardize safety.

Further, existing launch facilities are being squeezed for space and are facing limitations on the amount of air space controlled and down range overflight of occupied areas. There are occasional situations that require aborting a launch and blowing up the launch rocket with its satellite payload.

Based on the above trends and realities, the construction and offshore development of a floating satellite launching facility is inevitable.
It is recommended that system design studies including environmental and economic assessments be conducted for as first generation system of modest capability. A semisubmersible platform dynamically positioned along with a tension leg mooring would provide the heart of the facility. A second or third semisubmersible platform could be linked to the main unit to provide additional space. Additional options such as OTEC, wave energy, mariculture and ocean research facilities could be considered in the initial design and tradeoff analyses. However, these can be added later as modular units which can be incorporated later on to a basic design which has flexibility for growth. The site location, south of the Big Island of Hawaii was selected only as an example for this paper. There are other candidate offshore sites in the Pacific, Atlantic and Indian ocean that could meet many of the criteria. Comparative tradeoff analyses could evaluate the best candidate locations.

For the future, it is envisioned that a number of these floating launching facilities would exist and could be part of a global network cooperating for peaceful purposes in the dawn of the information age.

Behavior of a Floating Body in Multi-Directional Waves

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ABSTRACT

The new amended code of Mobil Offshore Drilling Units doesn't consider the multi-directional wave effects on the dynamic stability of floating offshore structures. Since the directionality of waves may have a profound effect on the response of floating structures, in this paper, the effects of wave directionality on the behavior of floating offshore structures will be illustrated.

We develop a simulation program in the time domain for the estimation of first and second order motions in multi-directional waves. Experiments were carried out for a semi-submersible rig model with eight columns and two lower hulls, which was moored horizontally by four soft linear springs. To validate the numerical simulations, the model was subjected to regular and irregular bi-directional waves corresponding to the ISSC wave spectrum.

It is confirmed through comparisons between the experiments and calculations that the developed programs give reliable estimation.

INTRODUCTION

Many investigations have been carried out to study the behavior of floating offshore structures, such as a semi-submersible rig. However most of the previous research investigations took account of only one-directional waves in calculating the wave exciting force. Since ocean waves are multi-directional in nature, theoretical and experimental studies should take account of wave directionality. There are a limited number of theoretical and experimental investigations which study first and second order motions in multi-directional waves.

Dalzell[1)] and Pinkster[2)] have suggested a procedure for computing the quadratic transfer function in multi-directional waves. Maeda[3)4)] has calculated the low-frequency motions in two-directional waves for a semi-submergible rig and Teiger[5)] has carried out similar calculations for a TLP. Takezawa[6)] has developed a wave generator which can generate directional waves in his long towing tank, and derived the transfer functions of the motions based on the experiments. Nwogu[7)] has presented a numerical procedure for computing the second order forces in the multi-directional waves, and carried out experiments for the rectangular barge model. However he didn't present results of his numerical calculation. Helvacioglu and Incecik[8)] has investigated the effects of the directional waves on the dynamic response of a compliant structure. Naess[9)] has provided a calculation method, using spectral analysis, for calculating the nonlinear second order wave exciting force on a compliant structure.

From the investigations cited, it follows that many problems remain even if correct estimations of the behavior of the floating offshore structures in multi-directional waves are to be generated. In this study we have developed a numerical simulation procedure in the time domain and a spectral analysis procedure in the frequency domain for investigating the effects of multi-directional waves.

Since the rotational motions contribute to the stability against capsizing of floating structures, it is very important to determine correctly the values of the rotational motions. When we design a semi-submergible rig and its mooring system, we must consider the effect of the directionality of waves on wave frequency and low frequency motions.

REPRESENTATION OF MULTI-DIRECTIONAL WAVES

Multi-directional irregular waves in deep sea can be represented by a linear superposition of one-directional regular waves which propagate in different directions with different frequencies and phases. A water surface elevation ζ (x,y,t), at location (x,y), is expressible in the form

$$\zeta(x,y,t) = \sum_{i=1}^{\infty} \sum_{j=1}^{\infty} A_{ij} \cos\left(k_i x \cos\theta_j + k_i y \sin\theta_j - \omega_i t + \varepsilon_{ij} \right), \tag{1}$$

where A_{ij} are the amplitudes of each component wave, k_i are wave numbers defined in terms of the wave frequency ω_i through the linear dispersion relationship, and ε_{ij} are the phase angles which are distributed randomly over the interval 0 to 2π. If we express the directional wave spectrum as,

$$S_\zeta(\omega,\theta) = D(\omega,\theta)\, S_\zeta(\omega), \tag{2}$$

where $D(\omega,\theta)$is a directional spreading function, and $S_\zeta(\omega)$ is a conventional one-dimensional frequency spectrum, then the mean square value of the water surface elevation can be expressed as

$$\zeta^2 = \int_0^\infty \int_{\frac{-\pi}{2}}^{\frac{\pi}{2}} S_\zeta(\omega,\theta)\, d\theta\, d\omega . \tag{3}$$

The directional spreading function, $D(\theta)$, is defined by the frequency independent cosine power function

$$D(\theta) = \frac{\Gamma(S+1)}{\sqrt{\pi}\,\Gamma(S+1/2)} \cos^{2S}(\theta - \theta_0), \tag{4}$$

where θ_0 is the principal direction of wave propagation and S is a directional spreading parameter describing the degree of directional spreading. As the spreading parameter S decreases, D represents more directionally spread seas, and when S becomes larger, D represents long-crested seas (one-directional waves). As the total energy should be constant for varying values of S, the directional spreading function should satisfy the relationship

$$\int_{\frac{-\pi}{2}}^{\frac{\pi}{2}} D(\theta)\, d\theta = 1 . \tag{5}$$

Here, we provide an example of the variation of the directional spreading function as S changes from 1 to 13 in Fig.1. The ISSC spectrum is then used as the one-dimensional frequency spectrum $S_\zeta(\omega)$ in the simulation of multi-directional waves.

EQUATION OF MOTIONS

We carried out our calculations and model experiments using a semi-submergible rig which has small diameter columns. Therefore, there are many nonlinear factors, like viscous damping effects, and therefore we have to solve the equation of motions in the time domain. The motion response in multi-directional waves is estimated by means of the following time domain equations of motion

$$\sum_{j=1}^{6}\left[\left\{M_{kj}+m_{kj}(\infty)\right\}\ddot{x}_j(t)+\int_0^t K_{kj}(t-\tau)\,\dot{x}_j(\tau)\,d\tau+b_{0kj}\,\dot{x}_j(t)\left|\dot{x}_j(t)\right|+C_{kj}\,x_j(t)\right]=F_k(t)\,.$$

$$(k=1,2,\ldots,6) \tag{6}$$

Here the $m_{kj}(\infty)$ are the infinite frequency added masses of the model , K_{kj} are the memory effect functions, b_{0kj} are the viscous damping coefficients, and x_1, x_2, x_3 represent the translational motions, and x_4, x_5, x_6 describe the rotational motions.

These equations express the hydrodynamic force in terms of a convolution integral taking into account the memory effect function and the velocities of the each motion modes, and of the drag force in proportion to a square of the velocity of the motions. A numerical solution of the equation is obtained using the Newmark-β method and we estimate the displacement, velocity and acceleration of each mode of motion at each time step.

Hydrodynamic Force

In the time domain analysis, the impulse function can be expressed as

$$K_{kj}(t)=\frac{2}{\pi}\int_0^\infty b_{kj}(\omega)\,cos\,\omega t\,d\omega\,, \tag{7}$$

in which, $b_{kj}(\omega)$ are the wave making radiation damping coefficients calculated by a 3-dimensional singularity distribution method in the frequency domain. In the case of the semi-submersible studied in this paper, the memory effect disappears after 4 seconds at model scale. We can investigate the accuracy of the memory effect function by the comparison between the added mass and wave damping coefficient values calculated by Fourier transform of memory effect function and those calculated by the 3-D singularity distribution method. The Fourier transform of memory effect function is defined as follows,

$$K^*_{kj}(\omega)=\int_0^\infty K_{kj}(t)\,e^{-i\omega t}\,dt \tag{8}$$

in this equation added mass $m_{kj}(\omega)$ and wave making damping coefficient $b_{kj}(\omega)$ are expressed as follows,

$$\begin{aligned} m_{kj}(\omega) &= m_{kj}(\infty)+\mathrm{Im}\left[K^*_{kj}(\omega)\right]/\,\omega \\ b_{kj}(\omega) &= \mathrm{Re}\left[K^*_{kj}(\omega)\right] \end{aligned} \tag{9}$$

Viscous damping coefficient b_{0kj} are estimated by the summation of the drag force on each component of the structure as follows

$$b_{0kj} = \sum_{i=1}^{M} \frac{1}{2} \rho A_i C_D \tag{10}$$

in which, A_i is area of the cross section of each component, C_D is drag coefficient. But here we correct the viscous damping coefficient using the results of the free motion decay tests.

Wave Exciting Force

When estimating the wave exciting force in the multi-directional irregular waves, we use the convolution integral of the impulse response function and the time history of water surface elevation. A time history of the wave exciting forces taken up to the second order can be expressed by Volterra series truncated on the second order term as follows,

$$F(t) = \int\int h^{(1)}(\tau,X)\zeta(t-\tau,X)dXd\tau$$

$$+ \int\int\int\int h^{(2)}(\tau_1,\tau_2,X_1,X_2)\zeta(t-\tau_1,X_1)\zeta(t-\tau_2,X_2)dX_1dX_2d\tau_1d\tau_2 \, , \tag{11}$$

in which $h^{(1)}$ and $h^{(2)}$ are the first and second order impulse response functions dependent on time and space, and ζ is the water surface elevation at the center of gravity of the model. The impulse response function is given by first and quadratic transfer functions of the wave exciting force namely,

$$h^{(1)}(\tau,X) = \frac{1}{2\pi}\int\int H^{(1)}(\omega,\theta)\, e^{i(kX+\omega\tau)}\, d\omega d\theta$$

and

$$h^{(2)}(\tau_1,\tau_2,X_1,X_2) = \left(\frac{1}{2\pi}\right)^2\int\int\int\int H^{(2)}(\omega_1,\omega_2,\theta_1,\theta_2)$$

$$\times\, e^{i\{(k_1X_1+\omega_1\tau_1)+(k_2X_2+\omega_2\tau_2)\}}\, d\omega_1 d\omega_2 d\theta_1 d\theta_2 \tag{12}$$

in which, $H^{(1)}(\omega,\theta)$ and $H^{(2)}(\omega_1,\omega_2,\theta_1,\theta_2)$ are the first and quadratic transfer functions varying with directionality of waves. We calculate the first order transfer function using 3-D singularity distribution method over all the incident wave heading angles and frequencies. The quadratic transfer functions are given by the method of direct integration of the fluid pressure on the wetted surface of the hull which is modified for multi-directional waves. If we take N discrete values for different directions, we can express the time history of the wave exciting forces as follows,

$$F(t) = \sum_{i=1}^{N} \int_{-\infty}^{\infty} h^{(1)}(\tau,X_i)\zeta(t-\tau,X_i)d\tau$$

$$+ \sum_{i=1}^{N}\sum_{j=1}^{N} \int\int_{-\infty}^{\infty} h^{(2)}(\tau_1,\tau_2,X_i,X_j) \times \zeta(t-\tau_1,X_i)\, \zeta(t-\tau_2,X_j)\, d\tau_1\, d\tau_2 \, . \tag{13}$$

From equation (13) , we can see that the first order exciting forces are the superposition of exciting forces of each direction, but second order exciting forces include the interaction components as well as the superposition of every component of each direction.

Here, the quadratic transfer functions in multi-directional waves can be expressed as

$$H^{(2)}\left(\omega_i,\omega_j,\theta_i,\theta_j\right)$$
$$= P\left(\omega_i,\omega_j,\theta_i,\theta_j\right) + iQ\left(\omega_i,\omega_j,\theta_i,\theta_j\right) \quad , \tag{14}$$

expanding the quadratic transfer function in uni-directional waves. This equation can be calculated for bi-chromatic and two directional waves with any combination of frequency and direction respectively. ω_i, ω_j, θ_i, θ_j are defined as frequency and direction of each component wave, and P, Q are real and imaginary part of the quadratic transfer function respectively. The second order transfer function has the complex conjugate symmetricity with regard to frequency and wave direction like

$$H^{(2)}\left(\omega_i,\omega_j,\theta_i,\theta_j\right) = H^{(2)*}\left(\omega_j,\omega_i,\theta_j,\theta_i\right) \ . \tag{15}$$

Since it takes much computational time to calculate the quadratic transfer functions according to the orthodox method, the development of more simplified practical calculation method is strongly desired. Then the authors propose two kinds of the practical calculation methods of the quadratic transfer functions. One of them is the extended Hsu's method[12)] in which each half cycle of irregular waves are used as regular waves in order to calculate drift forces. Another method is the extended Newman's method[13)] in which the quadratic transfer function is expressed as

$$H^{(2)}\left(\omega_i,\omega_j,\theta_i,\theta_j\right) = \frac{1}{2}\left\{H\left(\omega_i,\omega_i,\theta_i,\theta_j\right) + H\left(\omega_j,\omega_j,\theta_i,\theta_j\right)\right\} . \tag{16}$$

Time domain results in three directional waves due to Hsu's method are shown in Fig.2 which are lower than those due to the present method. The results of the quadratic transfer function due to both the present method and the extended Newman's method are shown in Fig.3 in order of real and imaginary part and the amplitude respectively. The abscissa of Fig.3 represents the mean frequency of each two different direction waves, the frequency difference of which is 0.5 rad/sec. The comparison between these two methods shows some discrepancy in large frequency region. Therefore in order to calculate the quadratic transfer function precisely, the present method such as equation (14) is required taking account of any frequency combinations.

STEADY DRIFT FORCE BY VISCOUS DRAG FORCE

When a small cylinder is allowed to oscillate harmonically in sinusoidal waves, a modified Morrison equation which represents the force on a unit length of a cylinder, is given by

$$f = -\,C_m D^2 u_R \, sin\,(\omega t+\varepsilon) + C_D D u_R^2 \left| cos\,(\omega t+\varepsilon)\right| cos\,(\omega t+\varepsilon) \tag{17}$$

in which, u_R is the amplitude of the relative velocity, D is the characteristic length and C_m and C_D are the inertia and drag force coefficients. If we respectively define the velocity of a fluid particle as $U_0(t) = u_0 \cos \omega t$ and the velocity of the cylinder as $\dot{X}(t) = \omega x_0 \cos(\omega t - \alpha)$, then the relative velocity can be expressed as

$$U_R(t) = U_0(t) - \dot{X}(t) = u_R \cos(\omega t + \varepsilon)$$
$$u_R = \left[u_0^2 + (\omega x_0)^2 - 2\omega u_0 x_0 \cos\alpha\right]^{1/2}$$
$$\varepsilon = \tan^{-1}\left(\frac{\omega x_0 \sin\alpha}{u_0 - \omega x_0 \cos\alpha}\right) \tag{18}$$

in which α is a phase angle of the displacement of a cylinder with respect to the wave. We know from the equation (17) that the second term has a steady component independent of time so that it can act on the body as a steady drift force. Total force on a cylinder from its bottom to wave surface is

$$F = \int_{-d}^{\zeta} f\, dy \tag{19}$$

The total steady drift force acting on the cylinder can be expressed by integration of the force over one period as follows[11],

$$F_D = \frac{2\rho D C_D \zeta_a^3 \omega^2}{3\pi}\left(1 + \frac{X_0}{\zeta_a}\sin\alpha\right) \times \sqrt{1 + \left(\frac{X_0}{\zeta_a}\right)^2 + 2\frac{X_0}{\zeta_a}\sin\beta} \tag{20}$$

Usually, when one estimates the second order force for the simulation of the low-frequency motions, it is not necessary to consider the steady drift forces due to viscous drag. However at the dominant range where viscous effects become important with respect to the second order forces due to potential flow, one must consider the steady drift forces due to viscous flow in order to achieve accurate simulations.

FREQUENCY DOMAIN ANALYSIS

The auto-correlation functions describing the multi-directional waves and the responses of the vehicle are given by

$$R_{\zeta\zeta}(\tau,\delta) = \langle \zeta(\tau, X) \times \zeta(t+\tau,\ X+\delta) \rangle$$
$$R_{XX}(\tau,\delta) = \langle X(t,X) \times X(t+\tau,\ X+\delta) \rangle \tag{21}$$

in which, δ is a lag of position vector and τ is time lag. The auto-correlation function of the responses can be expressed by using the impulse response function as follows,

$$R_{XX}(\tau,\delta) = \left\langle \int\int_{-\infty}^{\infty} h(\tau_1,\delta_1)\ \zeta(t-\tau_1, X-\delta_1)\, d\tau_1 d\delta_1\right.$$

$$\times \int\int_{-\infty}^{\infty} h(\tau_2,\delta_2)\, \zeta(t+\tau-\tau_2, X+\delta-\delta_2)\, d\tau_2 d\delta_2 \rangle$$

$$= \int\int_{-\infty}^{\infty} \left[\int_{-\infty}^{\infty} h(\tau_1, \delta_1) \int_{-\infty}^{\infty} h(\tau_2, \delta_2)\, R_{\zeta\zeta}(\tau+\tau_1-\tau_2, \delta+\delta_1-\delta_2)\, d\tau_2 d\tau_1 \right] d\delta_2 d\delta_1 \; . \tag{22}$$

From equation (22), the two dimensional response spectrum, in terms of wave number and frequency, is given by

$$S_x(k, \omega) = \left(\frac{1}{2\pi}\right)^2 \int\int_{-\infty}^{\infty} R_{xx}(\tau, \delta)\, e^{-i(k\delta-\omega\tau)}\, d\tau d\delta$$

$$= |H(k,\omega)|^2\, S_\zeta(k, \omega) \; . \tag{23}$$

Finally the one dimensional response spectrum in multi-directional waves can be determined from

$$S_x(\omega) = \int_0^{2\pi} \left| H_{x\zeta}(\omega,\theta) \right|^2 S_\zeta(\omega,\theta)\, d\theta \; , \tag{24}$$

in which $H_{x\zeta}(\omega,\theta)$ is the two dimensional transfer function of the responses defined in terms of frequency and wave direction, and $S_\zeta(\omega,\theta)$ is the directional wave spectrum. If we have the transfer function, we can get the response spectrum and estimate the statistical characteristic of the responses in the directional waves from the response spectrum.

EXPERIMENTS

The experiments were performed in the seakeeping basin of the University of Tokyo. The basin is 30m wide and 50m long, and can generate regular and random bi-directional waves. A model used in the experiments is a typical semi-submersible rig with 2 lower hulls and 8 columns.

The model was moored horizontally by linear springs with spring constant of 0.365 kg/m at four point of the model. Restoring force coefficients of the mooring lines used in the equation of motions are 1.152 kg/m and 1.451 kg/m for surge and sway modes respectively. The natural periods of the model with this mooring system found from the free motion tests are 12.24, 13.84, 2.36, 4.68, 5.20 and 6.56 sec for surge, sway, heave, roll, pitch and yaw respectively. The mooring line forces were measured with a ring gauge attached on each line. The position sensor with optical sensing source was used as the measurement device of six degree motions. Two cameras were positioned horizontally and one camera vertically to receive the signals from the light emitting diodes.

We used the incident wave heading angles of 35° and 305° for one-directional and bi-directional waves to investigate the behavior of the model in the oblique seas. In the case of irregular waves, the signal to operate the wave generator was produced using the ISSC spectrum with 8cm significant wave height and 1.1 sec mean period. Regarding the bi-directional irregular waves, in order to keep the ergodic, stationery-in-position characteristics, we avoided using the same frequency components in both directions.[10]

RESULTS AND DISCUSSION

We have carried out numerical simulations and experiments in other to study the effects of directional waves using two directional regular and irregular waves. Comparisons between the results of experiments and simulations in bi and multi-directional waves and numerical simulations in time and frequency domain have been carried out. Here, we discuss the results of two and multi-directional waves.

Two-Directional Waves

In order to validate the accuracy of the numerical simulation results, we have carried out the model experiments in oblique two directional waves with heading angles of 35° and 305°. Fig.4 shows the spectra of six first order motions in two directional irregular waves and comparisons of the results of experiments with those of calculations obtained from the time domain analysis and spectral analysis. According to this figure, we know that the three sets of results have good agreements in most mode of motions. However in the case of roll motions, the results by spectral analysis give larger values than those by the time domain analysis. Therefore, we can see that in the case of motions with large viscous damping like roll motions, spectral analysis methods can not yield accurate results.

The real and imaginary part of the quadratic transfer function is shown in Fig.5. Diagonal components of quadratic transfer function in 35 deg. wave, 305 deg. wave and 35+305 deg. wave are shown in Fig.6. From this figure one can find out there must be interaction effect between two directional waves, because superposition between 35 deg. wave and 305 deg. wave does not hold. The quadratic impulse response function of sway mode in 35 deg. incident waves is shown in Fig.7, where τ_1 and τ_2 are integrated up to 10 seconds.

Fig.8 shows the orthogonal terms of a quadratic transfer function of surge mode in 35° incident wave heading angle, where the circle, solid and dotted lines represent the values by the experiments, potential flows and those with viscous drag effects respectively. We know that if we use the wave spectra which has the peak of wave energy in the dominant range of the viscous drag effects, we must take into account the viscous drag effects in the drift force calculations to obtain accurate simulation results. In order to grasp the viscous effect on the low frequency motions, we give comparisons between experiments and simulations in the bichromatic waves shown in Fig.9. Here, the component waves have the frequencies of 5 and 5.5 rad/sec so that the mean frequency is 5.25 rad/sec where the viscous drag effects are dominant. We see from this figure that we could estimate correctly the low frequency motions by considering the viscous effects. In Fig.10 we show the time history of first and second order motions in two-directional irregular waves. In here, the same results as the bichromatic waves can be obtained regarding the viscous drag effects. The corresponding response spectra with 10 minutes duration in two directional irregular waves are shown in Fig.11. Two wave spectra are one for uni-directional wave, another for two directional one which has twice energy of uni-directional wave. The predicted results agree well with the experiments.

Multi-Directional Waves

We have verified the accuracy of the simulation method through the model experiments and now we can investigate the effects of directional waves on the motions of floating structures using the simulator. Fig.12 shows the significant values of each motions which were obtained by the statistical analysis of response spectra. In here, the principal directions of multi-directional waves are varied from 0deg. to 90deg. and the directional spreading parameter S is from 1 to ∞. The directional wave spectrum which has 0.16m significant wave height and 1.1 sec mean period and directional spreading parameter S = 5 based on the ISSC wave spectrum, is used. In the case of roll and pitch motions which influence stability of floating structures, we note that the significant values of roll motions in multi-directional waves are smaller than those in one-directional waves at beam sea, but considerable values appear at head seas. Same phenomena occur on the pitch motions. However there are a small difference between one and multi-directional waves at oblique seas. It will be interesting to consider the interactions of directionalities with another sources of exciting forces namely current and wind forces.

When we simulate the motions in multi-directional waves, we must use each component waves at the discrete direction. In the following we explain how many wave components are required to define the fully spreaded directional waves. Fig.13 shows the convergence of the significant values of each mode of motions as the number of discrete directions increases. In this figure spreading parameter S was taken as 5. When the number becomes thirteen, the statistical values nearly converge to a constant value. So we can express the fully spreaded directional waves by taking thirteen discrete directional waves into account.

CONCLUSIONS

We have developed a simulation procedure to estimate the first and second order motions of floating offshore structures in multi-directional waves using time domain and frequency domain analysis techniques. In case of small viscous damping the spectral analysis method can estimate the first order motions with a good accuracy. However, when the viscous damping is large, the spectral analysis method overpredicts. Therefore it is recommended that the time domain analysis is used for accurate simulation results. Since the directionality of waves affects all motions except heave motion, one needs to consider the effect of multi-directional waves assessing the stability of offshore floating structures.

Although it takes much CPU time to calculate complete set of quadratic transfer functions in multi-directional waves, there has been no way so far to obtain practical quadratic transfer functions such as ones due to the Hsu's or Newman's method.

Generally, when one simulates the low-frequency motions, one neglects the steady drift forces due to the viscous effects. However, in the frequency range where the viscous drag effects are dominant, one can simulate the low-frequency motions with good accuracy by taking into account the viscous terms. A simulation program for computing the low-frequency motions in multi-directional waves have been developed and its accuracy has been validated through model tests in two directional waves.

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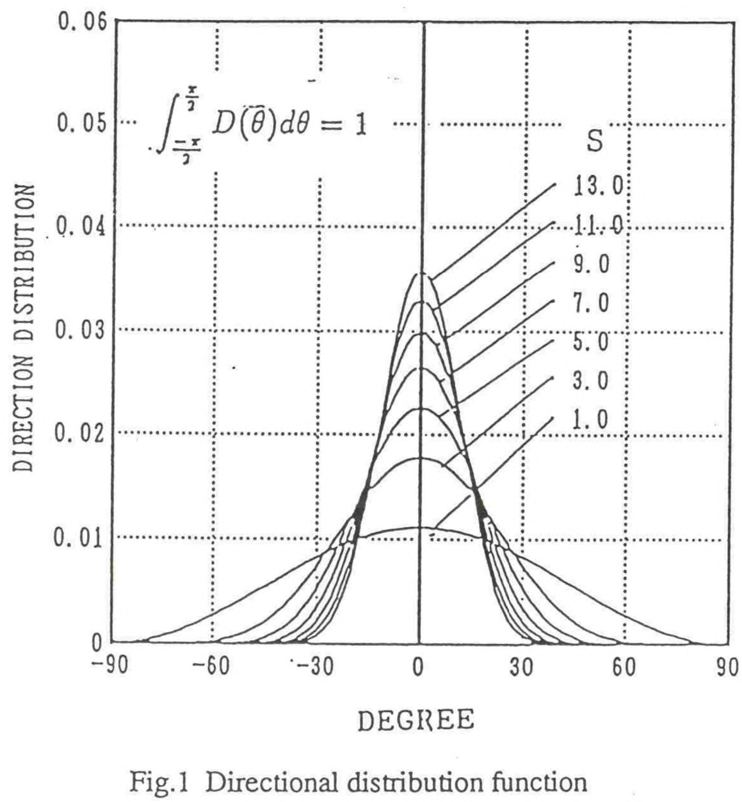

Fig.1 Directional distribution function

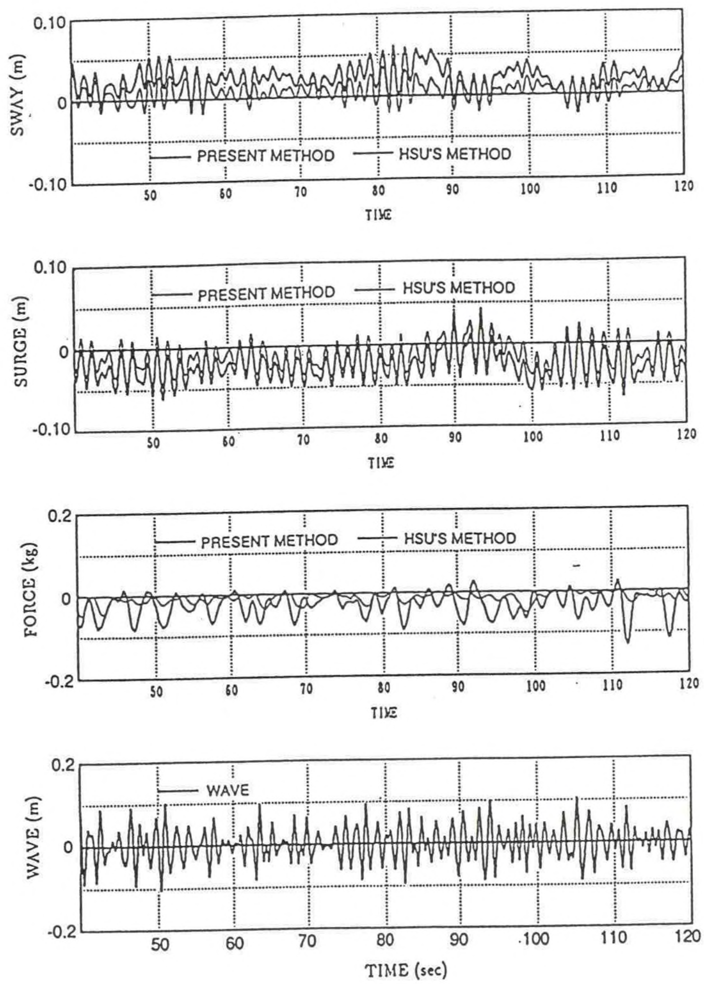

Fig.2 Comparison of time history of present method and Hsu's method

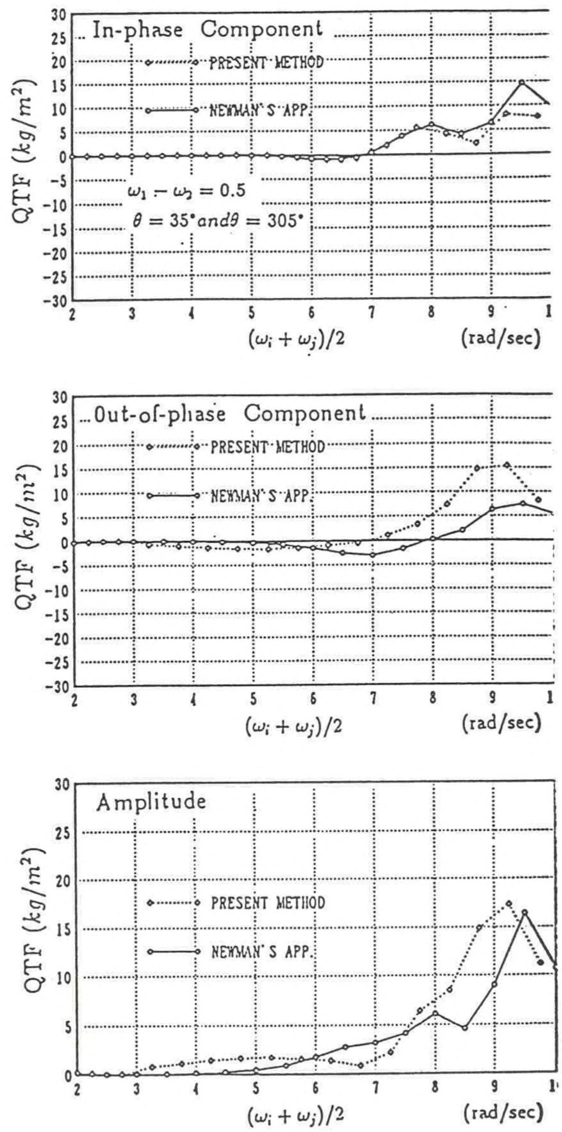

Fig.3 Quadratic transfer function on sway mode i directional waves

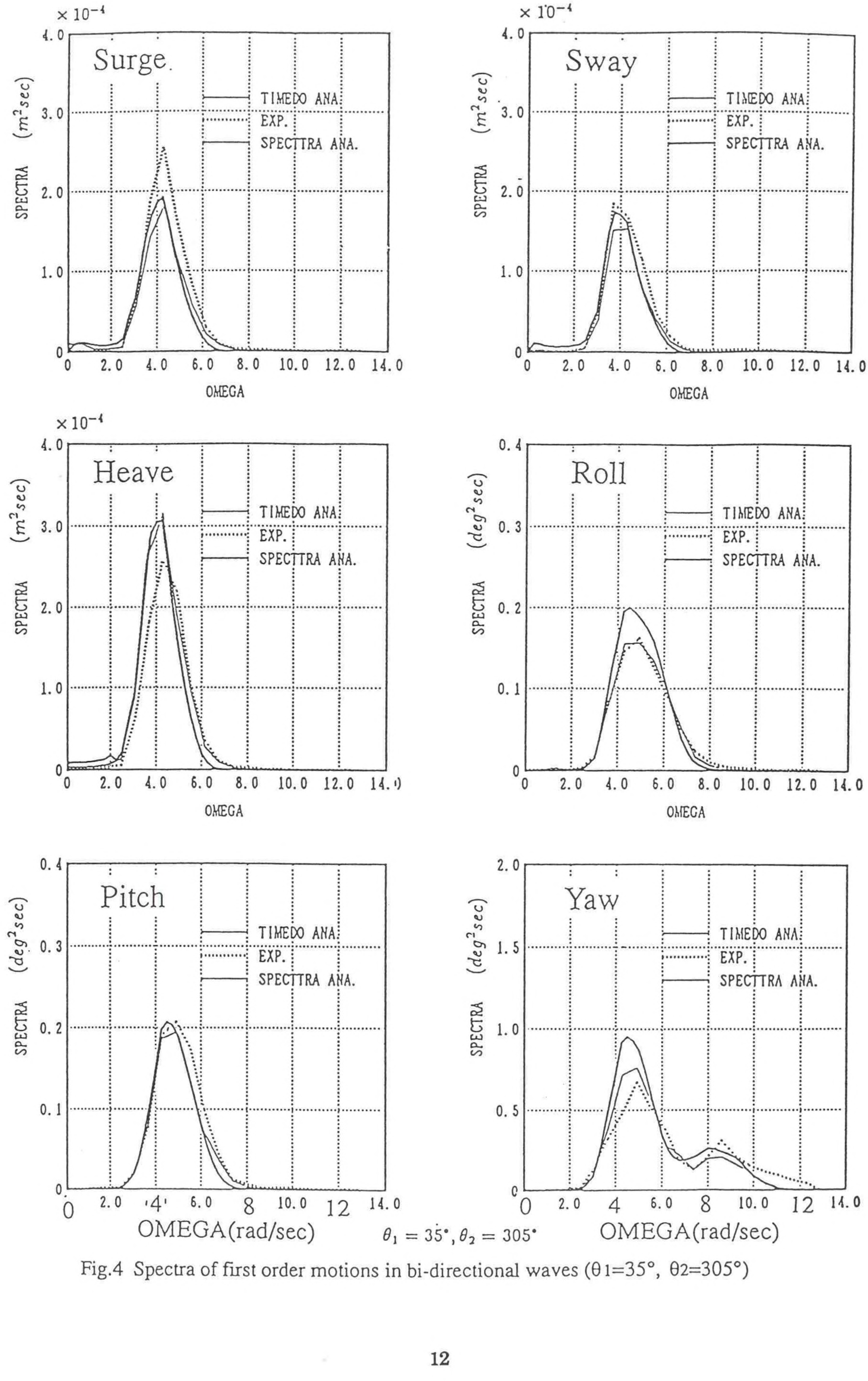

Fig.4 Spectra of first order motions in bi-directional waves (θ1=35°, θ2=305°)

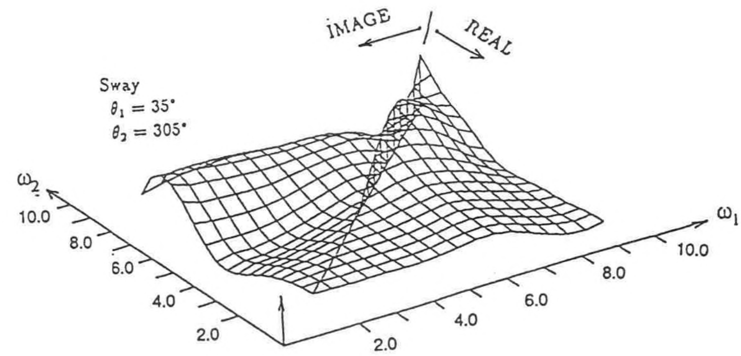

Fig.5 Quadratic transfer function of sway mode
($\theta 1$=35°, $\theta 2$=305°)

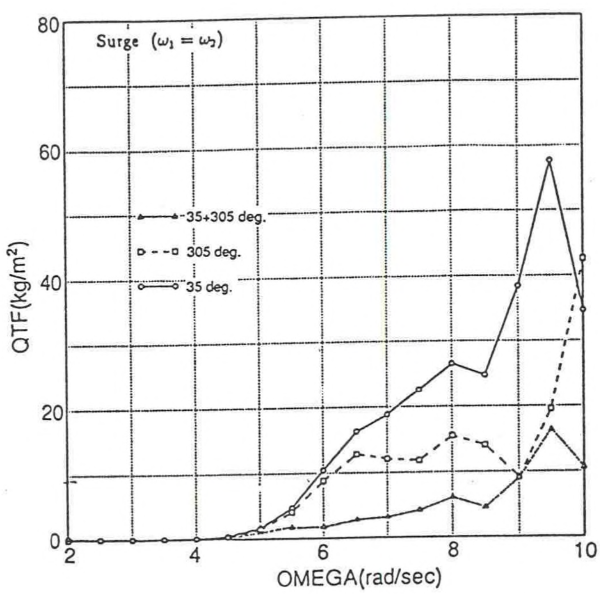

Fig.6 Diagonal components of quadratic transfer function of surge mode

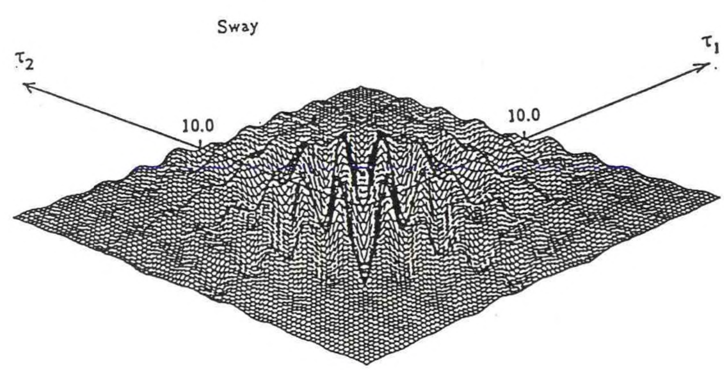

Fig.7 Quadratic impulse response functions of sway mode

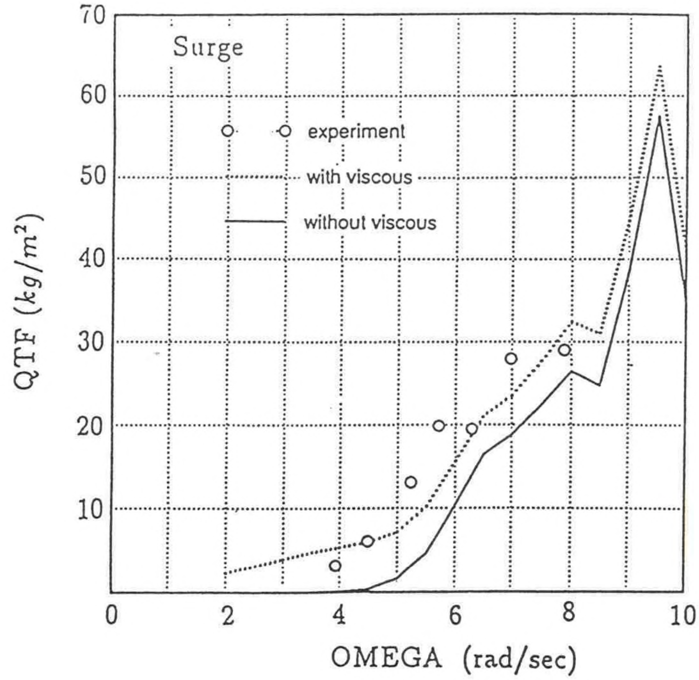

Fig.8 Quadratic transfer function of second order wave exciting force of surge mode (θ=35°)

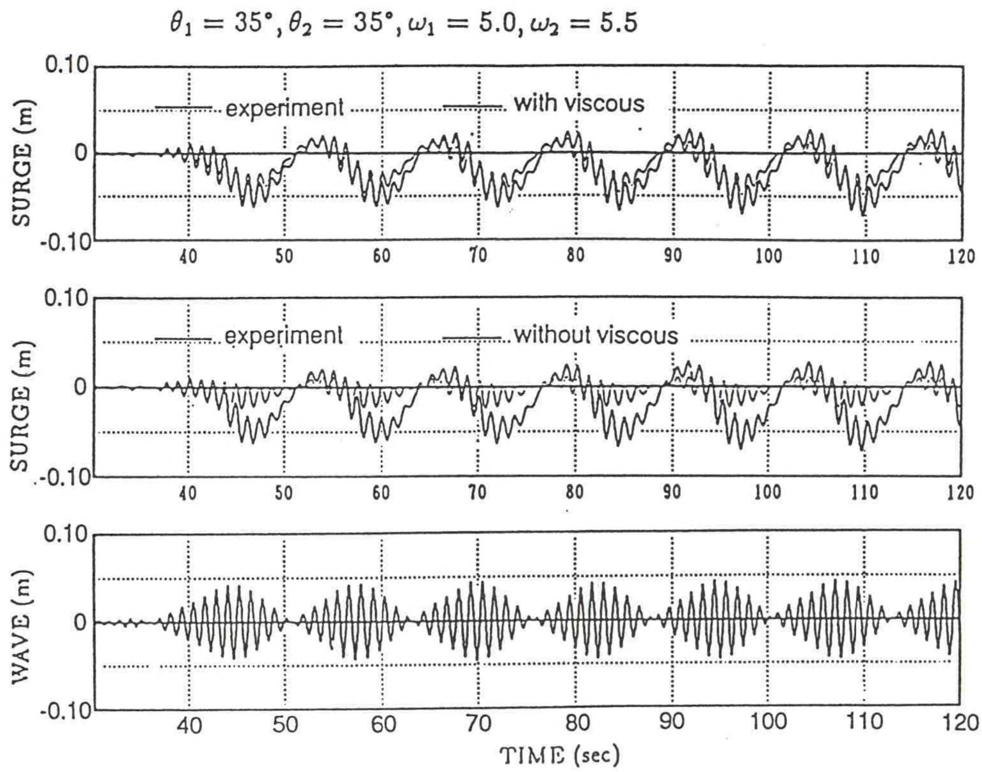

Fig.9 Comparison of time histories of surge in bi-chromatic waves (θ1=35°, θ2=35°)

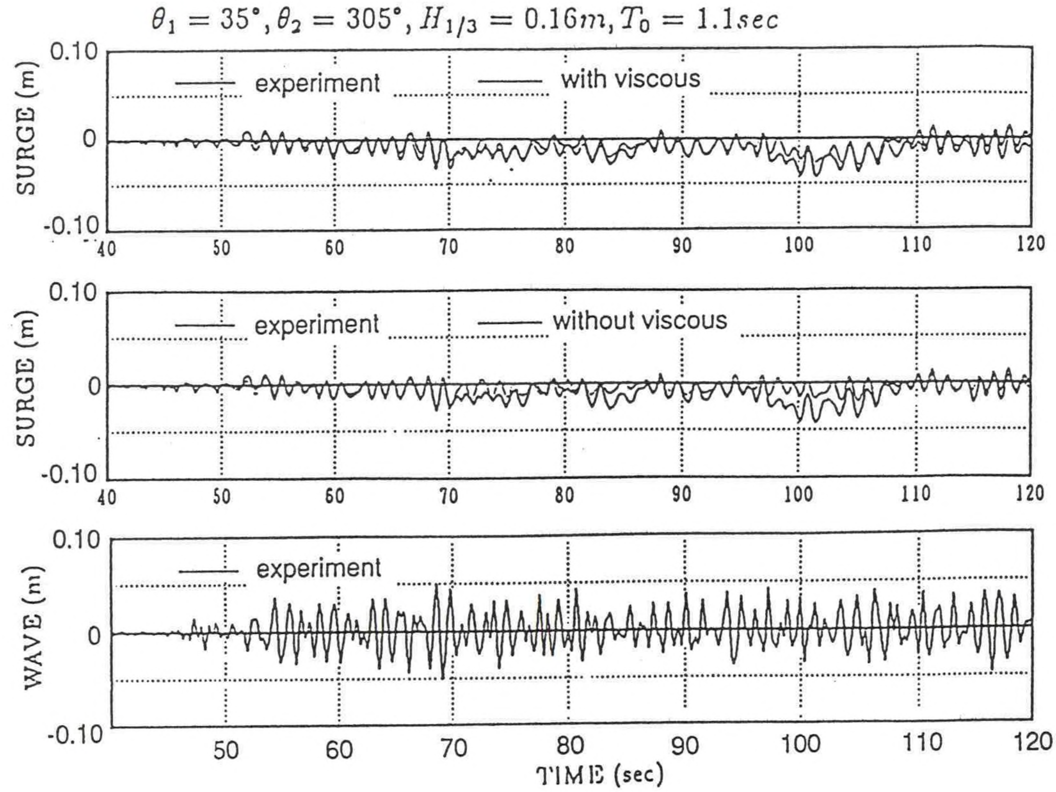

Fig.10 Comparison of time histories of surge in bi-directional waves (θ1=35°, θ2=305°)

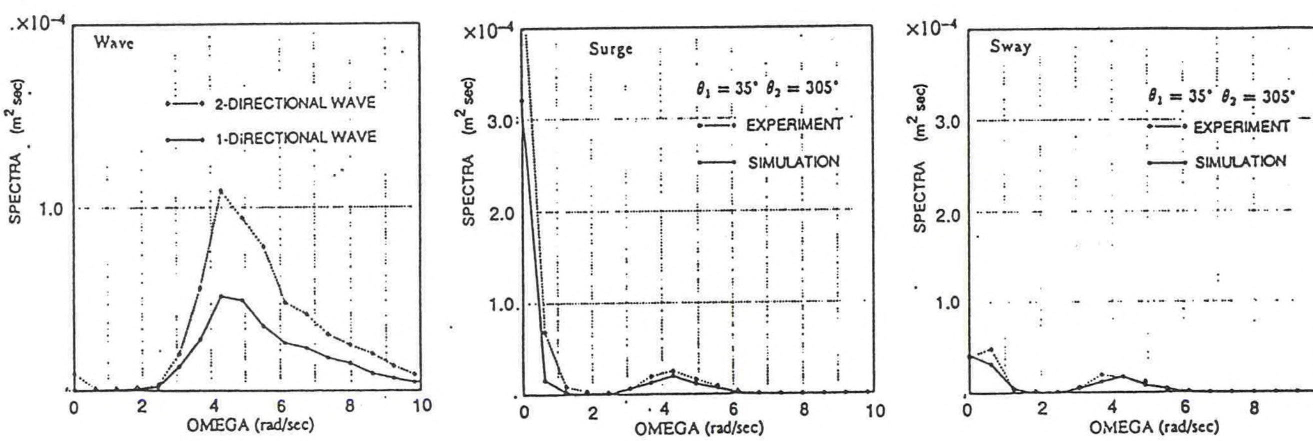

Fig.11 Spectra of motions in bi-directional irregular waves (θ1=35°, θ2=305°)

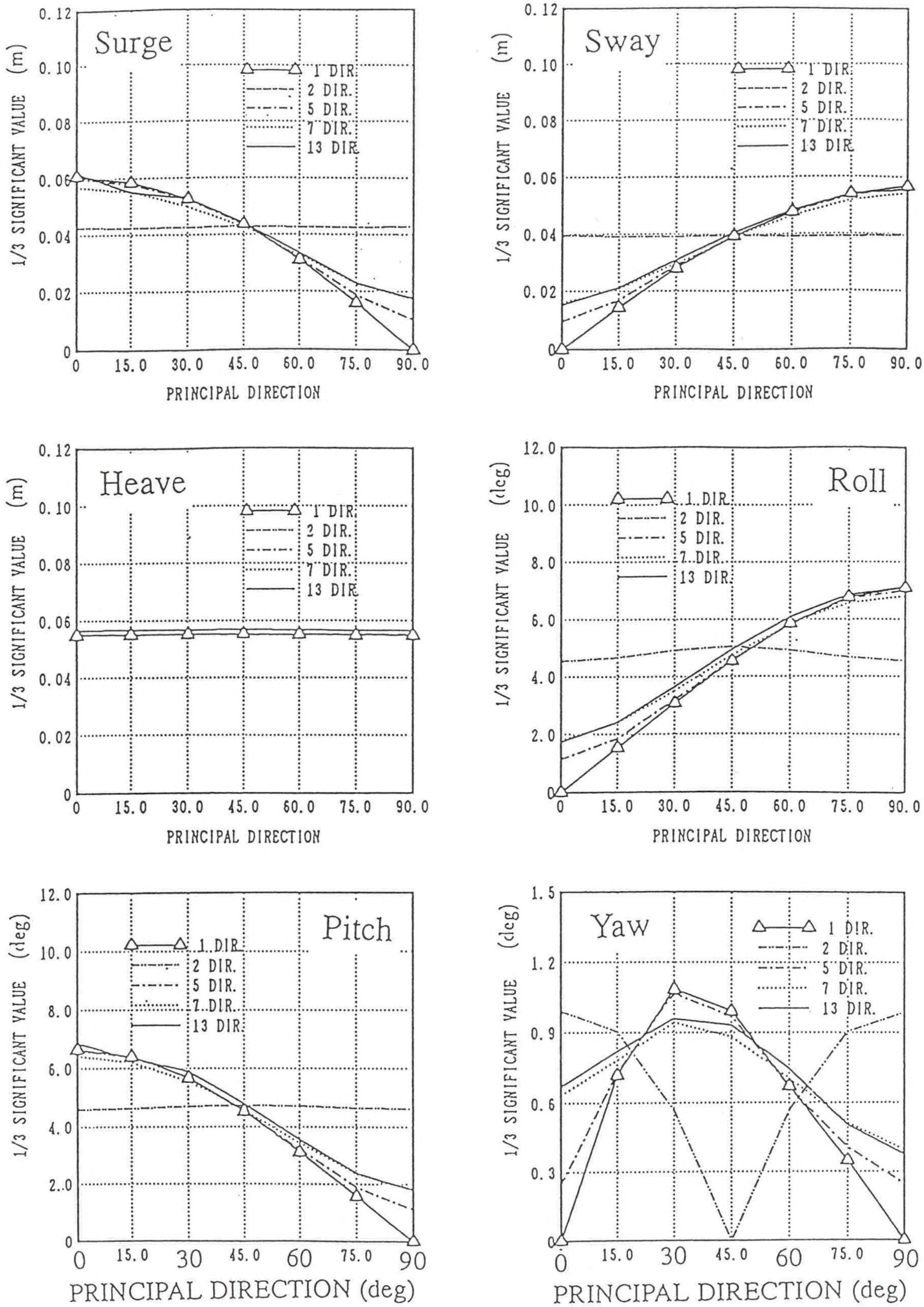

Fig.12 Significant values of motions for various principal directions and parameters of directional distribution function

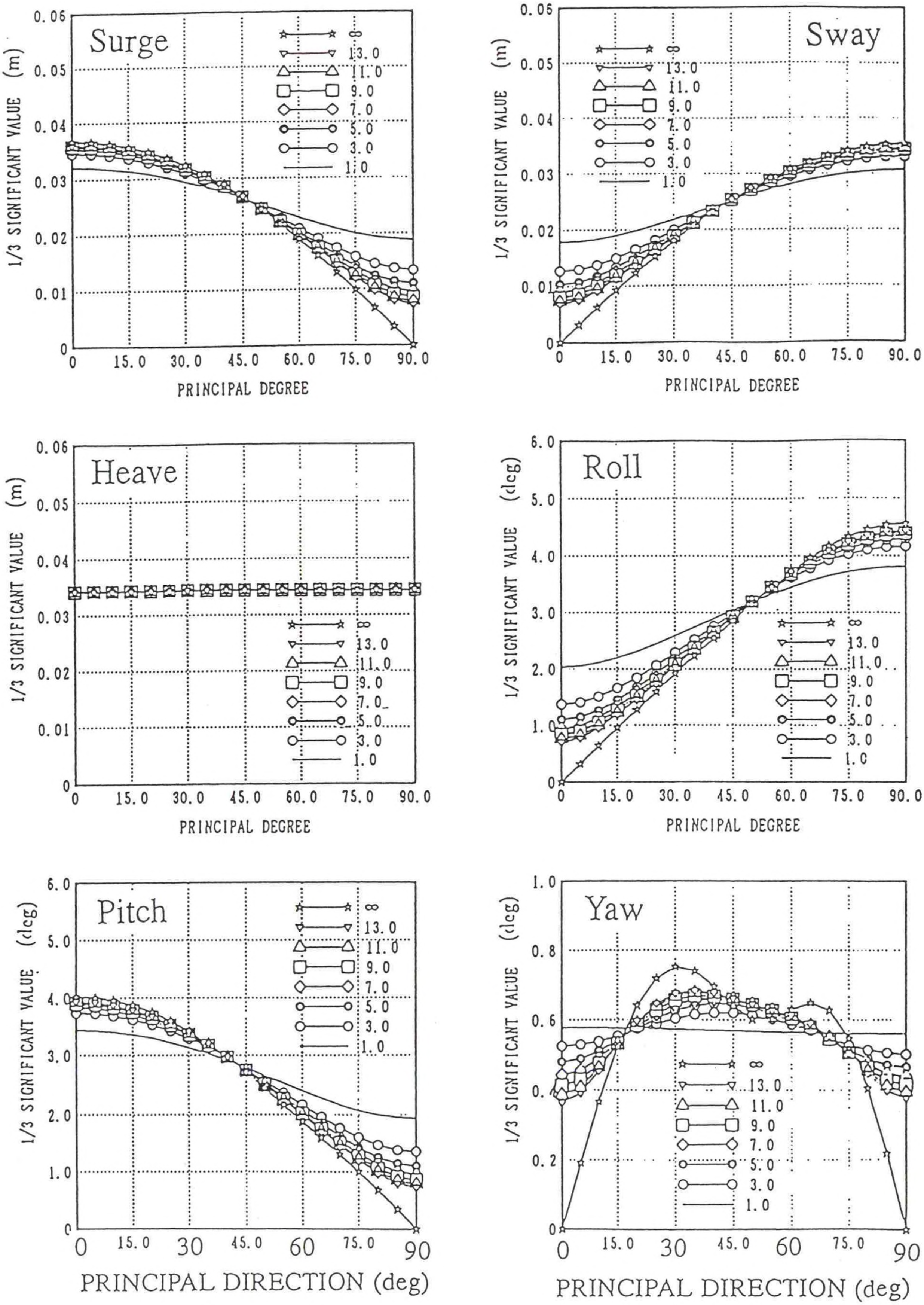

Fig.13 Significant values of motions for various principal directions and number of discrete wave directions

Inspection and Maintenance for Very Large Floating Structures

— Lessons Learned from Experience and Prospects for Future Technology —

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Abstract

This society (NK, a classification society) has many experiences to inspect ships and offshore structures, and the authors had a chance to exactly investigate a barge of the offshore oil storage system. The system is probably one of the biggest floating structures in the world. This paper summarizes a result of the investigation with the others experience involved, and describes prospects for future technology of the inspection and maintenance to such very large floating structures (VLFS).

1. Introduction

Many offshore floating structures have been operated such as, since long time ago ; platform vessels, floating docks, drilling rigs, in recent; floating hotels, floating exhibitions, and in quite recent: huge oil storage barges. Further, floating airports, floating cities etc. are planned by many parties concerned, and it is expected in future to be realized.

The floating structures, in case comparatively small, they are mobile like as ships, and they have been inspected and maintained by techniques experienced with ships. In case where big floating structures, difficulty to be mobile is increased. Such floating structures are inspected and maintained by advanced techniques being based on conventional techniques which have been applied to ships.

Inspections and maintenances such as floating air ports, cities shall be newly developed in accordance with the developments of such a project. The inspection and maintenance technology for the Very Large Floating Structures (hereinafter, so called as "VLFS") is one of the most important subjects to be studied. A great number of VLFSs will have a nature of very large, public facility, long life, and it means that the VLFSs can not be inspected and maintained by a conventional technique being based on a regular docking.

The authors had a chance to investigate a VLFS (Oil Storage Barge) at the first docking. This paper describes a summary of the investigation and a view of inspection and maintenance technology for VLFS expected in future as a result of the investigation.

2. Inspection and Maintenance of Offshore Floating Structures

There are many kinds of floating offshore structures in the world. Table 1 and Figs.1, 2 and 3 show typical ones classed by this Society (NK), and thus the Society have many experiences to inspect of the floating structures.

Strategy of the inspections and maintenances to the floating structures is like that of conventional ships, i.e. periodical surveys consist of:

(1) Annual Survey

(2) Intermediate Survey : max. 2.5 years interval

(3) Special Survey : max. 5 years interval

(4) Docking Survey : max. 2.5 years intervals. This survey is generally carried out simultaneously with the intermediate and special survey, and the docking survey is substituted by in-water survey or equivalent means.

In case of the floating structures which are very hard to be mobile, the docking survey is substituted by in-water survey for the most cases.

Maintenances for the hull of the floating structures are generally planned in line with the periodical survey, and major refit works of the hull are then carried out at the dockings.

3. Factual Example of VLFS (Offshore Oil Storage System)

3.1 Strategy of Inspection and Maintenance

It seems that two offshore oil storage systems, Kamigoto and Shirashima, realized in Japanese waters are two of the biggest VLFSs in the world.

One (Kamigoto) of them is shown in Fig.4 and the system has entered into service from 1988. The system consists of five storage barges with total tank capacity 880,000 $kl \times 5$, and the first barge has been placed in the waters at 1986.

The other system (Shirashima) is shown in Fig.5 and its foundation and barges are just being constructed. The system consists of eight barges with total capacity 700,000 $kl \times 8$, and shall enter into service from 1995.

The maintenance and inspection strategy for the Kamigoto system has been specified in accordance with the guidance for the surveys of offshore oil storage systems stipulated by this Society[1)]. The strategy for the hull structures are summarized in Table 2 and Fig.6. At present, the strategy for the Shirashima system is being planned in accordance with the guidance[1)].

The guidance[1] has been stipulated on the basis of oil tanker's experiences taking into account difference between the oil tankers and the barges. The main differences affected to the hull strength are as follows;

(1) placed in a restricted water areas in a calm sea protected from rough sea by banks and islands : i.e. reduced wave induced load and protection from incidental collisions, groundings etc.

(2) To confirm the design conditions and the strength of the barges, extensive tests using one of the barges are to be carried out in advance being commissioned after the barge is fixed on a planned position. The tests consist of structural tests simulated the most severe load condition during service, and observations of effects by the environmental sea and weather conditions. Figure 7 shows an example of the confirmation test for the Kamigoto barge carried out by the NK's Research Institute.[2]

(3) The oil tanks are always filled up with oils and inert gases, and the oils are agitated and the upper portions of the inner surfaces are wetted by the oils as a regular maintenance procedure.

(4) The water tanks around the oil tanks are always filled up with sea water : i.e. good condition for preventing corrosion.

(5) The hull structures are prevented from corrosions by specially heavy coatings with the best painting works, and cathodic protections.

(6) Storage conditions of the barges are not frequently changed as compared with oil tankers.

3.2 Lessons learned from Experience

The Kamigoto storage system has been operated for about five years at the middle of this year. The first dry docking survey of one of the barges was carried out in accordance with the schedule including objectives for reviewing the initial inspection and maintenance strategy because this was the first chance to thoroughly inspect the hull structures.

The authors attended to this docking and exactly investigated the hull structures. Essential objective of this investigation was to carefully observe effectiveness of the preventing measures to corrosion, i.e. the coating and the cathodic protections, and the conditioning in the oil tanks.

Preventing corrosions are the most important items for maintaining hull integrities not only the barges but also all ships and offshore structures. The preventing corrosions for the barges shall however account for much proportion to prevent failures on the hull structures, because they are less effect to wave induced loads and external causes as prescribed in 3.1(1),i.e. If the hull structures are not corroded, almost of the failure causes can be eliminated.

Lessons learned from this experience are summarized in below:

(1) Outer shell below water line

(a) A much amount of shellfishes were observed before the removed works of them (max. about 200mm thickness in visual). Almost of the shellfishes could be peeled off by an automatic removed machine, and conditions after the peelings were enough to inspect the outer shell (see, Figs.8 and 9).

(b) coatings of the outer shell were not attacked by shellfishes and they were found in good condition. (see, Fig.10)

(2) Water tanks

(a) Coatings inner surface of the water tanks were completely effective, (see, Fig.11) and anodes in the tank were to keep their original forms, and no shellfish and such other was found in the tanks though the lower tanks in which the waters had been opened to the sea.

(b) From experiences of water ballast tanks of ships, excellent works and materials (tar-epoxy) of paintings shall be effective to prevent corrosions for a long year, such as 20 years. The barge's conditions were found in more better than the best examples of ships. The authors then consider that the water tanks of the barges shall be prevented from corrosions for a long year such as over 20 years.(see, Fig.11)

(3) Oil tanks

(a) The upper and lower portions of the inner surfaces have been coated by tar epoxy-paints and the middle portions have been left as bare steels. Any corrosions was not found on the all surfaces. Slight rusts were found on the bare steel surfaces only due to tank cleaning waters for the preparation works of docking.(see, Fig.12)

(b) It was confirmed that the preventing measures to corrosions, i.e. the coatings and the agitation and wetting procedures, were so effective as to prevent the corrosions for a long time. The effectiveness can however not be assessed quantitatively because data such as Fig.11 is unavailable for the oil tanks at present. The oil tanks shall then be regularly inspected by sampling at least one tank from the all tanks.

3.3 Development of New Technology for Inspection and Maintenance

An under water unit for peeling shellfish off has successfully developed as shown in Fig.8 and it was already used for the preparation works of the docking.

The Japan National Oil Corporation, which has been engaging in the government stockpiling project, ordered a development of a new technology for inspections and maintenances to the Shipbuilding Research Centre of Japan. The new technology shall be applicable to the inspections and maintenances of the barges instead of the present strategies as shown in Table 2.

The Centre began to research and develop such a new technology from the last year. An example of the development is shown in Fig.13. This ROV is a process of conceptual designs and trial tests with models. Some of items equipped on the ROV unit are a process of tests by using experimental instruments.

Objective of the development is not only a hardware but also a software of new technologies for inspections and maintenances of the barges. The development project is scheduled for several years, and it is expected that a new rational inspection and maintenance technology shall be developed in future.

3.4 Comments to Inspection and Maintenance of the Oil Storage Barges

The strategy of inspection and maintenance prescribed in Table 2 is of an advanced technology as compared with that of ships such as VLCCs, but it seems that the concept is somewhat akin to a conventional one. There are of course no experience to operate VLFS such as the barges for a long year, and it is then difficult to develop immediately a quite new technology for the inspection and maintenance. Such a new technology will be developed by a steady progress with relevant experiences and technical advancements.

Fruitful lessons could be gained from the exact investigations at the first docking. The present strategy of the inspection and maintenance shall be reviewed by a result of such a valuable experience. And the lessons will be available to not only the barges but all of VLFSs which will be developed in future.

4 Prospects for Future Technology

4.1 General Prospect

There are many conceptual designs of VLFSs in the world, for examples a floating air port shown in Fig.14[3)] and a floating city shown in Fig.15[4)]. They have many subjects to be studied for realizations, and technology of the inspections and maintenances is one of the most important subjects to be studied. It seems however that the inspection and maintenance of ship's structures are a field of a technical lag by comparison with other fields. For an example, basic techniques of VLCC's inspection and maintenance are remained as they were before, i.e. a number of the inspection and maintenance depends on man powers with dry dockings.

A concept to be studied on the inspection and maintenance is shown in Fig.16. The authors consider that many kinds of technologies are of course necessary to be developed but a procedure combined an advanced technology for the inspection and maintenance with the structural designs should not be left for the development. For an example, an inspection robot for VLCCs instead of a skillful inspector is difficult to develop without any modification of the structural arrangement and performance, because any kind of robot has a limitation of its performance. Accordingly, the design of the structure and the robot shall be stepped up in each for a success of development.

4.2 An Example of Advanced Technology

The authors attempted to make a conceptual design of a new oil storage barge as an example of a VLFS which would be applicable to an advanced technology for inspection and maintenance.

An outline of the design is shown in Fig.17, and its explanations are as follows ;

(1) Ultimate objective of the design is to inspect and maintain an oil storage barge with no docking and less man power as far as possible.

(2) No docking can be achieved in cases where ;

   (a) An automatic peeling shellfish off machine is available

   (b) ROV is applicable to in water inspection. Such an ROV has been developed. This institute itself has confirmed that some of ROV have a performance applicable to in water inspection[5] and the Shipbuilding Research Centre in Japan is going to develop on ROV which is applicable to the Kamigoto barges as prescribed in Fig.13, and

   (c) Preventive corrosion of the outer shell is continuously effective for an expected life, or an in water painting system is available for repaints.

(3) No corrosion is also expected for all internals of the structures.

(4) The structures are to be so designed that the structural performance can be confirmed without a close up inspection by a skillful inspector. The close up inspection is necessary to many man powers in tanks, and such a work will be avoided as far as possible in future. To this end, the structures shall be confirmed the structural

performance by a strength test. The test condition is to be simulated the most severe loaded and environmental condition for the operations.

(5) Hull weight of the structure shall be increased, if the above concept is applied to. A cost to construct such a barge shall be increased about 15% of one as compared with the Kamigoto's barge by the author's trial.

(6) Confirmation of the structural integrity at the test is depended by ;

(a) an infrared ray system ; if there is a crack in the structures, the crack will be found by comparison of two colored pictures. One of them is of a confirmation test immediately after the completion of the barge, and other is of the strength test at a periodical survey. A fundamental test was carried by this institute[7], and an advanced study will be carried out continuously, or

(b) a laser beam system : to measure a deformation under the strength test, and to observe a crack and a local corrosion. A fundamental test to apply to a big structure's defect will be studied by this institute.

(7) Internal inspections by an inspection robot : it seems that the robot can be applicable to a close up inspection by a TV camera for an essential structural member which is defined by the designed. Simultaneously, the robot has performances to clean an area, to make thickness measurement and others.

(8) If the above mentioned is developed in successful, the internal structures can be inspected without any person to enter into the tanks.

5. Conclusions

Summaries of this study are as follows ;

(1) The experience at the first docking of the oil storage barge is valuable to review the initial inspection and maintenance strategy.

(2) It was confirmed that the barge's maintenance procedure is successful to keep a good condition of the hull structures. For the water tanks, effectiveness of preventing corrosion could be predicted quantitatively being based on ship's experience.

(3) It is preferable to continuously investigate the barge's conditions at the next and after docking of the barges. Such results will be a valuable information to all the concerned.

(4) The authors attempted a concept design of a new oil storage barge as an example of VLFS, and essential subjects for developing with no docking and less man power for an inspection and maintenance strategy were indicated. The authors hope to be developed a rational and advance technology for the inspection and maintenance to not only VLFSs but also all ships and offshore structures.

Acknowledgement

The authors of this paper wish to acknowledge the valuable advices given by many persons for preparing the paper. The authors particularly wish to acknowledge their indebtedness to personnel of the Japan National Oil Corporation, the Shipbuilding Research Centre of Japan, The Kamigoto Oil storage Co. Ltd, the Shirashima Oil Storage Co. Ltd, the Mitsubishi Heavy Industries Ltd, and the Hitachi Zosen Corp.

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2) Kumano,A. et al.: Measurement of Dolphin Mooring System an Oil Storage Barge and Simulation Analysis, Technical Bulletin of NK, Vol. 8 , 1990

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4) Arima,T. : A Conceptual Design of Huge Ring-like Structures for Ocean Space Utilization, Transaction of NK, No.214, 1991. (in Japanese)

5) Aoki,H. : Remotely Operated Vehicle and In-Water Survey, Transaction of NK, No.205, 1988. (in Japanese)

6) Nishimura et. al, A measurement of stress distributions by infrared ray, Transaction of NK, No.187, 1984.(in Japanese)

Table 1 Typical Examples of Offshore Structures
whose Inspection NK had Experiences in after 1970.

Year	Ship's Name	Type of Ship and Purposes	L×B×D (m)	Tonnage, Displ. (TON)	Note	Maintenace and Inspection Strategy <-----Conventional Advanced---->
1970	TAIYO GO	Floating Dock	72× 47×25	12,481		X
1971	HAKURYU II	Oil Drilling Rig	84× 61×31	16,412		X
1974	HAKURYU III	Oil Drilling Rig	100× 67×35	21,120		X
1974	HAKURYU V	Oil Drilling Rig	106× 67×35	21,963		X
1975	AQUAPOLIS	Exhibition Hall	104×104×32	28,082	Ocean Exhibition	X
1976	VIVA ISLAND	Floating Dock	162× 37×14	—		X
1976	MO'TA	Offshore Platform	150× 35× 6	—		X
1977	YARMOUK	Floating Berth	150× 35× 6	15,580		X
1976	Prestressed Concrete Barge	Barge (for Experiment)	37×9×3.1	500,000 (DW)	Draft=2.6m	(P.C.) X
1977	DONGHAE NO.5	Floating Dock	120× 31×11	—		X
1988	KAMIGOTO No.1-5	Oil Storage Barge	390× 97×28	934,520	880,000kl ×5ships	X······>
1989	FLOATNG ISLAND	Aquarium and Exhibition Hall	130× 40× 5	—		X
1991	AOSHIO	Fish Farm	112× 32× 5	21,120		X
199x	SHIRASHIMA	Oil Storage Barge under construction	397× 82×25		700,000kl ×8ships	X······>
xxxx	New Design of Oil Storage Barge				Conceptual Design	X
xxxx	Floating Airport				Conceptual Design	X
xxxx	Ocean City				Conceptual Design	X

M.B. : Conventional ; inspection and maintenance strategy is based on conventional technologies for ships

Advanced ; Advanced technology developed

P.C. ; Prestressed Concrete Structure and technology combined with civil engineers

Table 2 Principal Items of Inspection and Maintenance for

Hull Structre of Oil Storage Barge

	Outer Shell		Oil Tank	Water Tank (Cofferdam around Oil Tank)
	above W.L.	below W.L.		
[Periodical Survey]				
Annual Survey	Visual	—	—	—
Intermediate Survey (max.2.5 yrs.interval)	Visual * TM	TVC * TM	Visual & TM**	Visual & TM**
Special Survey (max. 5 yrs. interval)	Visual * TM	TVC * TM	Visual & TM**	Visual & TM**
Dry Docking Survey (max. 12 years interval)	Visual TM	Visual TM	Visual TM Leak Test (if necessary)	Visual TM Leak Test (if necessary)
[Daily Maintenance and Monitoring]				
General check	Visual	—	—	—
Oil leak monitoring	Leak from Water Tank	—	—	Leak from Oil Tank
Conditioning in Tanks	—	—	• Wetting on inner surface above oil • Agitation of oil (3months interval)	—

N.B. TVC : Visual ipection by TV camera operated by diver

TM : Thickness measurement

* : Under Water Survey instead of Docking Survey

** : After five years from the commission, Visual & TM will be required if necessary

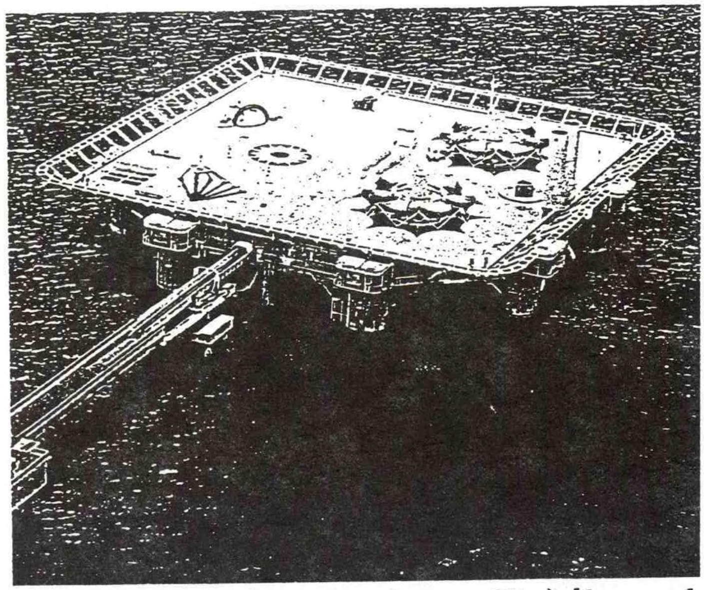


Figure 1 AQUAPOLIS (Floating Ocean City) [from a leaflet of AQUAPOLIS]

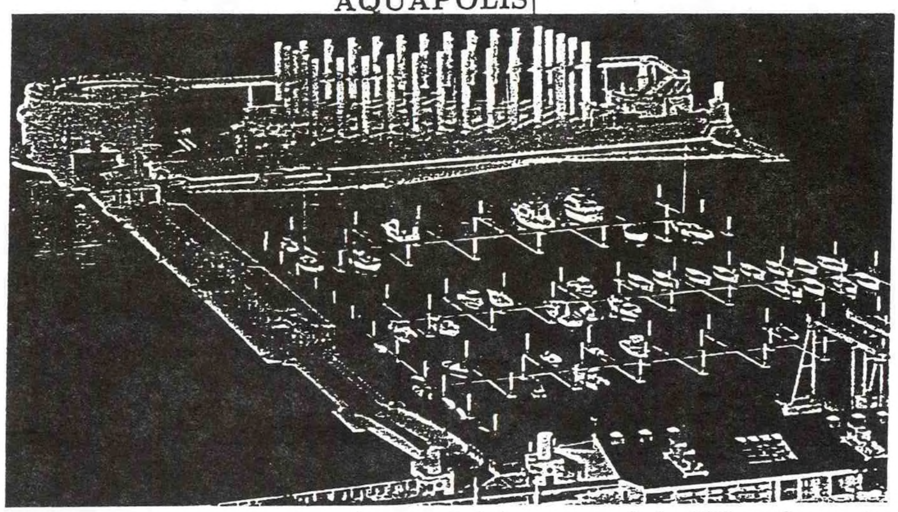


Figure 2 Sakaigahama Floating Island (the central facility of a waterfront leisure zone in Hiroshima)

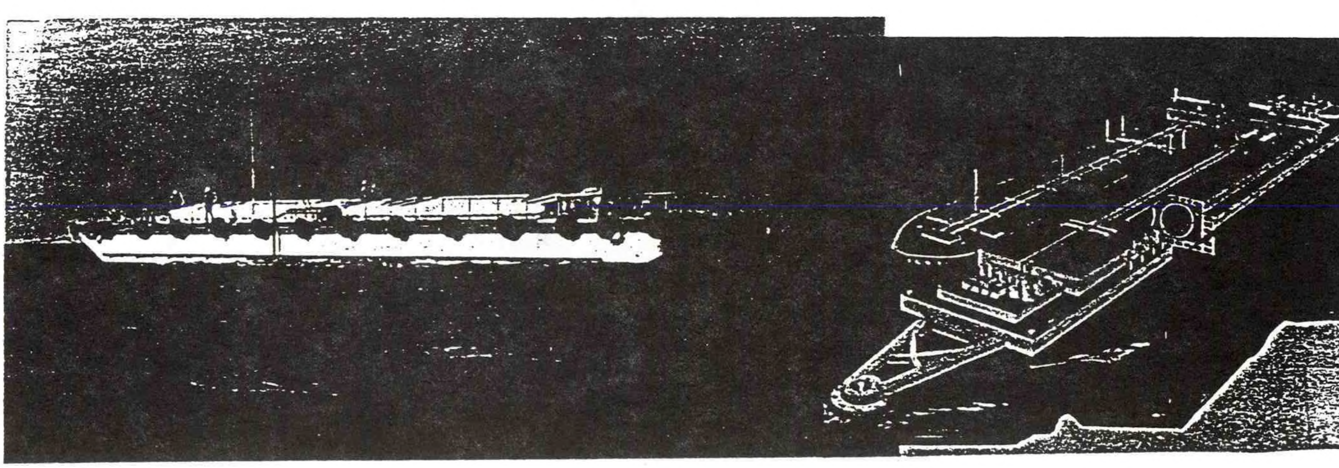


Figure 3 Prestressed Concrete Structures (Experimetnal Barge & Conceptual Design)

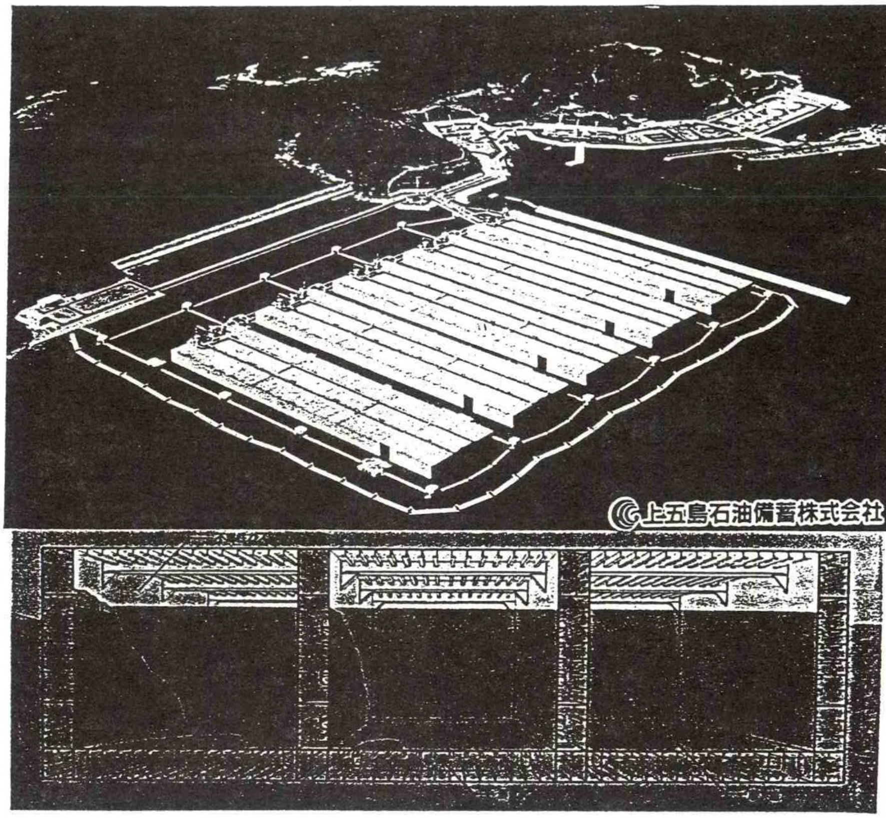
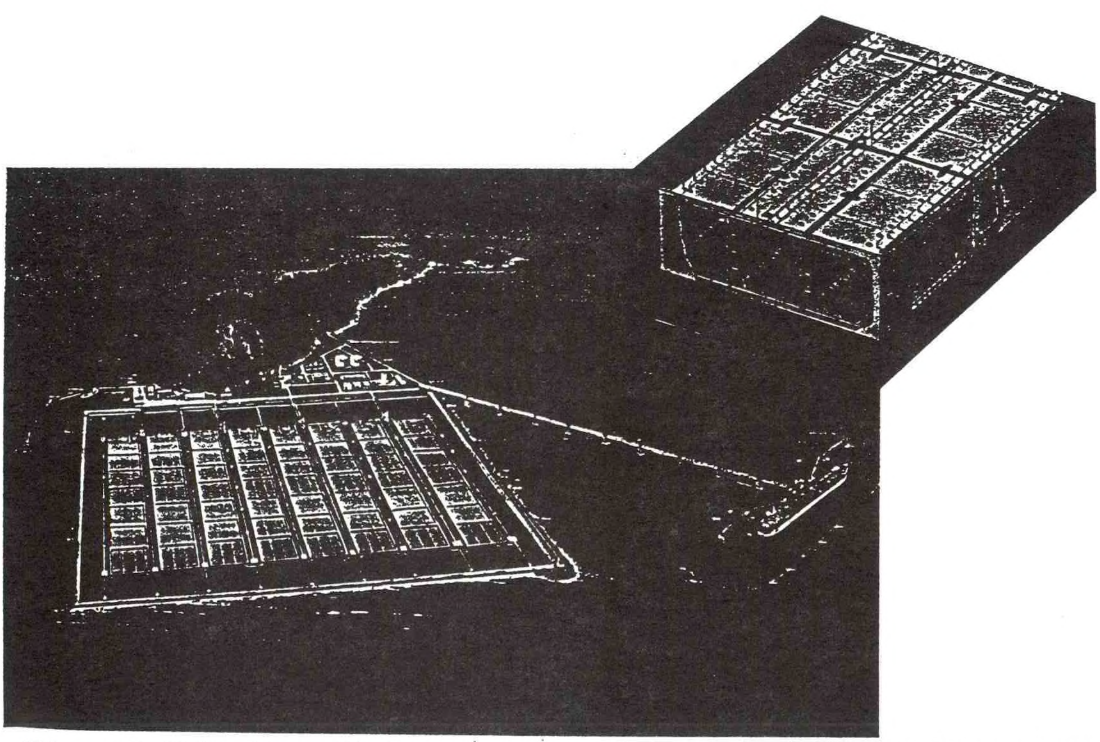


Figure 4 Kamigoto Oil Storage Barges [from a pamphlet of KAMIGOTO]



Fiugre 5 Shirashima Oil Storage Barges [from a pamphlet of SHIRASHIMA]

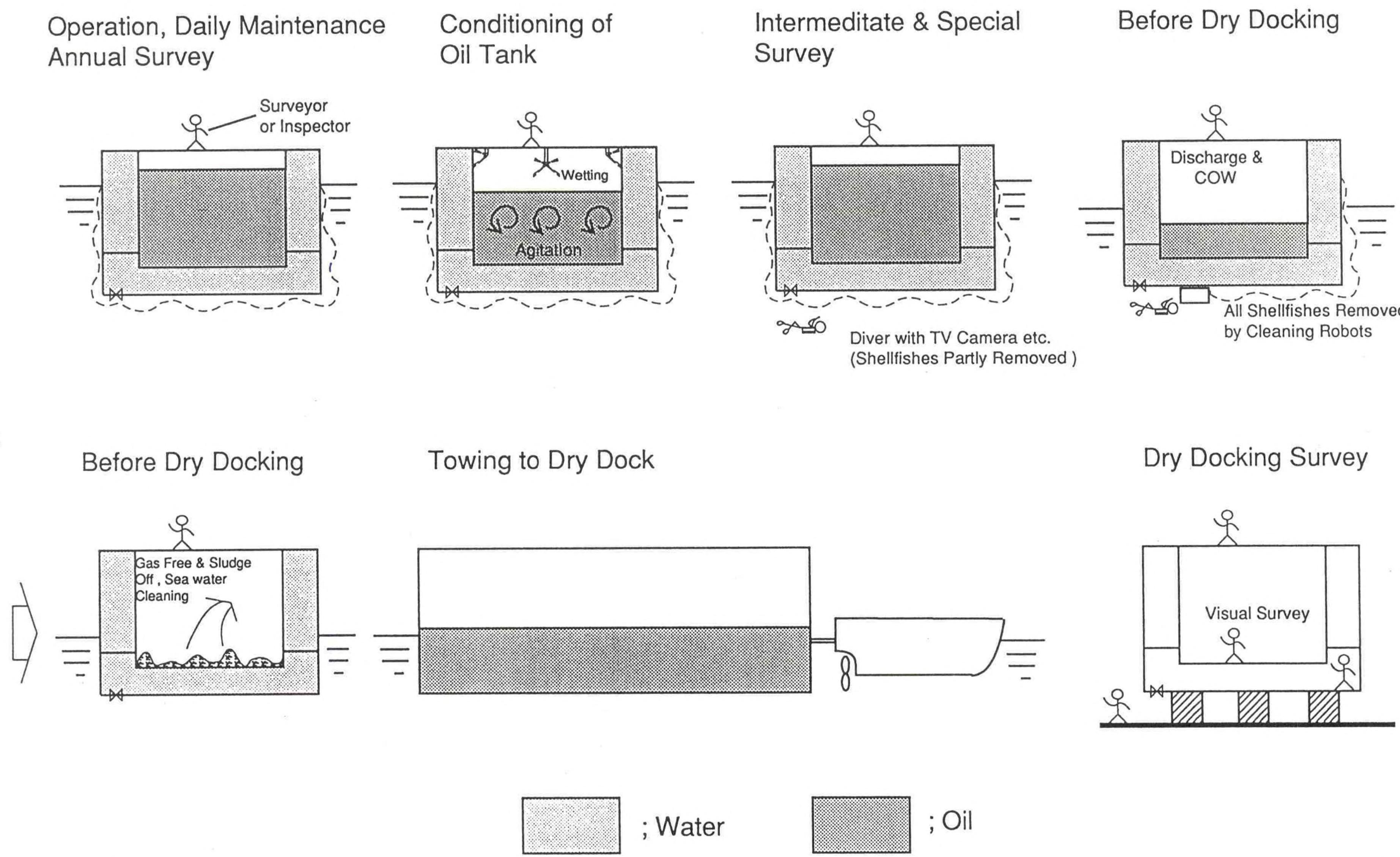
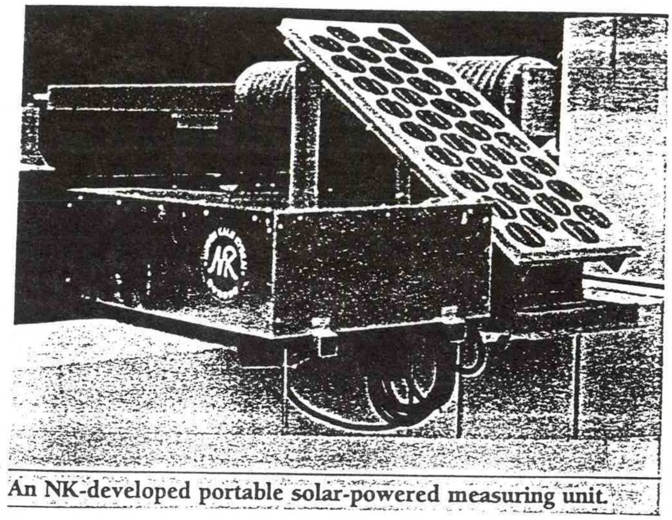
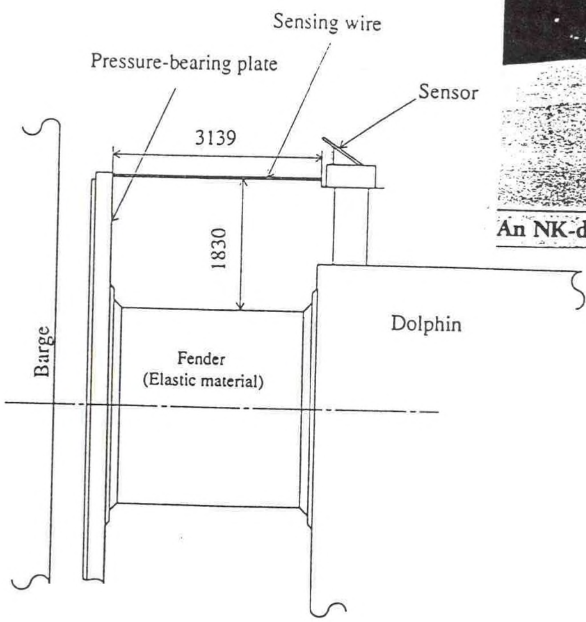


Figure 6 Inspection Procedure





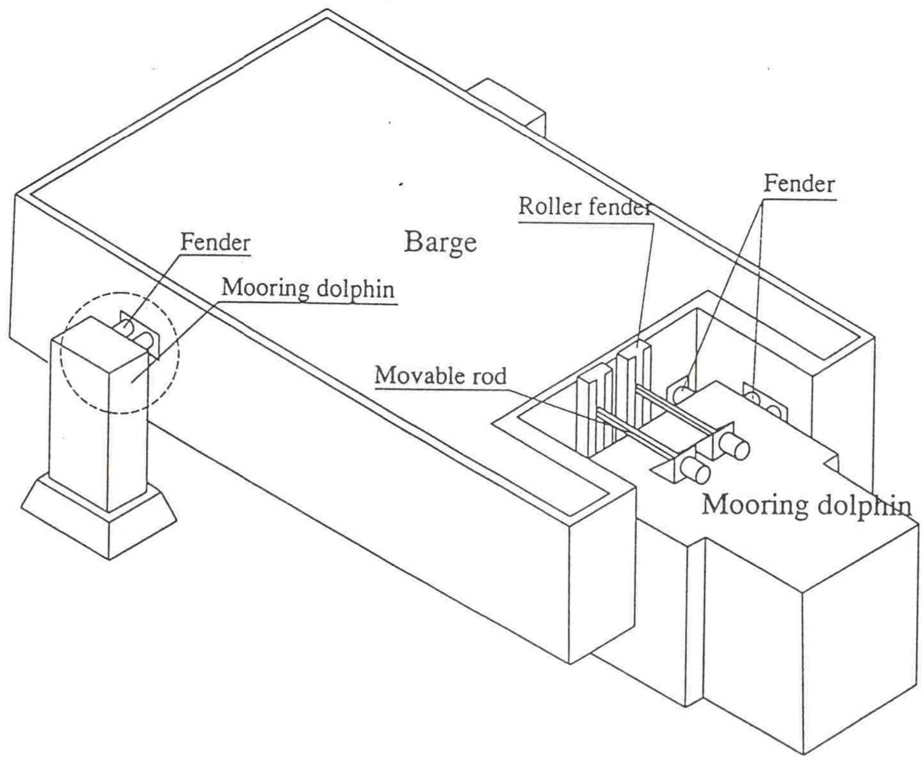


Figure 7 Field Measurement System on the Oil Storage Barges carried by NK

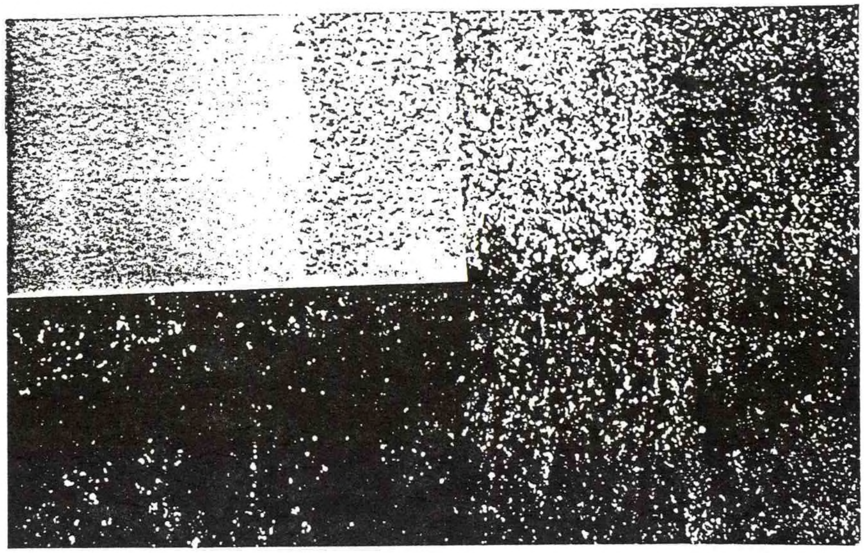


Figure 8 Outward appearance of the Side Shell Plating after peeling by robots

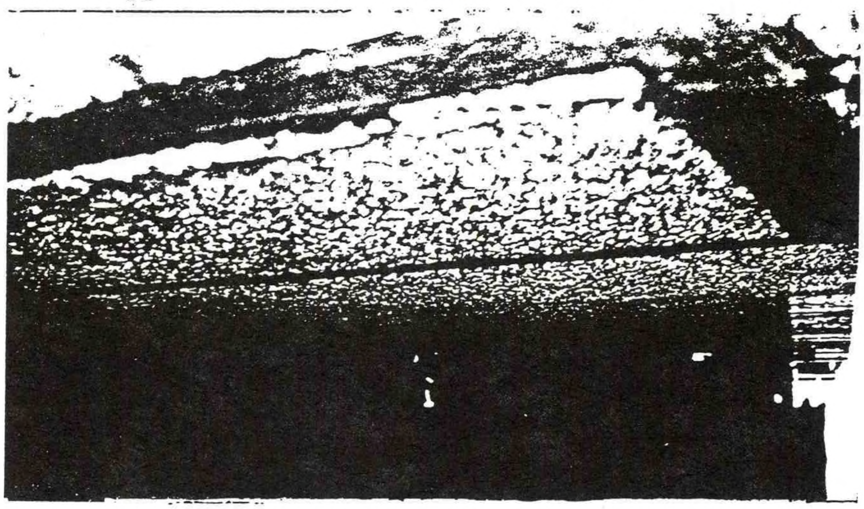
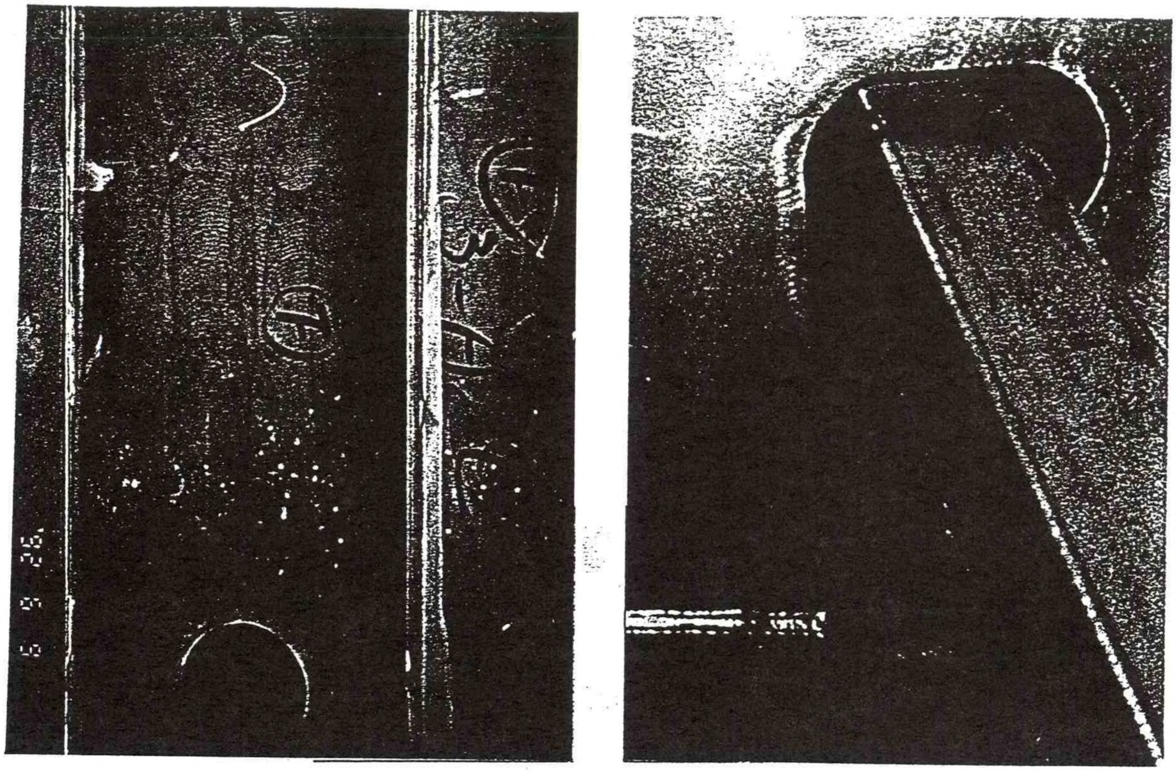
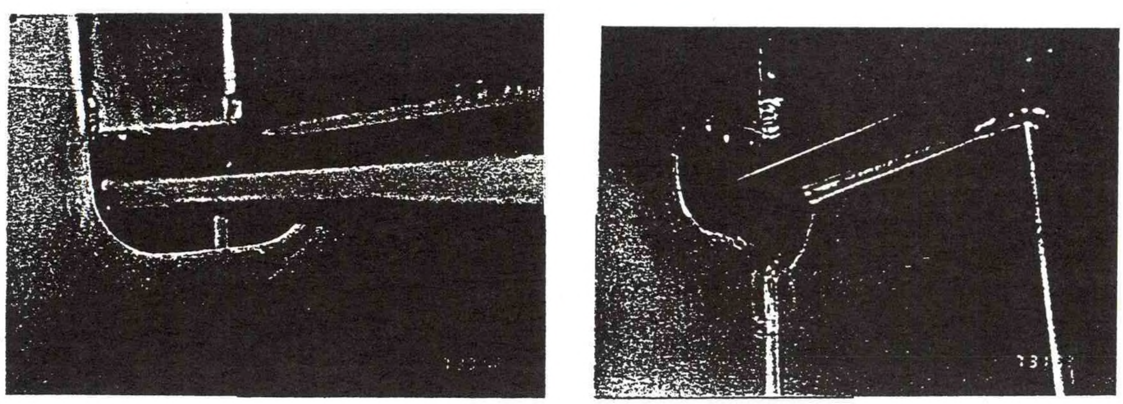


Figure 9 Outward appearance of the Bottom Shell Plating after peeling by robots


Figure 10 Outward appearance of the Coatings of the Outer Shell after cleaning



(a) before painting during construction

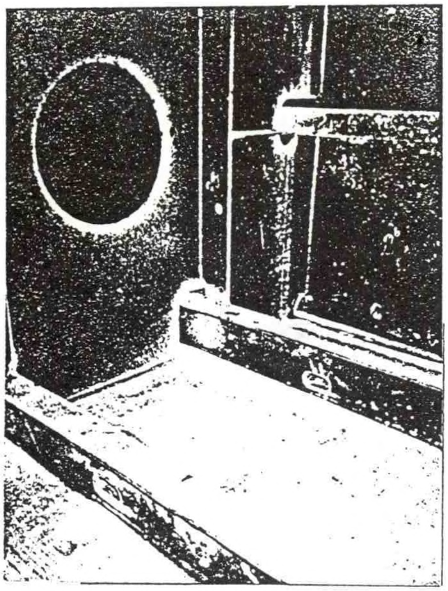


(b) after painting during construction

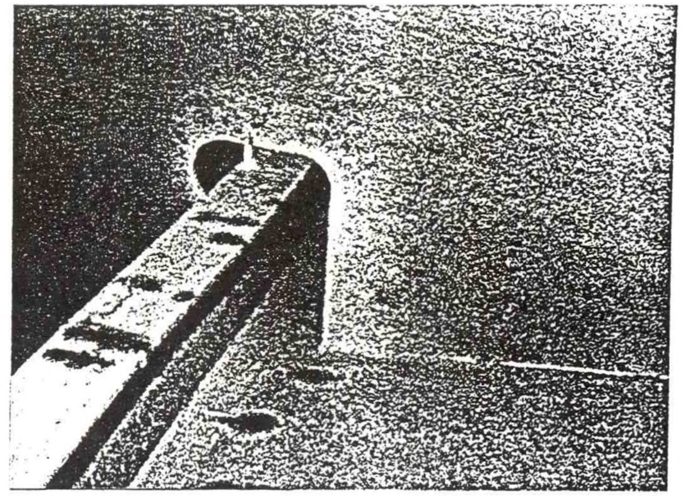
Fig.11 Condtion of Painting in Water Tanks (to be continued)

(paintings are as they are from the construction and they are supplemented by anodes)

[The Oil Storage Barges]



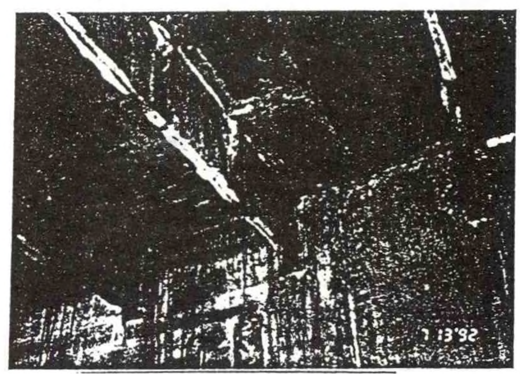
[Ships ; one of the best examples.]



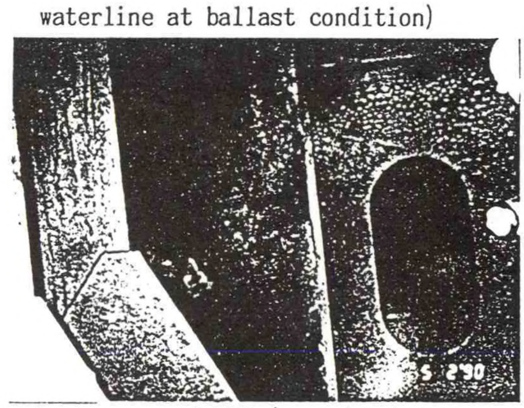
(c) conditions at internal examination after five years operation

A condition can be expected at least more better than the right pictures, because

(i) painting works are at least equivalent to the best ones of ships's hull,
(ii) at always, filled sea water up and no change the sea water during barge's operations.



upper part of WBT (portion above waterline at ballast condition)

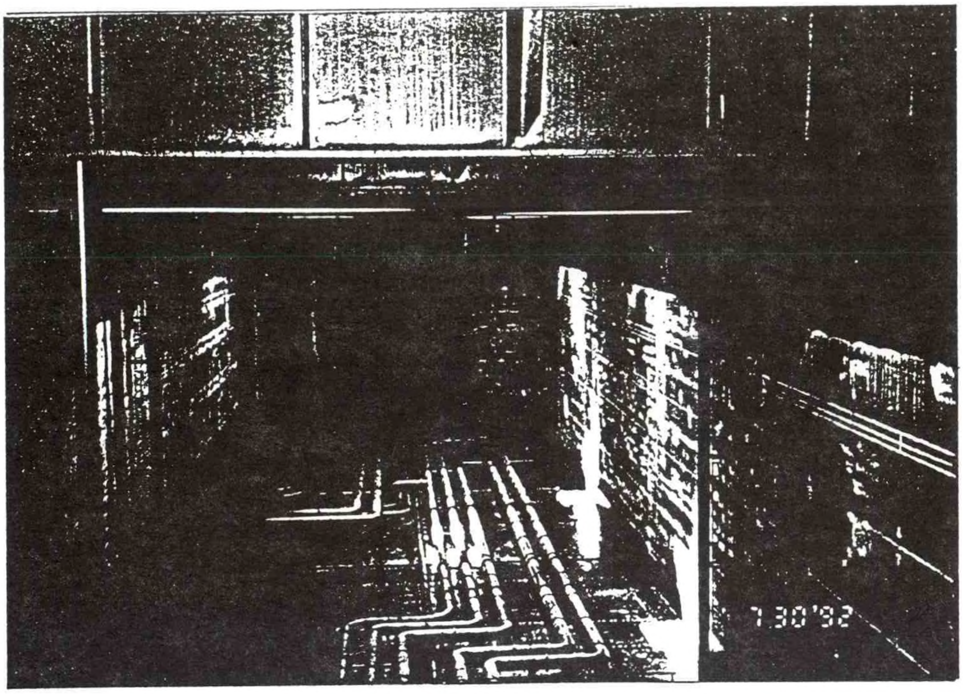


lower part of WBT (portion below waterline at ballast condition)

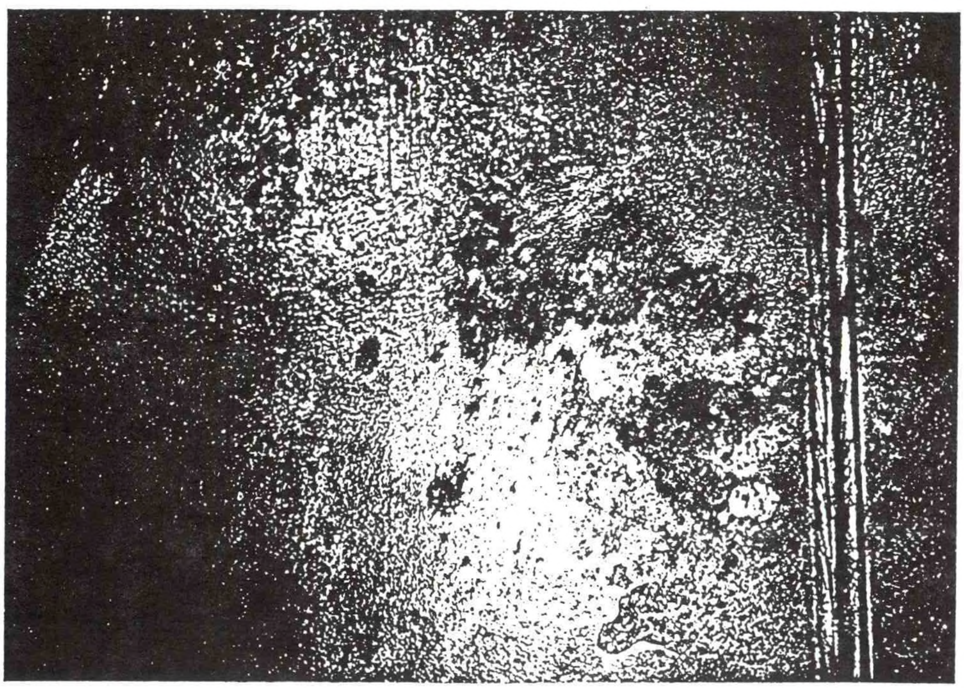
(d) conditions after abt. 20 years operation

Fig.11 Condtion of Painting in Water Tanks

(paintings are as they are from the construction and they are supplemented by anodes)



(a) A whole view of the Oil Tank



(b) Bottom Plating of the Oil Tank.

Figure 12 Inner Surface of the Oil Tank

[Items of ROV]

- to put any place on the outershell
- to peel off spotly shellfishes without any scrach on the coatings
- to observe the outershell and beam a TV picture of the observation to the persons concerned.
- to measure thickness of the outer shell
- to monitor effectiveness of the coatings.

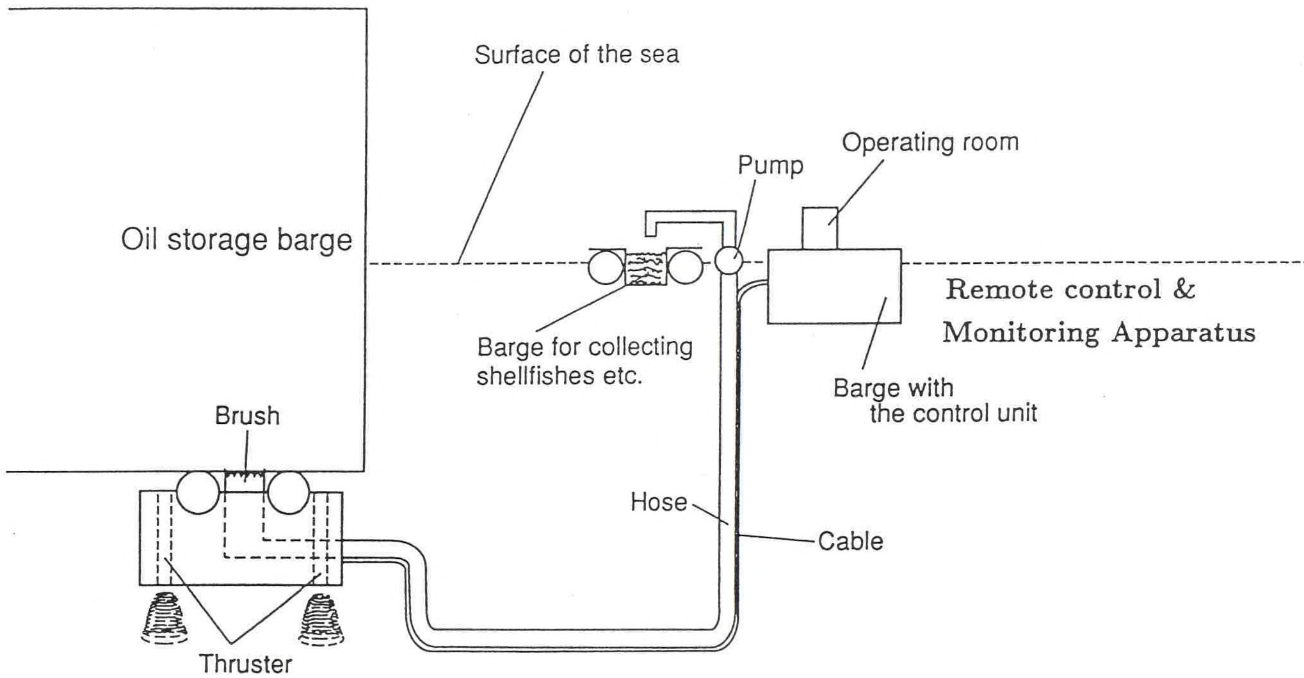


Figure 13 ROV and its Items under developing

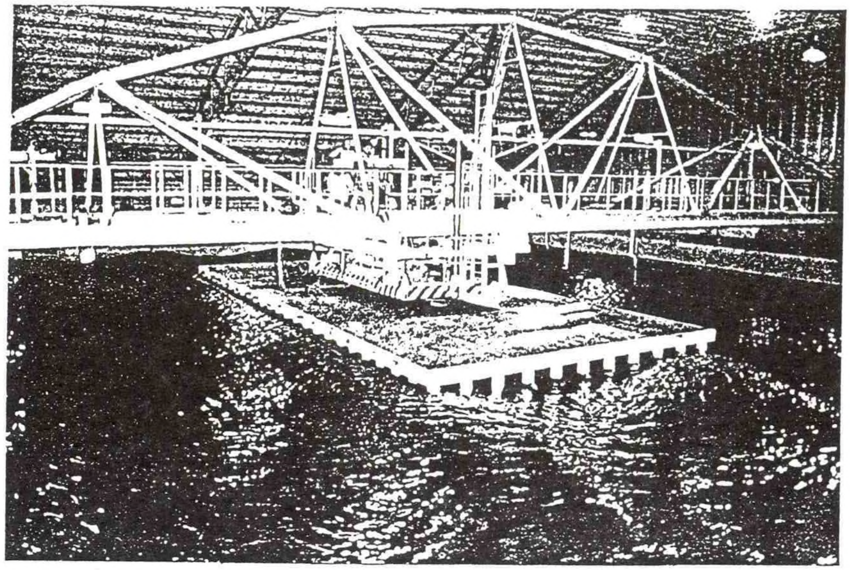


Figure 14 Water-Tank Test using a partial model of a Floating Offshore Airport

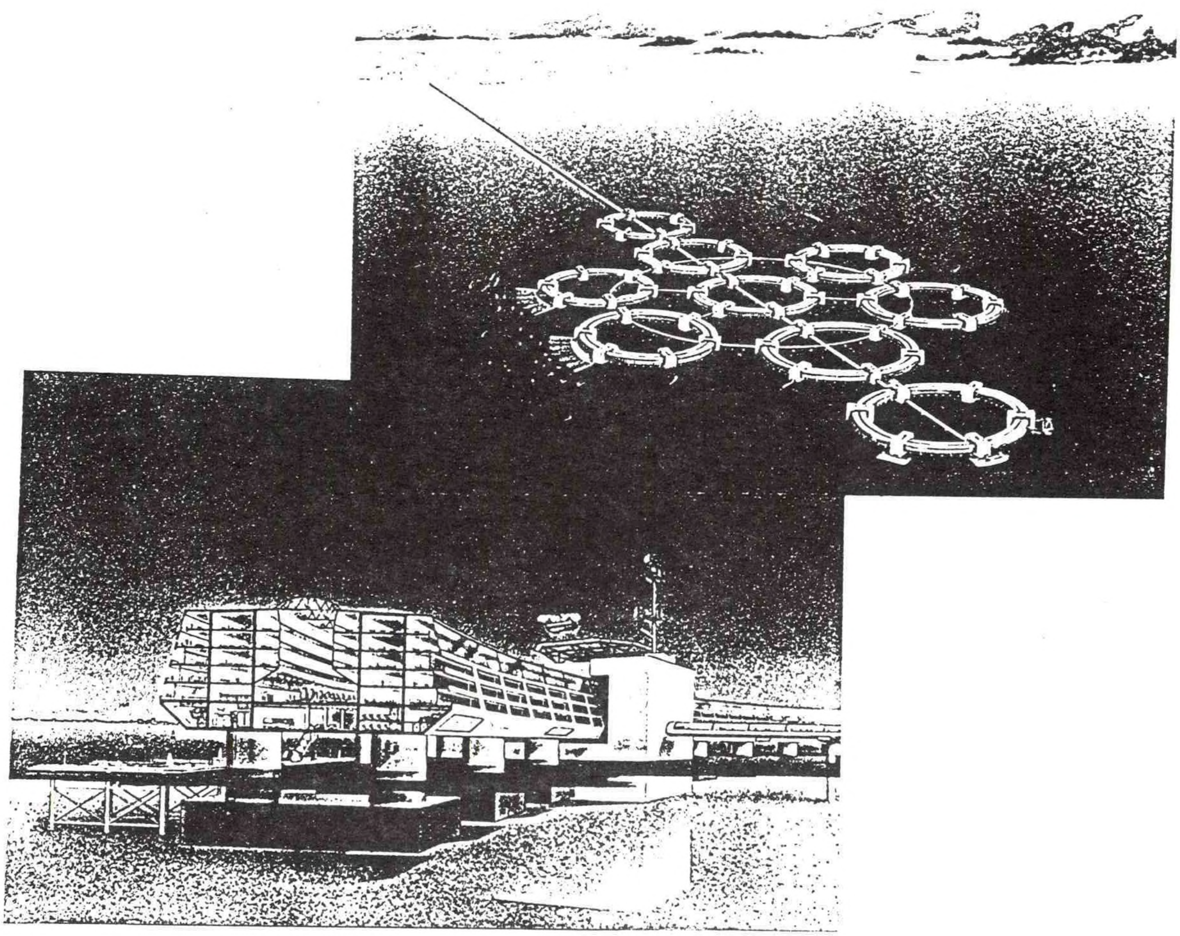


Figure 15 Artist Sketch of Business City Complex using huge ring-like Semisubmersibles.

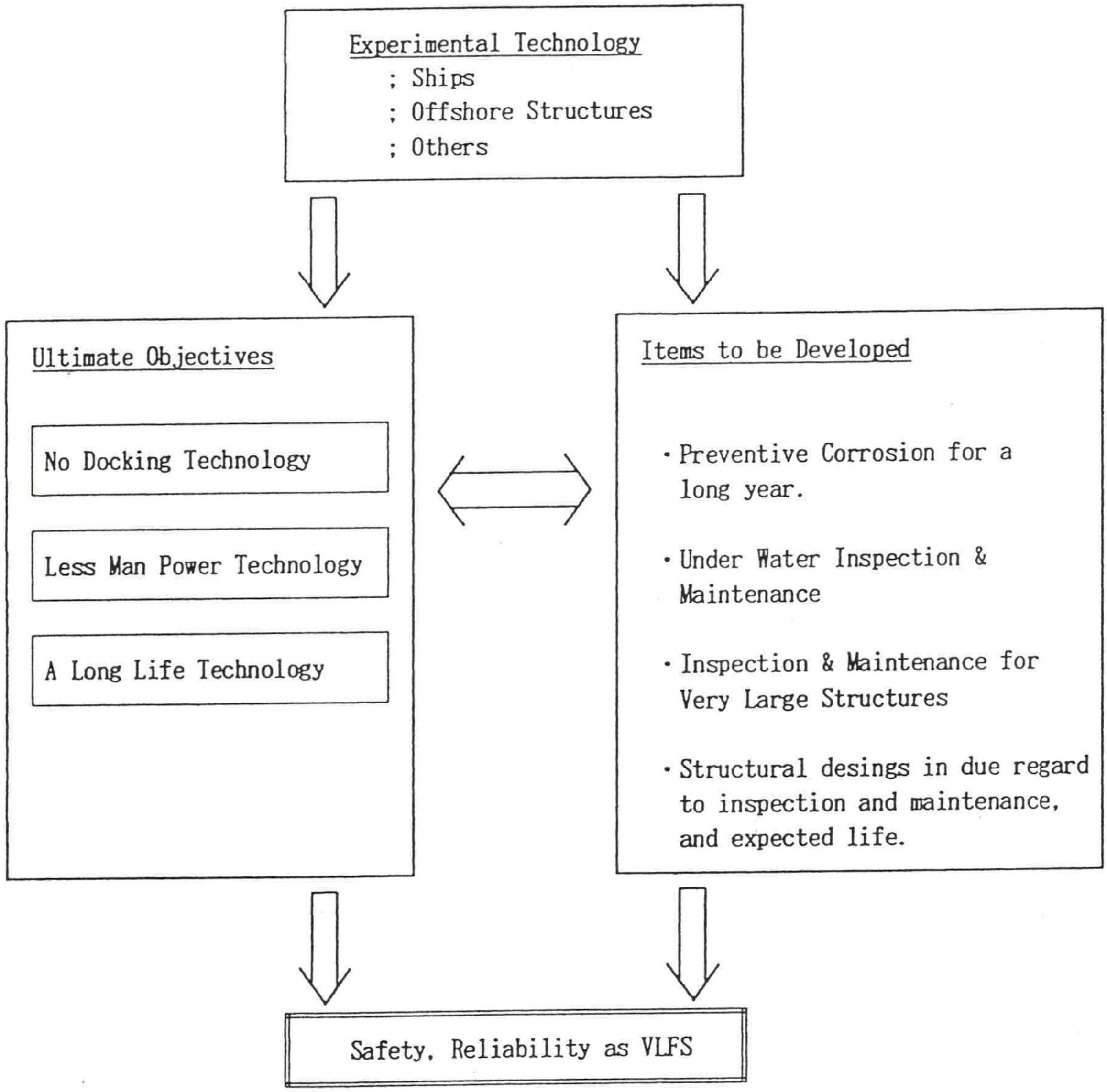


Figure 16 Concept for Inspection and Maintenance.

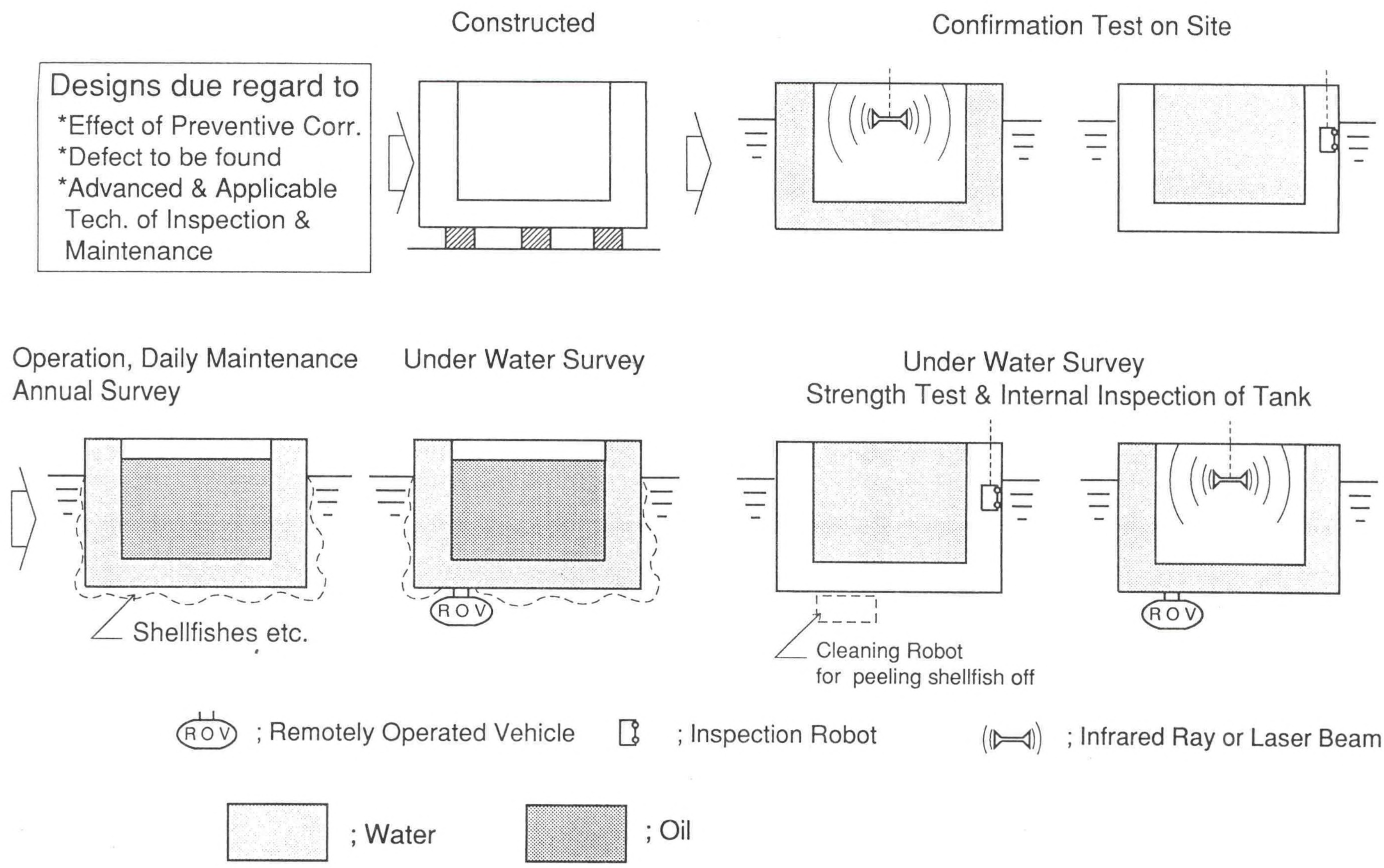


Figure 17 Concept of Inspection & Maintenance for New Oil Storage Barges

Mooring Facilities Based on the Single-Pile Structure

Shigeru Ueda*
Kunio Takahashi**
Satomi Kiuchi***
Toru Tamura****

1. Introduction

SPS (Single-Pile Structure) is a structural arrangement consisting of one high-tensile steel pile and making use of the subsoil's lateral resistance to plastic deformation. This arrangement offers greater lateral bearing capacity and larger deformative capacity than conventional pile structures. Other features of this structure are excellent workability and economy. By using SPS as a single-pile dolphin, it can be utilized as a breasting dolphin and mooring dolphin for deep water terminal, etc.[1)]

Development of SPS was undertaken jointly by the Port and Harbor Research Institute, Ministry of Transport, Taisei Corporation, and NKK Corporation. The design method has been fully studied by Coastal Development Institute of Technology and after passing a technical examination by the Technology Section, Ports and Harbor Bureau, Ministry of Transport, it was officially adopted as "Manual for the Design of SPS."[2)]

In this paper, development and design for mooring facilities using the SPS is discussed.

2. Single-Pile Dolphin using SPS

2.1 Examples of use of single-pile dolphin

Although the single-pile dolphin has long been used for small-vessel mooring facilities, there have recently been some examples of SPS being used as a breasting

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dolphin for large tanker berths in Germany, Holland, Australia, France, India, Thailand, and other countries.

2.2 Special features of single-pile dolphins using SPS

Use of single-pile dolphins using SPS offers the following advantages:

(a) Reduced construction costs since less steel is used
(b) Only one pile is used, so the construction period and costs are reduced
(c) Excellent stability in the case of earthquakes and waves
(d) Maintenance is easy because of the simple construction
(e) When used as a breasting dolphin, about 30-40% of the berthing energy is absorbed through deformation of the pile

Figure 1 compares the conventional design of dolphin with the single-pile dolphin using SPS. Figure 2, an example of comparison of construction costs between breasting dolphins using vertical pile structure, batter pile structure, and SPS, shows that construction costs are reduced by a large margin when SPS is used rather than vertical pile structure or batter pile structure in all areas; materials cost, corrosion protection cost, and execution cost are all reduced.

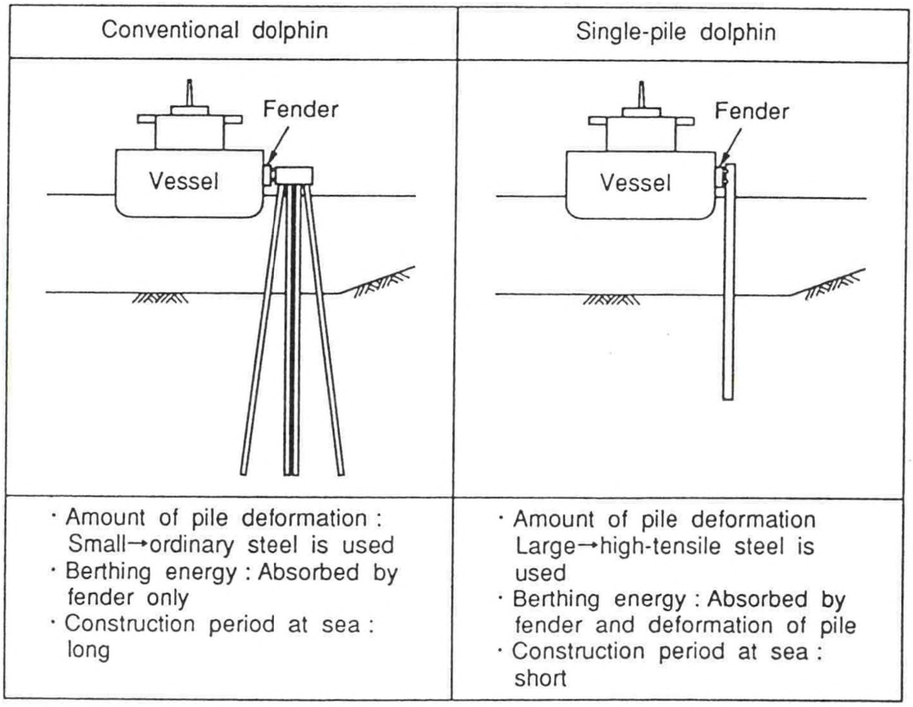

Fig. 1 Comparison of conventional dolphin with single-pile dolphin

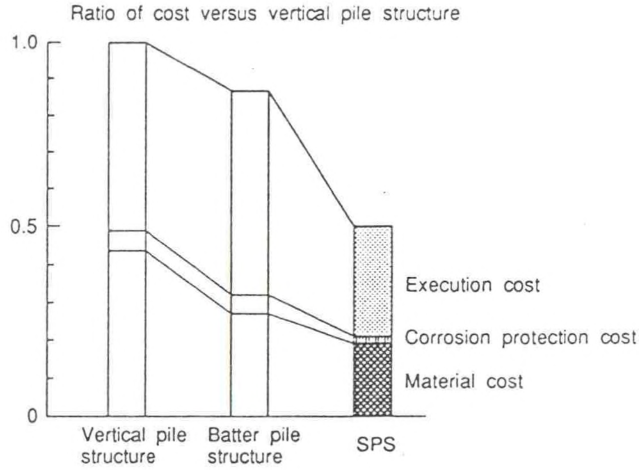

Fig. 2 Comparison of construction costs for a breasting dolphin

Figure 3 shows the relationship between displacement and reaction force of the fender of breasting dolphins designed using vertical pile structure and SPS. It is clear that nearly all the berthing energy of vessel is absorbed by deformation of the fender in the case of a vertical-pile design, while about 30-40% of the berthing energy is successfully absorbed by displacement of the pile head in the case of the SPS design. The result of this is a reduction in the reaction force.

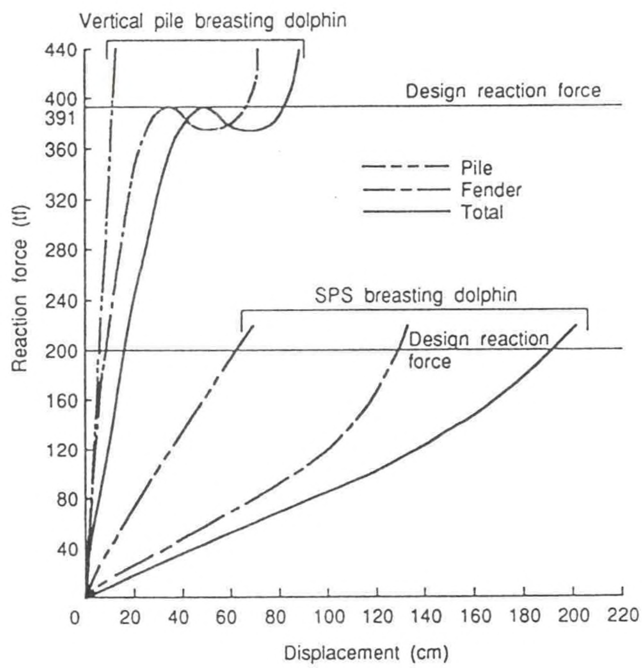

Fig. 3 Relationship between displacement and reaction force of the fender of vertical-pile and SPS breasting dolphins

The natural period is 1.1 sec. in the case of vertical pile structure and 0.4 sec. for SPS. Since the weight on the pile head is lower in the case of SPS compared with vertical pile structure, the natural period is shorter than vertical pile structure; and since it is isolated by the predominant period of earthquake and wave, resonance is a minor concern.

3. Research and Development of Mooring Facilities Using SPS

3.1 Particulars of the research and development program

The Port and Harbor Research Institute, Ministry of Transport, Taisei Corporation, and NKK Corporation worked on SPS-based mooring facilities through technical guidance in 1987 and actual joint research in 1988 and 1989. In 1990 and 1991, the Investigation and Research Committee on a Design Method for SPS (chairman: Professor Masatoshi Sawaguchi of Tsukuba University) was formed by Coastal Development Institute of Technology. After deliberation of the SPS design method, the result was submitted for a technical examination by the Technology Section, Ports and Harbor Bureau, Ministry of Transport before finally being published as "Manual for the Design of SPS."

Although in conventional SPS design the lateral resistance of a pile was calculated using Blum's method,[3] the applicability of this method to piles with large displacement is somewhat questionable, and the residual displacement and cumulative fatigue damage after repeated loading are as yet unclear. In consequence, the joint research concentrated on the experiments outlined below.

(a) Lateral loading experiments of mock-up piles in hard and soft sandy soil
(b) Repeated lateral loading experiments of model piles in sandy soil
(c) Examination of the weldability of different steels and corrosion resistance of welded joints
(d) Examination of the residual displacement and cumulative fatigue damage with a large displacement for breasting dolphins based on a single pile

3.2 Lateral loading experiments of mock-up piles in hard and soft sandy soil[4)5)]

The lateral loading experiments of mock-up piles were conducted at NKK's Ohgishima site in Kawasaki, Kanagawa Prefecture in 1987 and in Akanehama, Narashino, Chiba Prefecture in 1988.

Table 1 gives details of the mock-up piles used in these on-site loading experiments, as well as the loading conditions, the maximum displacement at the ground surface, and the maximum stress. Soil in the Ohgishima area is a relatively hard sandy soil with an N-value of about 20. At Akanehama, it is a relatively soft sandy soil with an N-value of about 5-10.

Table 1 Details of Mock-up Piles used for Lateral Loading Experiments and the soil Condition

Item	Loading experiments in hard sandy soil	Loading experiments in soft sandy soil
Pile diameter (mm)	812.8	812.8
Wall thickness (mm)	15	20
Type of steel	SHY685	SHY685
Loading height (m)	+5.0	4.0
Embedded length (m)	12.0	13.0
Soil conditions subsoil	Sandy soil (Reclaimed soil shallower than GL -11.1 m)	Fine sand or sandy silt (Reclaimed soil shallower than GL -3.6 m)
N-value	10-20	Below 10
Loading value	Maximum loading 80 tf Repeated loading 70 tf•10 cycles	Maximum loading 90 tf Repeated loading 75 tf•13 cycles
Maximum displacement at ground surface (cm)	12.5	23.0
Maximum stress (kgf/cm^2)	7211	7245

Figure 4 shows the relationship between lateral loading and pile-head displacement as obtained through the loading experiments of mock-up piles in the hard sandy soil. The results are compared with calculations using Blum's method, the API-RP2A method[6] (P-Y curve method; $\phi=40^{\circ}$, Chang's method[7]) k_h = 0.8 kgf/cm^3), and the PHRI method[7][8] (C-type subsoil, k_c = 2.0 $kgf/cm^{2.5}$). The figure demonstrates that calculations using the PHRI method and the API-RP2A method match the experiment measurements well and that they are even applicable in cases where the displacement at the ground surface reaches 12.5 cm.

Repeated loading was carried out 10 times in the hard sandy soil at 70 tf and 13 times in the soft sandy soil at 80 tf. The pile-head displacement and residual displacement due to this repeated loading were measured.

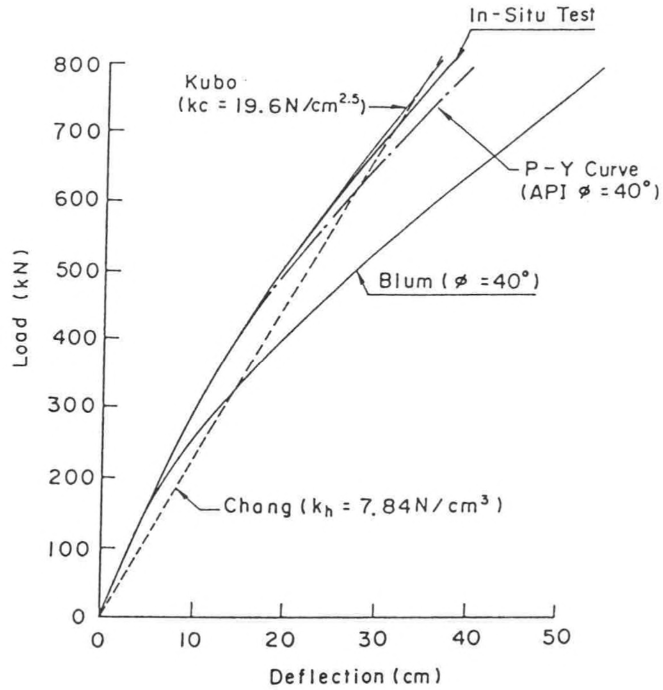

Fig. 4 Relationship between Load and Pile-Head Displacement (Lateral loading experiments of mock-up piles in hard sandy soil)

3.3 Repeated lateral loading experiments of model piles in sandy soil[9)10)]

These repeated lateral loading experiments were carried out in the soil basin at the Port and Harbor Research Institute, Ministry of Transport. Table 2 gives details of the 16 experiments that were carried out for various conditions of soil, rigidity of pile, loading pattern, and loading height. Two types of soil were used; one an ordinary subsoil prepared by dropping sand in air (unit weight 1.434 to 1.459 tf/m^3) and another harder subsoil relatively compacted by weight after dropping sand in air (unit weight 1.584 tf/m^3). Three values of moment of inertia of section were used, 0.5, 1.0, and 2.0 cm^4, and loading was applied at four vertical positions, 20, 25, 40, and 60 cm. Figure 5 shows the loading patterns.

Table 2 Experimental cases for the Repeated Lateral Loading of Model Piles

Case No.	Soil	I of pile	Loading pattern	Loading height	Remarks
1	Normal	1 cm^4	A	20 cm	Effect of loading height
2	"	"	"	40	"
3	"	"	"	60	"
4	"	"	B	25	Effect of loading pattern
5	"	"	C	"	"
6	Relatively hard	"	D	"	Effect of soil, rigidity of pile
7	"	0.5	"	"	"
8	"	2	"	"	"
13	Normal	1	A	"	Effect of loading height
14	"	"	B	"	Effect of measure against pulling of pile
15	"	"	E	"	Effect of preceding load
16	"	"	D	"	Grasping of convergent load or divergent load

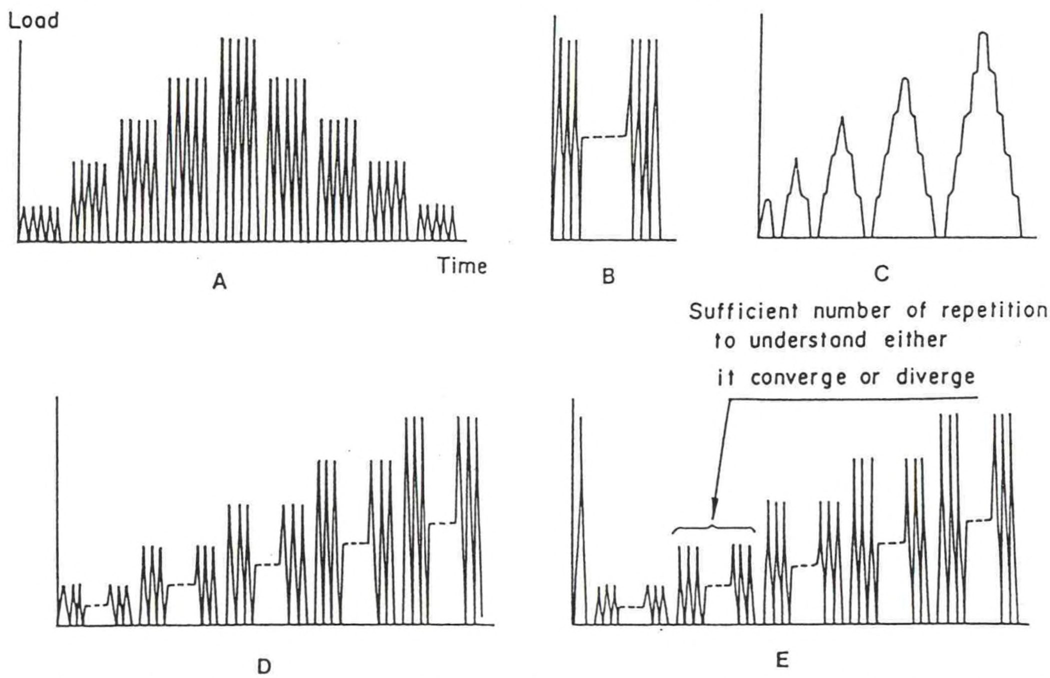

Fig. 5 Loading Patterns in Repeated Lateral Loading Experiments

Figure 6 shows the relationship between lateral loading and pile head displacement in these repeated loading experiments. From these results, the following conclusions can be drawn:

(a) During initial loading, the relationship between lateral load and pile-head displacement turns out to be approximately the same even when the loading pattern is different.

(b) When small loads are applied after loading with a large load, the hysteresis curves by lateral loads and pile-head displacements against the repeated small loads are included in that against the large load.

(c) Although the pile-head displacements increase with repeated loadings of the same magnitude, they gradually converge.

(d) The smaller the magnitude of load is, the less the number of repeated loadings until the pile head displacements converge.

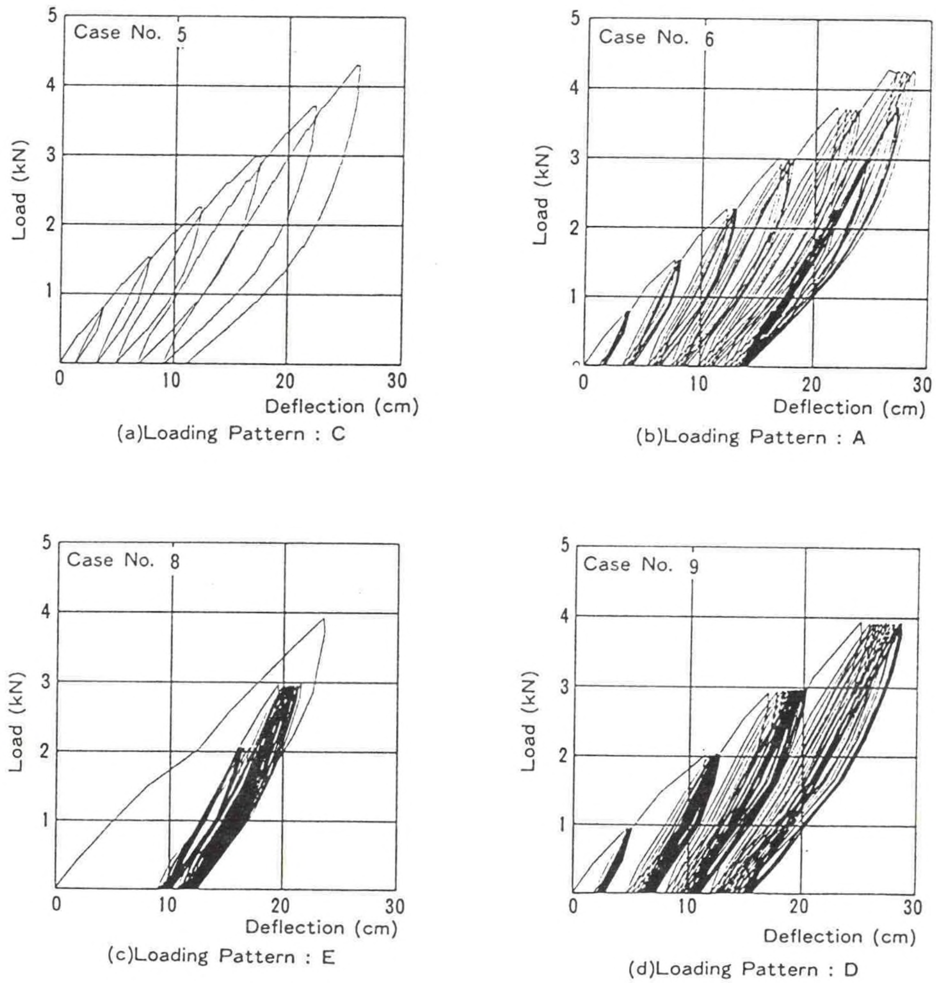

Fig. 6 Relationship Between Lateral Load and Pile-Head Displacement in Repeated Lateral Loading Experiments

From the above results, an equation for the increase in pile-head displacement and residual deformation due to repeated loading can be derived.

3.4 Examination of weldability of different steels and the corrosion resistance of welded joints[11)]

Steels of type SM490B, SM570Q, and SHY685 of the Japanese Industrial Standards were used in welding tests. Their tensile strengths are 490 N/mm^2, 570 N/mm^2, and 785 N/mm^2, respectively. Three types of joint, SM490B-SM570Q, SM570Q-SHY685, and SHY685-SM490B were fabricated to examine the weldability of these steels, and it was clarified that the welded joints had no defects, that the strength of the joints was sufficient, and that lowering the heat input temperature at the time of welding had a good effect on brittleness at the boundary between the base metal and welded material, and that defects such as to cause brittle fracture could be confirmed using the method as provided for the WE2805, Japanese Industrial Standards, etc. So it is concluded that there was no problems regarding weldability of steels of different materials.

Accelerated corrosion tests were also carried out on the same three types of joints between the different steels in an artificial sea water environment. The SM490B-SM570Q joint corroded almost perfectly uniformly, while tests of SM570Q-SHY685 and SHY685-SM490B joint showed that SHY685 hardly corroded and that SM490B and SM570Q did corrode. At the bond on the SM490B side of the SHY685-SM490B joint, slight corrosion of the notch form was seen. Although the degree of corrosion was small, it points out that adequate monitoring must be considered when electrolytic protection is implemented.

3.5 Examination of residual displacement and cumulative fatigue damage of SPS breasting dolphins suffering large displacement[12)]

Techniques for calculating the probability of rupture, residual displacement, and cumulative fatigue damage over the service life of an SPS breasting dolphin have been established in consideration of the probability distribution of the load at vessel's berthing and mooring, the probability distribution of strength of materials such as subsoil, steel, etc., and the hysteresis between lateral load and pile-head displacement against repeated loading. Also, calculations of 100 cases on a berth of 5,000 dwt and a berth of 20,000 dwt with varied size tankers berthing in arbitrary sequence showed that the maximum value of residual displacement after berthing was about 8 cm and 27 cm for two berths, respectively, and that the cumulative fatigue damage was 0.0011 and 0.0013, respectively. For 5,000 dwt tanker berth which was designed for berthing conditions only, assuming that vessels are moored when the wave height is smaller than 0.5 m and the wind velocity less than 5 m/s, calculations of residual displacement and the cumulative fatigue damage due to motion of vessel show that the maximum value of residual displacement among the 100 cases was 0.226 m when the wave direction was 60° and 0.315 m when the wave direction was 90°. These values are larger than the 0.08 m obtained when considering the berthing force alone. Although the cumulative fatigue damage was 0.55 when the wave direction was 60°, it rose to 2.41 when the wave direction was 90°. It is therefore necessary to create a design with adequate attention to vessel motion when the wave direction is 90°.

The above examination of cumulative fatigue damage was carried out by means of simulations in which the sequence of vessels to be moored was at random. A simpler method of examining the fatigue strength, focussing on the condition under berthing and mooring of vessels, in consideration of fluctuations in wave conditions is now shown. Figure 7 shows the procedure for this method. Although this evaluation of fatigue strength relies on calculating the fatigue damage using Miner's rule, the "C-curve" as given in Classification Note [13]) of DnV may be used to obtain the S-N curve when calculating the fatigue damage.

The procedure for examining fatigue strength is as follows.

(a) Based on the combined frequency distribution of wave height and period at the location of the SPS, periods of waves are classified according to their lengths and limitations on the wave height at the time of mooring for each classification of periods are established. The combined frequency distribution of wave height and period under mooring vessel is then calculated.

(b) The loads acting on the SPS are calculated by evaluating the motion of vessel at the limitation of the wave height in each period classification above to obtain their frequency distribution.

(c) The number of times the berthing force acts is obtained.

(d) By multiplying the frequency distribution of the load at the limitation of wave height for each period by the respective probability of occurrence (Ni/N) obtained in (1) above, the magnitude of loads and the number of occurrences during one berthing are obtained. Multiplying the sum adding berthing force thereto by the number of berthings in a year and the service life, the stresses occurring at the SPS and their numbers of occurrences are calculated.

(e) Using the S-N curve, the cumulative fatigue damage is calculated.

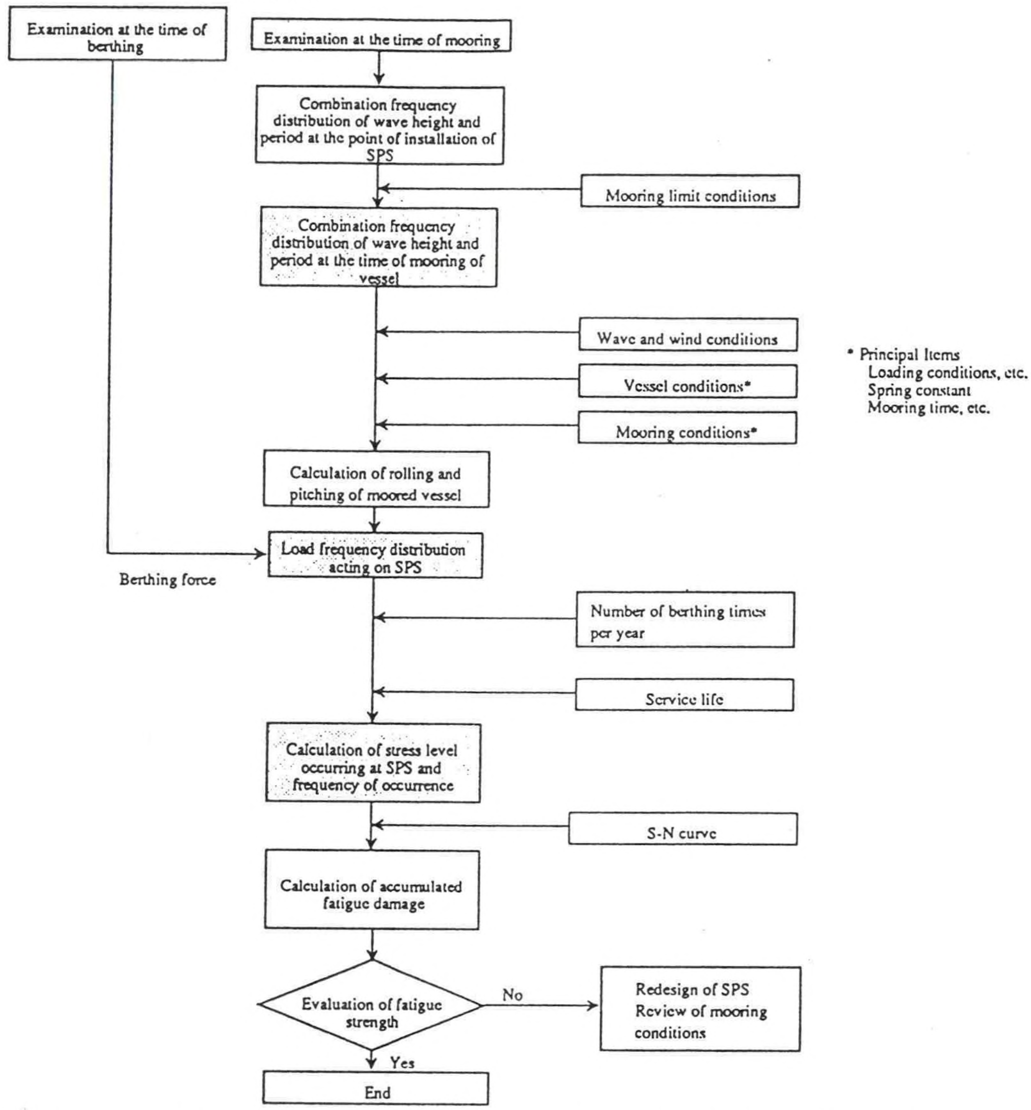

Fig. 7 Flowchart for examination of fatigue strength

4. Manual for the Design of SPS and an Example of Design

4.1 The "Manual for the Design of SPS"

The "Manual for the Design of SPS" describe matters such as a definition of SPS, the scope of its application, the design procedure, the design conditions, the necessary constants, the allowable stress in the steel, the welding of different steels and their corrosion protection, the method of estimating the lateral behavior of the pile, the stress in the pile cross section, the examination of embedded length, the examination of facility and equipment layout, and the examination of maintenance and fatigue strength, etc.

4.2 Design example

Figure 8 gives an example of a breasting dolphin designed for a 100,000 dwt tanker berth using SPS. The berthing velocity was assumed to be 0.15 m/s and the berthing energy is 180 tfm (1,746 KNm), of which 92 tfm was designed to be absorbed through displacement of the pile and 118 tfm through deformation of the fender. The pile-head displacement at the time of berthing was 63 cm and the ground surface displacement 7 cm.

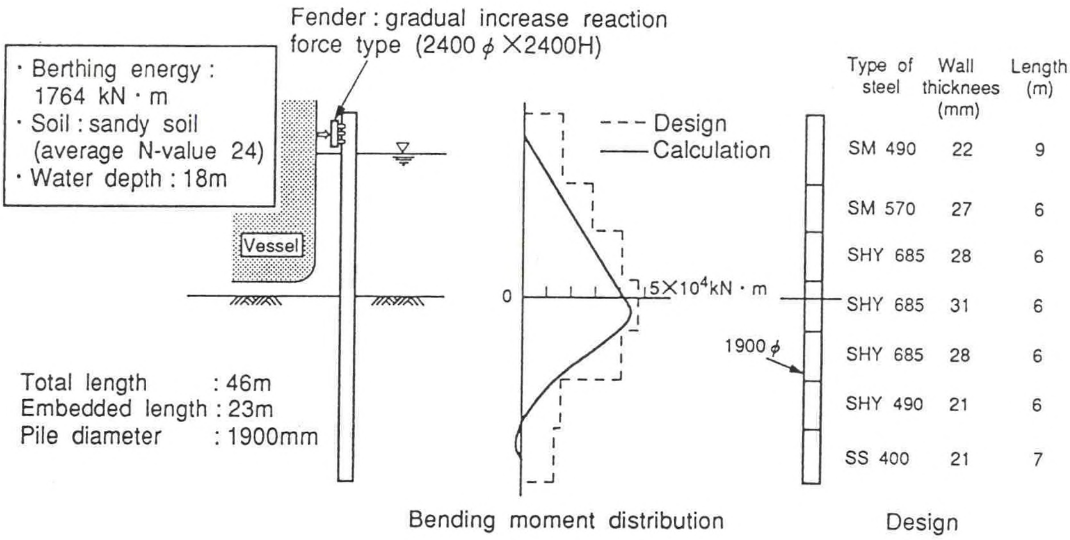

Fig. 8 Example of breasting dolphin design using SPS for 100,000 dwt tankers

5. Postscript

SPS is a new structure type offering excellent economy and workability. We hope that in future SPS will be widely used in mooring facilities such as deep water terminal, offshore structures, etc. We have received encouragement from those concerned at the Port and Harbor Research Institute, Ministry of Transport, at Taisei Corporation, and at NKK Corporation for this SPS research and development program. Careful deliberation has also been undertaken by committee members, including professor Masatoshi Sawaguchi of Tsukuba University, of the Investigation and Research Committee for SPS Design Methods. We would like to take this opportunity to express our sincere thanks to them.

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ESTIMATION OF ENCOUNTER PROBABILITY OF SLIDING FOR PROBABILISTIC DESIGN OF BREAKWATER

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1. Introduction

In the present Japanese design guide of a breakwater, the design wave in deep sea is determined as the wave of a desired return period by statistical analysis of hindcasted or observed storm waves during more than 30 years. Generally the period of 50 years is employed as the return period. The wave in deep sea transforms during its propagation to the site of a breakwater. The wave transformation is computed numerically, and the parameters of the wave at the site are determined. The wave forces acting upon the the breakwater are calculated by suitable empirical formulas. The stabilities of the breakwater are checked to the wave forces. If the stability is not sufficient, the caisson is weightened by widening its width until the safty factors of sliding and overturning are satisfied.

Thus the breakwater is designed deterministically. Though several uncertain factors appear in the design process, these factors are not considered in the present design of breakwaters. In order to establish the probabilistic design of breakwaters the authors (1989, 1990, 1991a,b,c) has developed the computation method of the sliding failure probability of the breakwater designed according to the present design guide in Japan. The present paper describes the outline of their study.

2. Present Design of Composite Breakwater

2.1 Estimation of design wave in deep sea

The present technical standards for port and harbour facilities in Japan gives a guide line of determination of deepwater design wave as follows:

1)Parameters of the deepwater waves shall be determined from following.

①The measured values of waves over a considerable long period.

②The values obtained by taking account the probability of occurrence through appropriate statistical processing to the hindcasted values obtained from the meteorological data over about 30 years or more and corrected by the measured wave data.

③The values of hindcasting of waves calculated based on hypothetical typhoons.

2) The parameters of deepwater wave shall be assigned among 16 bearings to permit any significant wave actions with respect to their assigned directions.

In the past the hypothetical typhoon of 'Isewan', which was the biggest typhoon which attacked the Isewan and caused the most disastrous damage, was sometimes employed for the hindcast of deepwater wave. In the present the determination of deepwater design wave is executed by the statistical processing to the hindcasted extreme waves. The various distributions of extreme values like FT-I, FT-II and Weibull distributions are usually applied to select the most probable distribution of the occurrence probability of deep water wave heights.

2.2 Computation of wave transformation

The design wave in deepwater is transformed by the infulence of sea bed topography in shallow water during its propagation to the site of a breakwater. Two different equations are employed for the numerical computation of the wave transformation: One is the wave energy balance equation proposed by Karlson (1969) and the other is the mild slope equation proposed by Berkoff (1972).

Breaking wave acts on a breakwater under the condition that the breakwater is located at the place shallower than wave breaking depth. The wave transformation due to breaking should be considered in the computation, but the above wave energy balance and mild slope equations cannot compute wave attenuation due to breaking. Takayama et al. (1991) and Isobe (1986) have introduced the term of wave energy dissipation into the energy balance and mild slope equations, respectively. They both assume that the energy dissipation due to breaking is proportinate to the spectral level, but they use different factors of proportion for the energy dissipation.

The parameters of maximum wave in random wave group are employed for the estimation of wave forces acting on a composite breakwater. The computation of the wave transformation as previously described is capable to obtain the parameters of significant wave but not of maximum wave. Takayama et al. (1991) regard the maximum wave height as larger value between $1.8H_{1/3}$ and H_b, where $H_{1/3}$ and H_b represent the significant and breaking wave heights, respectively.

Goda (1975) has proposed the computation method of wave transformation due to breaking on the two-dimensional uniform slope under the consideration of the effect of wave set-up and surfbeats in a surf zone.

2.3 Empirical formulas of wave forces for design

The different formulas of wave forces have been proposed for different shapes of composite breakwater, but in Japan these formulas are given as the modified form of the formulas proposed by Goda (1973) for the estimation of wave forces acting upon a vertical breakwater. The Goda's formulas including modification factors is shown here.

Goda has assumed that the wave pressure acts up to the height of η^* above the still water level and distribute in a triangular shape above the still water and in a trapezoidal one in water, as shown in Fig. 1. The value of η^* and the horizontal wave pressures at the still water level and the bottom are formulated empirically through systematical model tests as follow:

$$\eta^* = 0.75\lambda_1 (1+\cos\theta_i) H_D \tag{1}$$

$$p_s = \frac{\lambda_1}{2}(1+\cos\theta_i)(\alpha_1+\lambda_2\alpha_2\cos^2\theta_i) w_0 H_D \tag{2}$$

$$p_b = \alpha_3 p_s \tag{3}$$

where

$$\alpha_1 = 0.6 + \frac{1}{2}\left[\frac{4\pi h/L}{\sinh(4\pi h/L)}\right]^2 \tag{4}$$

$$\alpha_2 = \min\left\{\frac{h_b - d}{3h_b}\left(\frac{H_D}{d}\right)^2, \frac{2d}{H_D}\right\} \tag{5}$$

$$\alpha_3 = 1 - \frac{h'}{h}\left[1 - \frac{1}{\cosh(2\pi h/L)}\right] \tag{6}$$

and

h : water depth at the front face of a breakwater

h_b : water depth at the location at a distance $5H_{1/3}$ seaward of the breakwater

h' : water depth at the bottom of the breakwater

d : water depth above the armour unit in front of the breakwater

w_0 : weight of sea water in unit volume

L : wavelength at the water depth

θ_i : wave attacking angle shifted by 15 degree toward daingerous side from incident wave direction

H_D : wave height in design

λ_1 and λ_2 : modification factors which depend on the shape of a breakwater

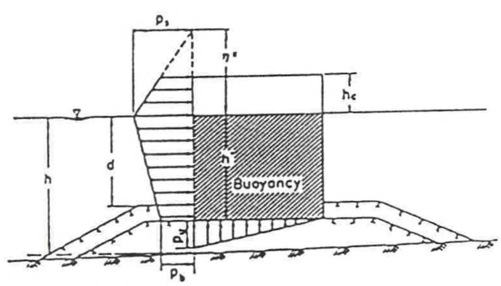

Fig. 1 Wave pressure distribution on a vertical breakwater

The design wave height H_D is employed as the maximum wave height in a random wave train and is given as follows:

1) Action of non-breaking waves

$$H_D = 1.8H_{1/3} \tag{7}$$

where $H_{1/3}$ denotes the significant wave height at the breakwater.

2) Action of breaking waves

The design wave height is employed as the maximum wave height at the water depth h_b in recognition of the fact that the greatest wave pressure is not exerted by waves just breaking at the site, but by waves which have already begun to break at a short distance seaward of the breakwater.

The uplift pressure acts upon the bottom face of the breakwater simultaneously with the above horizonntal pressure. The uplift presssure is regarded as the triangle distribution as shown in Fig.1 and the largest uplift pressure at the front bottom is given as follows:

$$p_u = \frac{1}{2}(1+\cos\theta_i)\lambda_1\alpha_1\alpha_3 w_0 H_D \tag{8}$$

(2) Vertical breakwater

The fundamental formulas have been obtained by Goda for the vertical breakwater. Therefore, the forces exerted upon the breakwater can be calculated as $\lambda_1=\lambda_2=1$.

The wave pressure at the still water level is no more than $2.2w_0H_D$ at maximum, but hydraulic model tests indicate that the impulsive wave prssure which exceeds $2.2w_0H_D$ appears for the case of high front mound which satisfies the condition that the value of $(h-d)/h$ is around 0.6 and the front width of rubble mound is comparable to water depth. The design standard recomends to avoid the occurrence condition of impulsive force as far as possible.

(3) Breakwater covered with concrete blocks

The composit breakwater is sometimes covered with concrete blocks in order to decrease unfavarable effect of reflected wave from the breakwater. The concrete blocks placed in front of the breakwater dissipate wave energy and reduce the wave force, especially the impulsive force. The following formula of the modification factor is proposed empirically by Takahashi et al.(1990) from various hydraulic model tests:

$$\lambda_1 = \begin{cases} 1.0 & (H_D/h<0.3) \\ 1.2-2(H_D/h)/3 & (0.3\leqq H_D/h\leqq 0.6) \\ 0.8 & (H_D/h>0.6) \end{cases} \tag{9}$$

$$\lambda_2=0 \tag{10}$$

(4) Vertical slit caisson

The construction cost of the breakwater covered with concrete blocks rapidly increases as the water depth at the site becomes deep, because the necessary number of the concrete block units increases. The vertical slit caisson is often adopted in stead of the breakwater covered with concrete blocks in order to avoide increase of the cost. The wave energy is dissipated at the passage of wave through the narrow slits of the front wall and also the impulsive wave forces is reduced. The following values of modification factors have been proposed by Tanimoto et al.(1981):

$$\lambda_1=1.0 \tag{11}$$

$$\lambda_2=0$$

(12)

2.3 Stability analysis of breakwater

The stability of the breakwater is checked for the following three possible modes of failures:

1) Sliding failure

The horizontal wave force is supposed to be resisted by the friction force which is proportionate to the weight of a caisson in water. However, the weight is reduced by the action of the up-lift force upon the bottom face of the caisson. The safety factor S_F of the sliding failure is calculated as

$$S_F = f_D(W_W - U)/P_H \qquad (13)$$

where W_W and f_D represent the weight of the caisson in water and the friction factor in design, and U and P_H represent the up-lift and horizontal forces, respectively. The prsent design guide takes the value of 1.2 as the allowable safety factor. Generally the friction factor is employed as 0.6 in design.

2) Overturning failure

The horizontal and up-lift forces exert the overturning moment upon the breakwater and the weight of the caisson in water resists the moment. The safety factor S_M for the overturning failure is calculated as

$$S_M = (M_W - M_U)/M_P \qquad (14)$$

where M_W, M_U and M_P represent the moments around the heel induced by the weight of the caisson, the up-lift and horizontal forces, respectively. The design guide employs the value of 1.2 as the allowable safety factor.

3) Failure of foundation

The bearing capacity of the foundation is to be analized by means of the methodology of the foundation engineering for eccentric inclined load. A simplified technique of examining the magnitude of the pressure at the heel is often employed. The bearing pressure at the heel is to be kept below the allowable pressure. In the past the allowable prsessure was taken as the relatively small value like 40 and 50 tf/m^2, but now taken as 60 or 70 tf/m^2.

3. Computation method of sliding failure probability of a breakwater

3.1 Uncertain factors and their error characteristics for probabilistic design

As described in 2, the breakwaters in Japan are designed deterministically and the allowable safety factors introduced in the check of the stability of the beakwaters are considered to sufficiently cover the influence of the uncertain factors. However, the safety factors do not indicate the degree of safetyness of the designed breakwater. The uncertain factors included in the design and their treatment for the computation of the sliding failure probability are described bellow.

(1) Uncertanity of deepwater wave

The parameters of design wave in deepwater is determined by statistical analysis of observed or hindcasted extreme waves during more than 30 years as mentioned previously. However, the occurrence probability distribution of the extreme waves estimated as the most reliable distribution does not assure the agreement with the actual distibution, because the number of adopted wave data is restricted.

For the probabilistic design it is assumed that the error of estimated probability distribution can be expressed by the normal error function as follows:

$$p_{0e}(X_0)=\frac{1}{\sqrt{2\pi}\,\sigma_0}\exp\left\{-\frac{(X_0-\overline{X}_0)^2}{2\sigma_0{}^2}\right\} \tag{15}$$

where X_0 , $\overline{X}_0$ and σ_0 represent the wave height, the mean wave height and the standard deviation. The mean wave height and the standard deviation of the error function are assumed to have following relation with the wave height estimated from the most reliable distribution:

$$\overline{X}_0=(1+\alpha_0)X_e \tag{16}$$

$$\sigma_0=\gamma_0 X_e \tag{17}$$

where α_0 and σ_0 denote the factor of mean shift from X_e and the coefficient of variation to X_e . The reliable probability distribution is modified by the assumed error function of Eq. (15) as follows:

$$p_0(X_0)=\int_0^\infty \frac{1}{\sqrt{2\pi}\,\sigma_0}\exp\left\{-\frac{(X_0-\overline{X}_0)^2}{2\sigma_0{}^2}\right\}p_e(X_e)\,dX_e \tag{18}$$

where $p_0(X_0)$ and $p_e(X_e)$, respectively, represent the modified and original probability density functions of extreme waves in deep water.

(2) Uncertanity of water level

The highest water level of spring tide, occasionally adding the water rise induced by the storm surge corresponding to the return period of the design wave, is taken as the design water level in the present design guide, but the design wave does not always attack at the highest water level.

The storm surge is caused by the sunk-up due to the depression of air pressure and the water transport due to wind blow. The storm surge becomes severe in a broad extension of shallow water like Tokyo, Osaka or Ise bays, but it is small in the coast faced to an ocean. Therefore, the storm surge is not always necessary to consider for the design of breakwater.

The storm surge as well as waves becomes large as the wind blows strongly. Consequently, the storm surge for design corresponding to the given return period can be estimated from obseved or hindcasted data in the manner same as design wave.

The tidal level varies independently. Real tide consists of various components with different periods, but the variation of tidal level is assumed to be sinusoidal in order to simplify the tidal phenomena. The occurrence probability of the tidal level is derived under the above assumption as follows:

$$p_\zeta(\zeta)=1/\left[\pi\zeta_a\sqrt{1-\{(\zeta/\zeta_a)-1\}^2}\right] \qquad (0\leqq\zeta\leqq\zeta_H) \qquad (19)$$

where ζ and ζ_a denote the tidal level and the amplitude of the variation of tidal level. The probability density of the tidal level expressed by Eq. (19) is shown in Fig. 2 where the occurrence probability is large at the low and high tidal level.

(4) Uncertanity of wave transormation

The parameters of the design wave are changed by the phenomena of wave refraction, shoaling and breaking during its propagation to the site of the breakwater. The wave transformation is computed numerically and the result of the computation can be expressed as follows:

$$X_{me}=B_{m1}X_0+B_{m2}h \qquad (20)$$

where X_{me} denotes the computed significant wave height, and B_{m1} and B_{m2} represent the transfer coefficients related to the wave height in deep water and to the water depth at the site, respectively. The values of B_{m1} and B_{m2} depend upon the parameters of the deep water wave and the condition of the sea bottom topography.

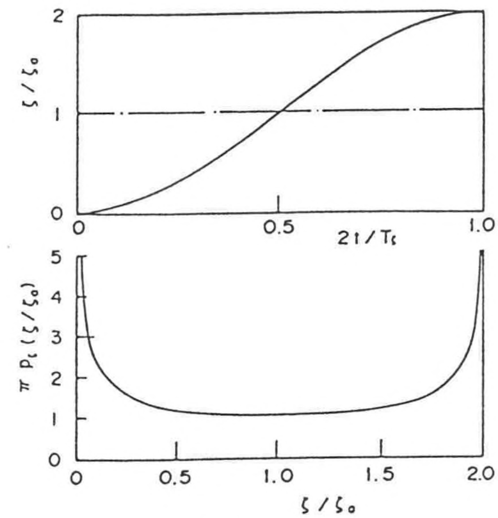

Fig. 2 Occurrence probability of tidal level

The computed wave height does not always agree with actual wave height because of the assumputions in the computation. The occurrence probability density of the significant wave height at the site is modified under the consideration of the error of the computation and is given as

$$p_m(X_m)=\int_0^\infty \frac{1}{\sqrt{2\pi}\,\sigma_m}\exp\left\{-\frac{(X_m-\overline{X}_m)^2}{2\sigma_m{}^2}\right\}p_0(X_0)\,dX_0 \qquad (21)$$

where the error of the computation is assumed to be expressed as the normal error function and the mean value and the standard deviation are assumed as follows:

$$\overline{X}_m=(1+\alpha_m)X_{me} \qquad (22)$$

$$\sigma_m=\gamma_m X_{me} \qquad (23)$$

where α_m and γ_m denote the factor of mean shift from X_{me} and the coefficient of variation to X_{me}. For the negative and positive values of α_m the actual wave height is smaller and larger than the computed one in average, respectively.

The wave forces are evaluated by the maximum wave but not by the significant wave, as described previously. The maximum wave height X_{Me} can be expressed by the following equation:

$$X_{Me}=B_{M1}X_m+B_{M2}h \qquad (24)$$

where B_{M1} and B_{M2} denote the transfer coefficients from the significant wave height to the maximum one. These values are given as $B_{M1}=1.8$ and $B_{M1}=0$ at the place so deep as wave breaking does not occur, but generally the values depend upon the parameters of the significant wave, the sea bottom slope and the depth at the site. The occurrence probability density function of the maximum wave height is modified under the consideration of the estimation error of Eq. (24) and is given as

$$p_M(X_M)=\int_0^{\infty}\frac{1}{\sqrt{2\pi}\,\sigma_M}\exp\left\{-\frac{(X_M-\overline{X}_M)^2}{2\sigma_M^2}\right\}p_m(X_m)\,dX_m \tag{25}$$

where the error of the estimation is assumed to be expressed as the normal error function and the mean value and the standard deviation are assumed as follows:

$$\overline{X}_M=(1+\alpha_M)X_{Me} \tag{26}$$

$$\sigma_M=\gamma_M X_{Me} \tag{27}$$

where α_m and γ_m denote the factor of mean shift from X_{Me} and the coefficient of variation to X_{Me} .

(4) Uncertanity of wave forces

As desribed previously, two types of wave forces act upon the breakwater; one is the horizontal force exerted upon the front face of a caisson and the other is the up-lift force exerted upon the bottom face. These wave forces can be expressed as

$$P_{He}=B_P X_M \tag{28}$$

$$U_e=B_U P_{He} \tag{29}$$

where P_{He} and U_e represent the horizontal and uplift forces, respectively, and B_P and B_U denote the transfer coefficients from the wave height to the horizontal force and from the horizontal force to the uplift force, respectively. As shown in Fig. 3 the coefficient of B_P varies with the wave height, but the coefficient of B_U is almost constant. Since the formulas of the wave forces are empirically obtained through hydraulic model tests, they must be considered to contain some estimation error. If the error is assumed to be expressed as the normal error function, the occurrence probability density of the horizontal force is derived as

$$p_P(P_H)=\int_0^{\infty}\frac{1}{\sqrt{2\pi}\,\sigma_P}\exp\left\{-\frac{(P_H-\overline{P}_H)^2}{2\sigma_P^2}\right\}p_M(X_M)\,dX_M \tag{30}$$

where $\overline{P}_H$ and σ_P represent the mean value and the standard deviation in the error function, and they are assumed as follows:

$$\overline{P}_H=(1+\alpha_P)P_{He} \tag{31}$$

$$\sigma_P=\gamma_P P_{He} \tag{32}$$

where α_P and γ_P represent the factor of mean shift and the coefficient of variation of the horizontal force.

(5) Uncertanity of friction factor

The breakwater withstands the horizontal wave force by the friction force between the caisson and the rubble mound. The value of 0.6 is employed as the friction factor in desi gn, but it is empirically given through various experiences of design until now. Therefore, the friction factor is considered to scatter around the value employed in design. The scattering of the friction factor is assumed to be formulated as the following normal error function:

$$p_f(f)=\frac{1}{\sqrt{2\pi}\,\sigma_f}\exp\left\{-\frac{(f-\overline{f})^2}{2\sigma_f^2}\right\} \tag{33}$$

where $p_f(f)$ represents the occurence probability density function of the friction factor, and $\overline{f}$ and σ_f denote the mean value and the standard deviation of the friction factor, respectively. The values of $\overline{f}$ and σ_f are assumed to have the following relationship with the friction factor in design:

$$\overline{f}=(1+\alpha_f)f_D \tag{34}$$

$$\sigma_f=\gamma_f f_D \tag{35}$$

where α_f and γ_f represent the factor of mean shift and the coefficient of variation from the friction factor f_D in design.

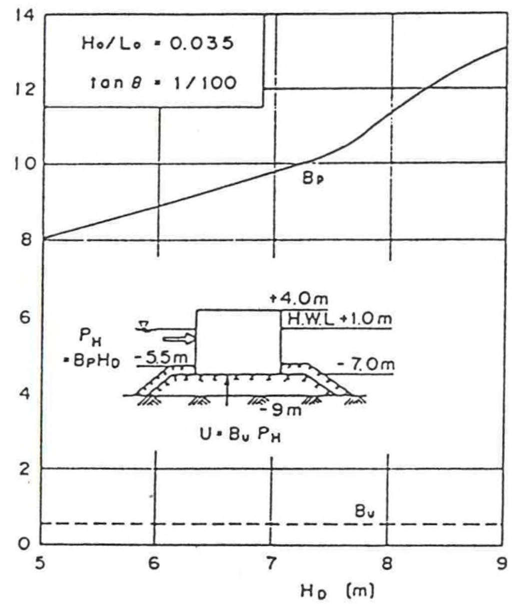

Fig. 3 Transfer coefficients of wave forces

3.2 Estimation of sliding failure probability

The breakwater will slide for the condition that the horizontal wave force exceeds the resistance friction force. Even if the impulsive horizontal force exceeds the friction force, the sliding failure, however, does not always occur because of the very short time action of the impulsive force. The Goda's formulas of the wave forces have been presented to calculate the force which would be effective on sliding failure. Therefore, the breakwater should be considered to always slide when the horizontal force estimated by the Goda's formula exceeds the resistance friction force. When a horizontal wave force acts upon the breakwater, the limiting friction factor for slide is caluculated as follows:

$$f<f_0=P_H/\{W_B+w_0(\eta_R-\eta_{SL}-\eta+\zeta_H-\zeta)-B_UP_H\} \tag{36}$$

where W_B and w_0 represent the caisson weight in water per unit length and the unit weight of sea water, and η_R, η and η_{SL} denote the magunitude of the storm surge of the return period, the magnitude of a storm surge, and the sea level rise in future. If the actual friction factor is smaller than the value of Eq.(36), the breakwater is considered to slide. As shown in Fig.4 the probability of the sliding failure at the horizontal wave force of P_H and the tidal level of ζ is obtained as

$$P_{SP\zeta}=\int_0^{f_0}\frac{1}{\sqrt{2\pi}\,\sigma_f}exp\left\{-\frac{(f-\overline{f})^2}{2\sigma_f^2}\right\}df \tag{37}$$

The probability of the sliding failure of the breakwater is computed as

$$P_S=\int_0^{\zeta_H}\int_0^{\infty}\int_0^{f_0}p_f(f)\,p_P(P_H)\,p_\zeta(\zeta)\,df\,dP_H\,d\zeta \tag{38}$$

where P_S represents the probability of the sliding failure of the breakwater.

Supposing that the occurrence probability distribution is determined by using N extreme wave data during K years, an extreme wave in the group of the distribution averagely appears in every K/N years. Therefore, the encounter probability during the life time of a caisson T_L can be obtained as

$$P_{ES}=1-(1-P_S)^{qT_L} \tag{39}$$

where $q=N/K$.

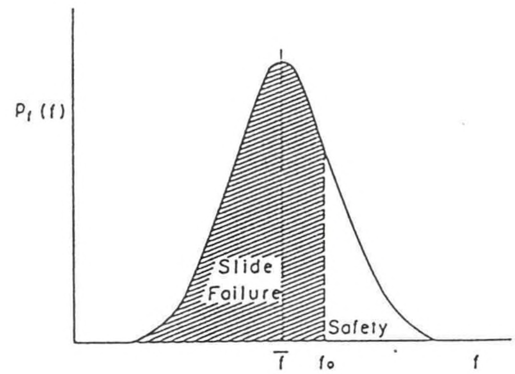

Fig. 4 Region of friction factor of sliding

The frequency of the sliding failure of the breakwater during the life time can be calculated by the following equation:

$$N_{ES}=qT_LP_S \tag{40}$$

Figure 5 shows the flow of the estimation of the sliding failure probability of the breakwater designed according to the present design guide in Japan.

4. Empirical Estimation of Error Function for Computation of Sliding Failure Probability

4.1 Design wave in deep sea

The estimation error cannot be determined from field observed or hindcasted wave data because the population of extreme waves cannot be specified. Goda (1988) has discussed the reliable range of the estimated design wave height by the statistical analysis of numerically simulated extreme waves in a given population. Refering the results of his study, we adopt the values of 0 and 0.1 as the factor of mean shift and the coefficient of variance.

4.2 Wave transformation in shallow sea

As described previously, the energy balance and mild slope equations are generally used for the computation of wave transformation. The estimation errors of these equations are

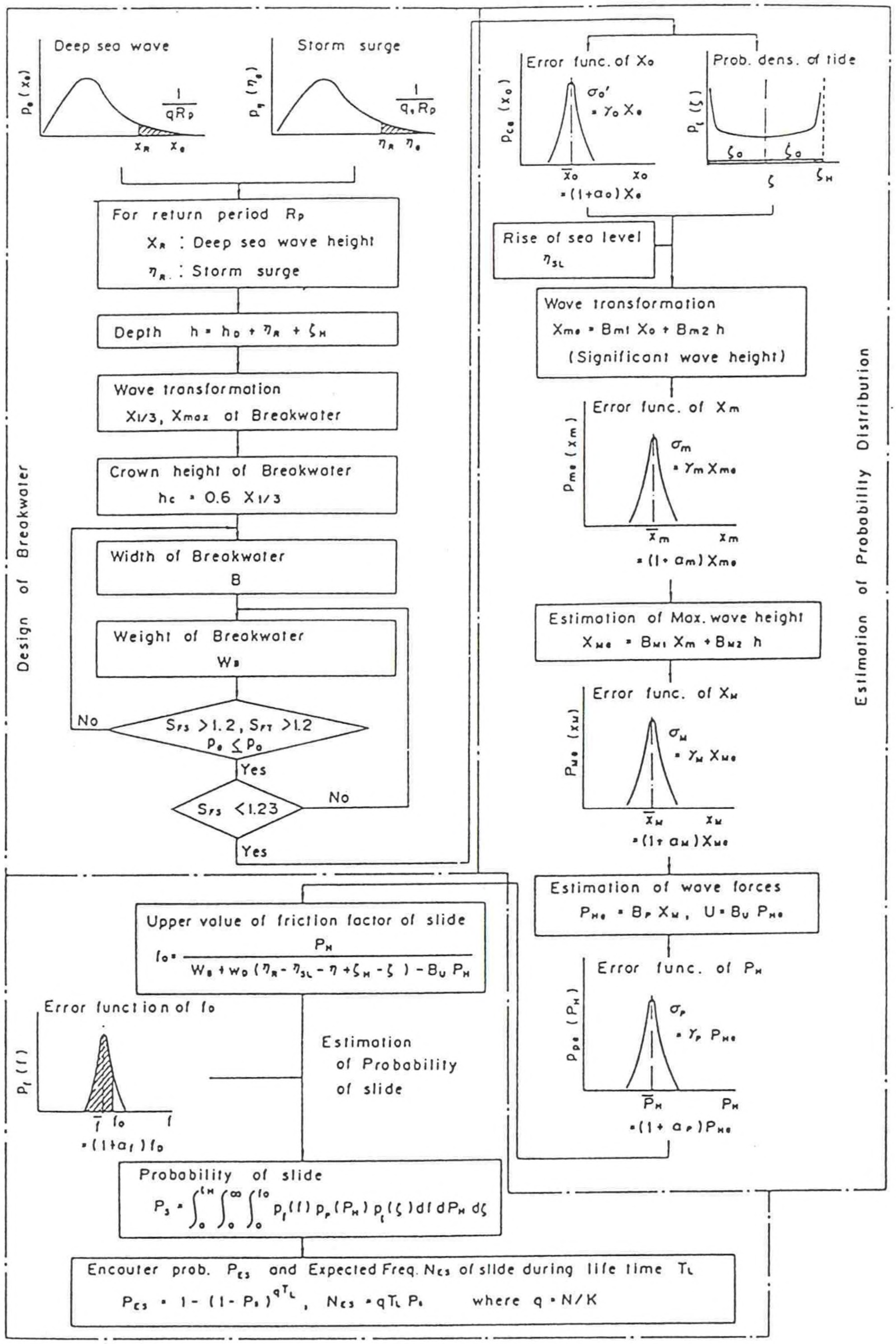

Fig. 5 Computation flow of probability of sliding failure of breakwater

investigated by the comaprison with hydraulic model test and field observation data. The mean value and the standard deviation of the error function are determined by the results of the investigation.

Figure 6 shows the normalized histogram of the estimation error and the estimated normal error function for the energy balance equation. The horizontal axis indicates the ratio of experimental value to computed one. The mean value and standard deviation of the ratios are estimated as 0.92 and 0.04, respectively. The computation overestimates wave height by 8% in average, and the standard deviation is small. Thus the energy balance equation estimates wave height with a practical accuracy.

Figure 7 shows the normalized histogram and the estimated error function for the mild slope equation. The horizontal axis indicates the ratio same as in Fig. 6. The meam value and the standard deviation of the ratios are 0.94 and 0.15. Though the mean value is almost same as that in Fig. 6, the standard deviation is larger than that in Fig. 6. The increase of the standard deviation is caused by the adoption of field observation data for the comparison.

The estimation error of the Goda's formula of wave transformation due to wave breaking described in 2.2 is also investigated by using the field obsevation data by Goda (1975) and the experimetal data by Tanimoto et al. (1984). The results shows that $\alpha_M = -0.13$ and $\gamma_M = 0.09$.

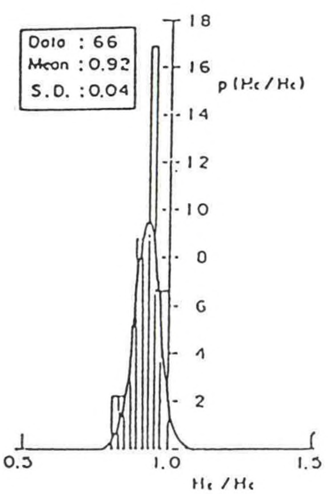

Fig. 6 Estimation error distribution of energy balance equation

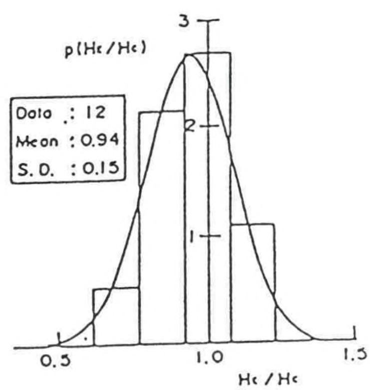

Fig. 7 Estimation error distribution of mild slope equation

4.3 Wave forces

The estimation error of the wave force formulas shown in 2.2 is also investigated by refering various experimental data. The investigation is made in the manner same as that for the wave transformation.

(1) Vertical caisson

The estimation error of the Goda's formulas is shown in Fig. 8 as an example. The figure shows that the mean ratios of the wave force is 0.91. Thus the formulas estimate wave force larger than the experimental ones by about 10% in average. The standard deviation of the ratios is 0.19. The normalized histogram can be well approximated by the normal error function indicated by the solid line. Referring the comparison results with other experimental data carried by Tanimoto et al. (1976, 1984), the values of the factor of mean shift and the standard deviation of the normal error function are determined as $\alpha_p=-0.09$ and $\gamma_p=0.17$.

(2) Caisson covered with concrete blocks

As described previously, the wave forces acting upon the caisson covered with concrete blocks are estimated by the Goda's formulas modified by the introduction of the reduction factors. Figure 9 shows the estimation error of the formulas. The formulas estimate the wave force larger than the experiments by about 20%. The standard deviation of the wave force ratios is 0.06. Combining other experimental data, the values of α_p and γ_p are determined as -0.16 and 0.10, respectively.

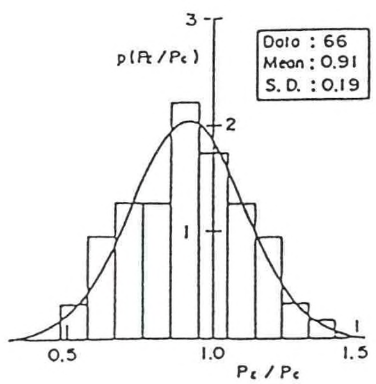

Fig. 8 Estimation error distribution of wave force on vertical breakwater

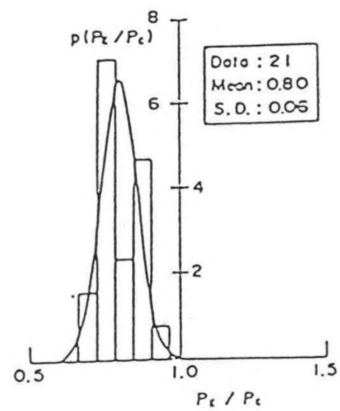

Fig. 9 Estimation error distribution of wave force on caisson covered with concrete blocks

(3) Vertical slit caisson

Tanimoto et al. (1976) carried out experiments for various shapes of slit. The estimation error for perforated wall is shown in Fig. 10 as an example. Though the estimation error is different with every shape, the values of α_p and γ_p are averaged because of the small difference among the different shapes. The mean values of α_p and γ_p become -0.16 and 0.10.

4.4 Friction factor

The scattering of the friction factor of a caisson on a rubble mound is investigated through the model tests which were performed for near prototypes of caissons by Morihira et al. The probability distribution of the friction factors is shown in Fig. 11, where the friction factors in the horizontal axis are indicated by the ratio to the value of the design factor. The mean and standard deviation of the ratios are obtained as 1.06 and 0.16, respectively. The distribution shows that 35% of friction factors is less than the design value of 0.6 though the mean exceeds the value in design.

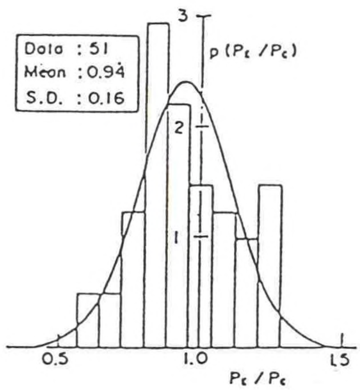

Fig. 10 Estimation error distribution of wave force on vertical slit caisson

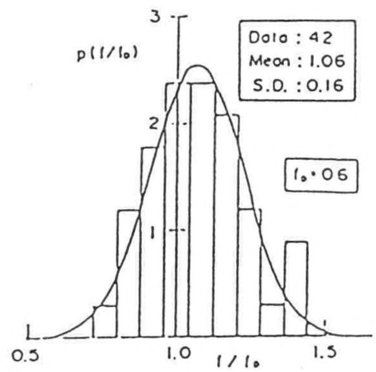

Fig. 11 Distribution of friction factor

5. Computation of Sliding Failure Probability of Breakwater in Present Design

5.1 Computation conditions

The occurrence probability distribution of extreme waves in deep sea in every year is assumed to be expressed by the Weibull distribution shown in Fig. 12. The assumption of the return period of 50 years gives the design wave height indeepwater as 6.5m. To simplify the computation condi-tion, it is assumed that the bottom slope is uniform and the wave attacks the breakwater perpendicularly. The Goda's formulas is employed for the wave transformation due to breaking by neglecting the effect of the refraction.

The water depths at the breakwater and above the mound, and the bottom slopes for the computation are sumerized on Table 1. The width and height

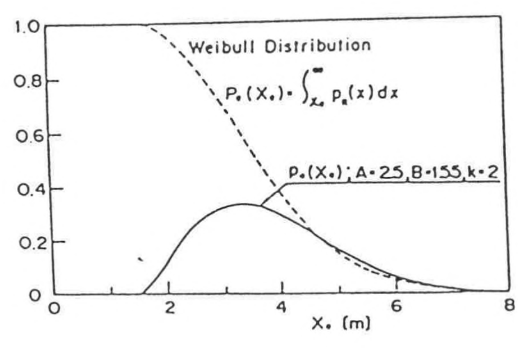

Fig. 12 Deep water distribution for computation

of the caisson are calculated as the rounded values in every 0.5m as taken in the practical design. The life time of the breakwater is employed as 50 years same as the return period. The amplitude of tide in the computation is assumed as 0.75m and storm surge is not taken into account.

The the values of α and γ in the estimation error are given as shown on Table 2. The values in the parentheses on Table indicate the values rounded toward the dangerous side and are also used for the computation of the sliding failure probability.

Table 1 Settlement condition of breakwater

Items	α	γ
Deep water wave	0	0.10
Wave transf.	-0.13(-0.10)	0.09(0.10)
Wave force	-0.09(-0.05)	0.17(0.20)
Friction factor	0.06(0.05)	0.16(0.15)

Table 2 values of α and γ for computation

h[m]	h'[m]	d[m]	tanθ
5	3.5	2	1/10
10	8	6.5	1/20
15	11	9.5	1/50
20	15	13.5	1/100

5.2 Encounter probability of sliding failure

The encounter probabilities during the life time of 50 years are computed for the vertical breakwater, the caisson covered by concrete blocks and vertical slit caisson.

(1) Vertical breakwater

Figure 13 shows the variations of the encounter probabilities of the sliding failure of the vertical breakwater. The variations of the encounter probabilities are computed in every water depth and bottom slope shown in Table 1. In the figure the black and white circles indicate the encounter probabilities computed for the estimated values themselves and their rounded ones of α and γ, respectively.

The encouter probabilities for the rounded values of α and γ are larger by 0.1 to 0.2 than those for the estimated values, but their variations to the water depth show almost same features between the corresponding slopes. The encounter probabilities for the estimated values are almost same even if the bottom slopes are different except the slope of 1/10.

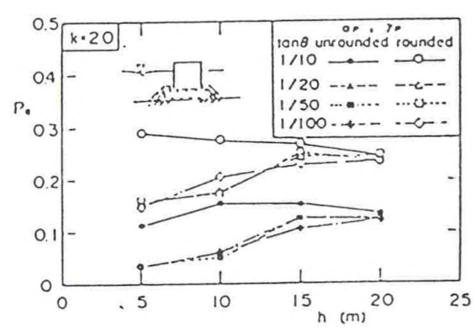

Fig.13 Encounter probability of sliding failure of vertical breakwater

The probabilities gradually increase from 0.03 to 0.12 for the milder slopes than 1/20 as the water depth at the site of the breakwater becomes deep. The difference of the encounter probabilities between the slope of 1/10 and the other slopes is large at the shallow depth of 5m, but the differnce becomes small as the water depth becomes larger. The difference vanishes at the water depth of 20m. Thus the encounter probability has different value depending on the bottom slope and the water depth at the site. This means that the vertical breakwa-ters are not designed with a same degree of stability and the degree of their stability isdiffernt in the design condition.

(2) Caisson covered with concrete blocks

Figure 14 shows the variations of the encounter probabilities for the caisson covered with concrete blocks. The encounter probabilities for the caisson are 0.01 at the water depth of 5m and 0.05 at the depth of 20m for the estimated values of α and γ . Thus these probabilities are small compared with those for the vertical breakwaters in Fig.13, because the values of α_p and γ_p are smaller than those for the vertical breakwater.

If the waves larger than the design wave attacks the caisson, some concrete blocks would be moved and consequently the wave forces larger than those cal-culated by the formulas would be exerted upon the caisson. In the com-putation of the probability, the con-crete blocks are assumed to be stable even if the excessive waves act upon the concrete blocks. It is very impor-tant for more accurate estimation of the encounter probabilities to formu-late the wave forces in the state of the movement of some concrete blocks.

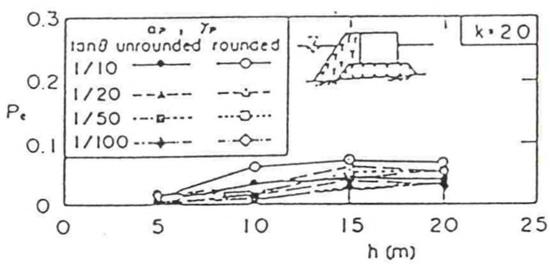

Fig.14 Encounter probability of sliding failure of caisson covered with concrete blocks

(3) Vertical slit caisson

Figure 15 shows the variations of the encounter probabilities for the verti-cal slit caisson. The encounter proba-bilities gradually increase as the water depth at the site becomes deep. The probabilities for the slope of 1/10 are little bit larger than those for the slope milder than 1/20 around the depth of 10m to 15m. The probabilities for the rounded values of α_p and γ_p are larger than those for the estimated values by about 0.1. The probabilities

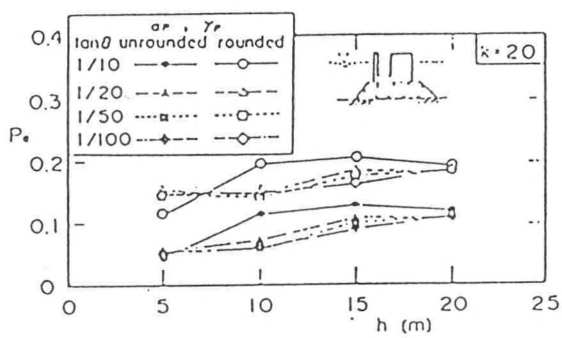

Fig.15 Encounter probability of sliding failure of vertical slit caisson

for the rounded and estimated are no more than 0.2 and 0.1. The probabilities for the caisson are almost same as those for the vertical breakwater.

6. Conclusions

The following main conclusions can be drawn from the present study on the probabilities of the sliding failure of breakwaters designed according the Japanese design guide:

1) The computation method for the estimation of sliding failure probability of a breakwater has been developped for probabilistic design of breakwater.
2) The estimation errors of deepwater design wave, wave transformation, wave force formulas and design friction factor are introduced into the computation and they are assumed to be expressed by the normal error distribution. Futhermore, the uncertain tidal level at the attack of design wave and the sea level rise in future can also be considered in the computation.
3) The shapes of the estimation errors are evaluated through the comparison with the data of the hydraulic model tests and field observations. The estimation errors were determined as the normal error function by calculating the tmean and standard deviation statistically.
4) The encounter probabilities of various types of breakwaters designed according to the present design guide are computed in various water depths and bottom slopes. The encounter probabilities in the present design vary with the conditions of the water depth and the slope. This means that present breakwaters are not designed with the same degree of safetyness.
5) The caisson covered with concrete blocks are designed with higher stability than the vertical breakwater and the vertical slit caisson under the condition without the movement of concrete blocks.

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Creation of Calm Sea Area by New-Type Offshore Breakwater

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Takaaki UDA 2)
Mamoru KOARAI 3)

I. INTRODUCTION

Because of the geography of Japan, a large part of Japan's population and property is centered in coastal zones subject to harsh natural conditions such as storm surges, tsunamis and beach erosion. The Ministry of Construction has been constructing shore protection facilities to protect both people and property from natural disasters due to these harsh conditions.

Recently, with the increase in leisure time, the use of resorts has expanded, and issues related to the development of such resorts are now frequently discussed. Under these conditions, the need for coastal recreation facilities is increasing, and therefore many environmental projects have been undertaken throughout Japan. However, except for the use case of the development of inner bay areas, the use of coastal areas without human intervention is difficult due to high waves and littoral transport in the area facing the open sea. Hence, the development of structures controlling waves, nearshore currents and littoral transport is necessary. These coastal areas are also the site prone to certain types of natural disasters due to beach erosion and storm surges. Therefore, the shore protection is

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extremely important. If the above-mentioned structures can be used to protect the shoreline, they will serve a dual purpose as resort facilities and as protection facilities against natural disasters.

Under these circumstances, the Ministry of Construction of Japan has launched the Marine Multipurpose Zone (MMZ) concept and is promoting the effective use of seashores facing the open sea. The major project in this concept is the development of effective permeable offshore breakwaters which will be constructed at depths between 10 and 20m to create a calm wave zone. This paper explains the development of a calm coastal region in terms of offshore breakwaters.

II. OUTLINE OF MARINE MULTIPURPOSE ZONE (MMZ) PROJECT

The Marine Multipurpose Zone (MMZ) project is one of the future shore protection project concepts. By constructing large-scale offshore breakwaters with the function of dissipating wave energy at a depth of 10-

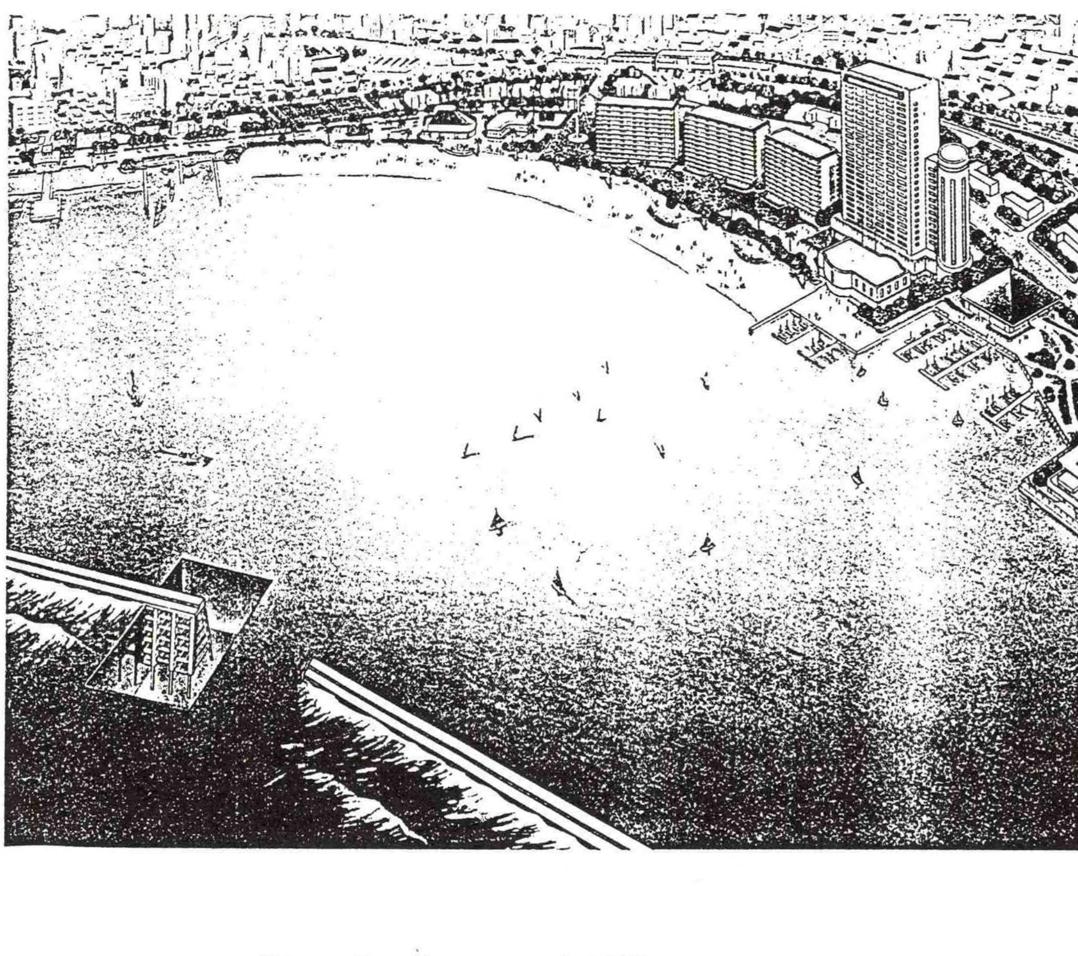


Fig. 1. Image of MMZ project

20m, a wide and calm sea area is created between the structures and the shoreline. Also, we can use the coastal zone facing the newly created calm area for a variety of purposes.

A conceptual drawing of the MMZ project is shown in Fig. 1, and Fig. 2 shows the effects of the MMZ project as a model of the difference between before MMZ and after MMZ. The predicted effects are shown below.

1) Large-scale offshore breakwaters dissipate the wave energy and stabilize the beach. The permeable structures function to maintain good water quality.
2) These structures create a calm sea area which can be utilized for purposes such as marine sports and marine culture. These structures are expected to provide an artificial environment for fish.
3) The beach stabilized by these structures is widened by the progress of the shoreline. Multipurpose use of this area is greatly promoted, and a good waterfront environment is created.
4) The land area created by the progress of the shoreline has the characteristics of a waterfront in that it can be used for a residential area, roads, parks and a recreation area.

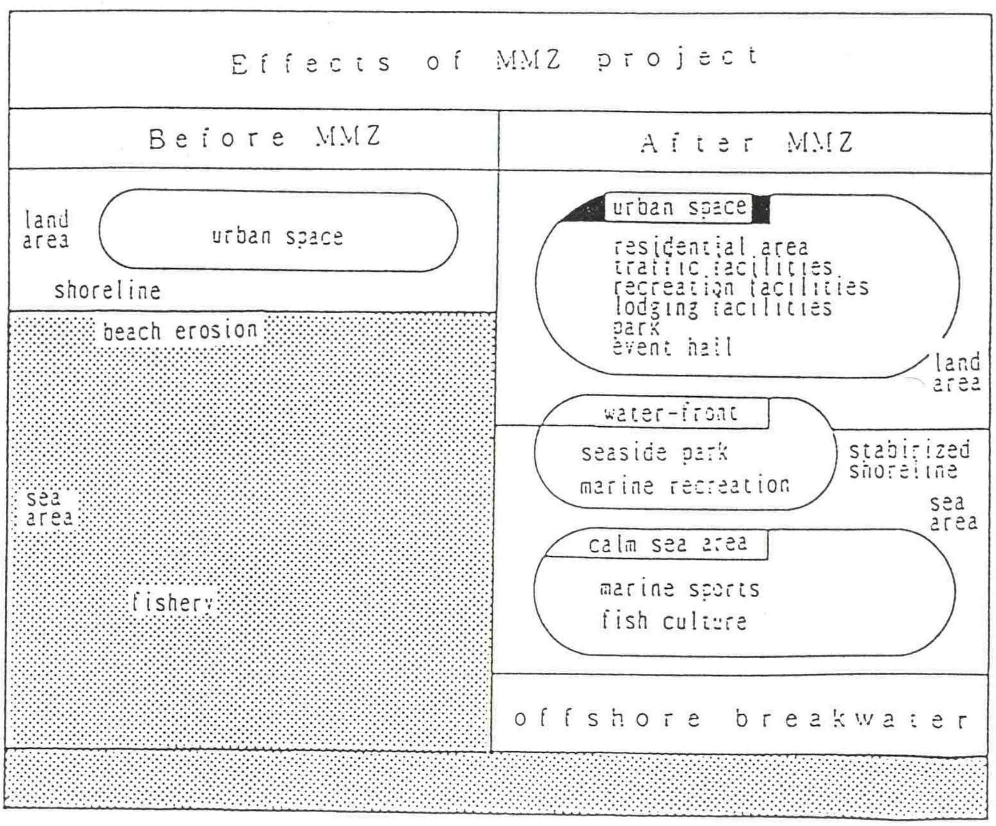


Fig. 2. Effects of MMZ project

III. DEVELOPMENT OF LARGE-SCALE OFFSHORE BREAKWATERS

The research and development for the MMZ project has been carried out by the Ministry of Construction as a project entitled the "Development of Offshore Technology for the Creation of a Marine Multipurpose Zone (MMZ)." The project has three main themes: the "development of offshore structure," the "development of material and maintenance technology," and the "protection and utilization of marine space." The study of offshore breakwaters is jointly conducted by the Public Works Research Institute and private enterprises. In this section, eleven large-scale offshore breakwaters under consideration are described (Fig.3).

1. Slit-Type Structure with Horizontal Plates

This structure consists of multiple vertical slits and horizontal slit plates and is installed near the surface of the water when the sea is calm. It is constructed of steel piles and precast concrete blocks. In addition to the wave dissipation effects due to the energy dissipation and reflection by slits, the waves are broken by horizontal plates during high tides, and the wave energy is attenuated. Depending on the combination of the gap ratios of each slit, the structure can be classified into one type whose function depends more on the function of the horizontal plate and another type whose function depends more on the vertical slits.

2. Multislit Structure

This structure is constructed of piles and precast blocks in the same way as in the case of the slit-type structure with horizontal plates. However, in this structure, there are no horizontal plates. By gradually decreasing the vertical slit ratios from the offshore side, the transmission waves and reflected waves are reduced, and the waves are effectively dissipated.

3. Jacket-Type Structure With H-Shaped Plate

In this structure, two permeable vertical plates and a permeable horizontal plate are combined in the H-shape. Wave dissipation effects are created by the energy dissipation arising from the reflection of waves through the permeable plates and the energy dissipation of waves passing through gap sections. The upper section of the structure consists of steel-framed reinforced concrete jackets, and the lower portion consists of steel jackets. The structure is fixed to the sea bed with steel piles piercing through the pier section of the upper and lower sections.

4. Slit Caisson Structure with Permeable Horizontal Boards

This structure is a low-top caisson coastal structure consisting of frontal, middle and rear walls with slits and top plates. The energy dissipation obtained by slits and low-top structure is utilized for wave breaking, and the waves are dissipated. The pile method and self-weight method are available as means of securing the structure, and the appropriate method is selected on the basis of the wave and ground conditions of the installation area.

5. Sloped Plate Offshore Breakwater

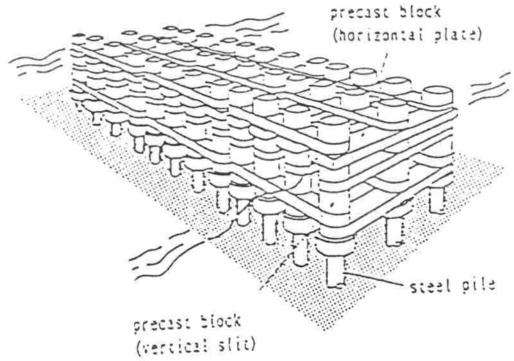
The breakwater is constructed of a partially immersed sloped plate and supporting piers. The waves are dissipated by forced waves breaking on the sloped plate. The support legs are made of steel-jacket-type structures, and the plate and the legs are constructed on land. The legs are fixed to the ground by the piercing piles. When the depth of the water is between 10 and 20m, the wave dissipation effect is independent of the dimensions of the sloped plates. In particular, for incident waves of short period, the permeability and reflection percentage can be decreased.

6. Swash-Plate-Type Submerged Breakwater

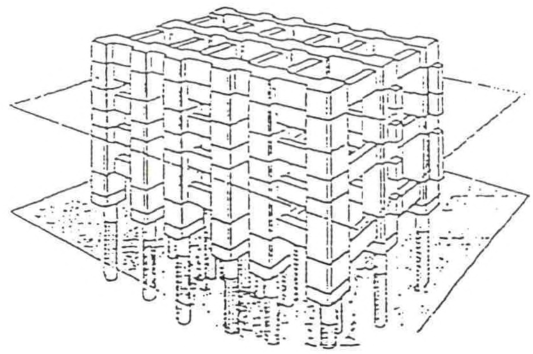
The concrete caisson structure of the submerged-bank structure is characterized by a top plate (swash plate) and ducts and sills. The combination of forced waves breaking on the tilted plate, enhancement of energy dissipation by the protrusion on the tilted plate, and a function by which a portion of the shoreward flow on the tilted plate enters the sills and ducts via the opening of the tilted plate causes wave dissipation. Therefore, this structure has a wave dissipation effect for long wavelengths which is superior to that of submerged breakwaters with blocks of different sizes, and the size of the cross section of the breakwater can be decreased.

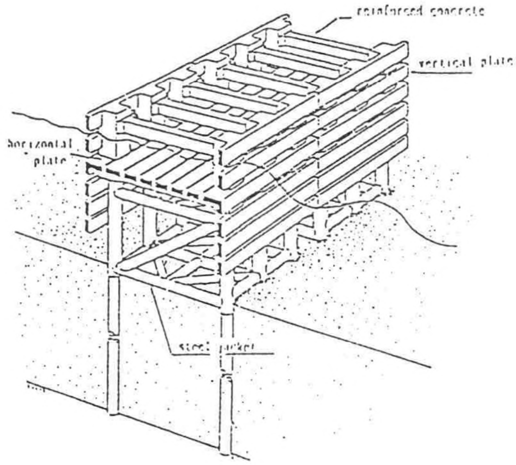
7. Double-Permeable Submerged Breakwater

This submerged structure consists of two parallel submerged permeable breakwaters which contain different sizes of blocks in slit spacing. The top of the onshore submerged bank is arranged close to the surface of the water, and that of the offshore side is set lower than

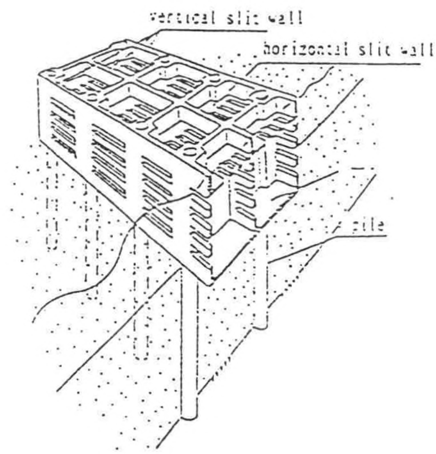


(1) Slit-Type Structure
with Horizontal Plates

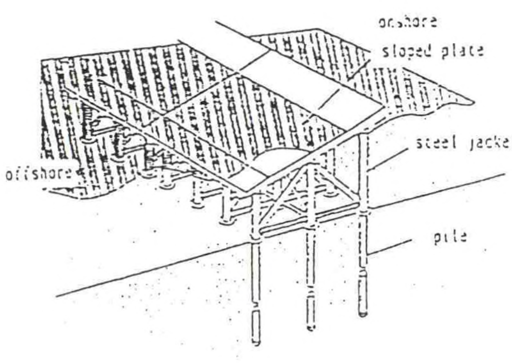

(2) Multislit Structure



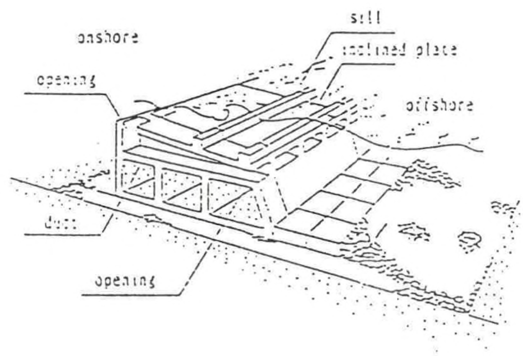
(3) Jacket-Type Structure
with H-Shaped Plate



(4) Slit Caisson Structure
with Permeable Horizontal Bords

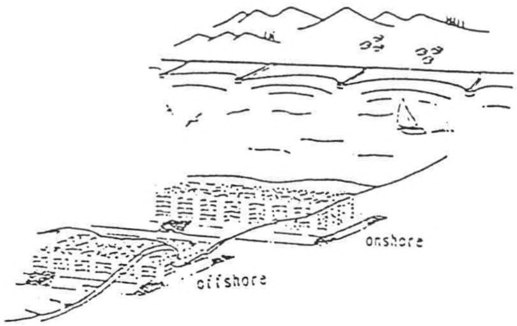


(5) Sloped Plate Offshore Breakwater

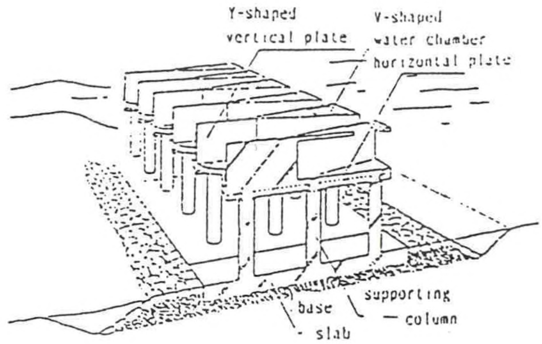


(6) Swash-Plate-Type
Submerged Breakwater

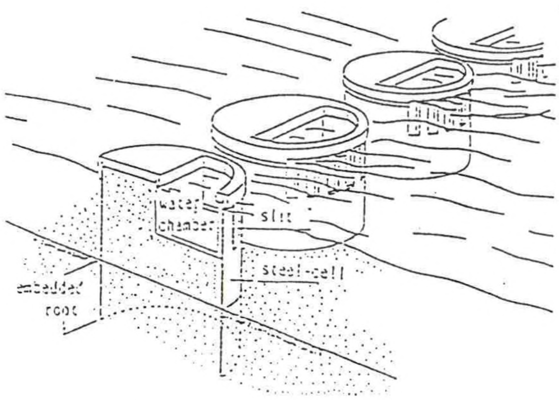
Fig. 3 Structures under consideration (1)



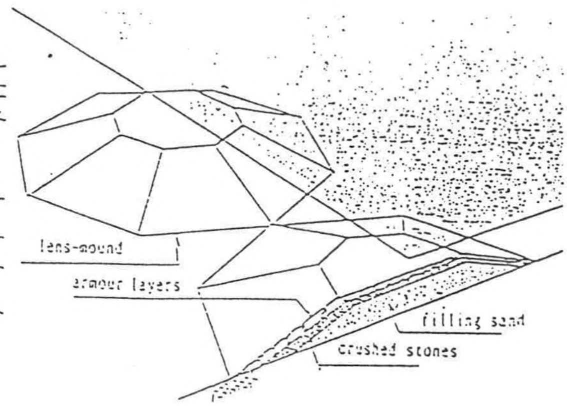
(7) Double-Permeable
Submerged Breakwater



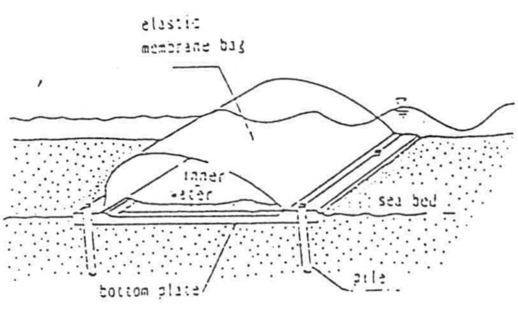
(8) Compound Wave
Dissipation Structure



(9) Embedded Steel-Cell Structure



(10) Lens Mound



(11) Flexible Mound

Fig. 3. Structures under consideration (2)

that of the onshore top. The offshore-side submerged breakwater provides forced wave breaking, and the onshore side submerged breakwater provides energy dissipation. Also, the interference effect is generated between the two breakwaters. The combination of these effects produces the overall wave dissipation effect.

8. Compound Wave Dissipation Structure

The upper section of the structure consists of Y-shaped vertical and horizontal plates, and the lower supporting section consists of supporting columns and base slab. The wave energy is converted to vortices and flow energy by the horizontal plates, horizontal slits, Y-shaped vertical plates and V-shaped water chambers. Thus, wave dissipation effects for incident waves with a wide range of periods can be provided. The structure is assembled on land and is towed to the appropriate site.

9. Embedded Steel-Cell Structure

This structure consists of linearly arranged cylindrical steel cells. Due to the reflection by the cells and flow compression between the cylinders, the basic wave dissipation is produced. Furthermore, by arranging vertical slits at the upper portion of each cylinder, the wave dissipation effect is improved. The steel cells can be hammered into the ground by the synchronized operation of multiple vibrohammers (root-embedded steel-cell procedure).

10. Lens Mound

The lens mound is a submerged spherical breakwater; wave dissipation is achieved by diffracting and focusing incident waves. The breakwater is a structure consisting of crushed stones, inner medium and an armor layer and is constructed to resemble an artificial reef. Since the structure is in the water, the reflection can be reduced and does not affect the view. Also, since the structure is similar to that of a natural reef, the structure may serve as a gathering place for fish.

11. Flexible Mound

The flexible mound is an underwater semicylindrical structure whose envelope is filled with sea water. The interference of incident waves and waves of the structure generated by the incident waves causes energy dissipation and wave dissipation. The top portion of the structure can be immersed relatively deep into the water, and the structure is soft. This structure interferes little with marine traffic.

IV. CONSTRUCTION OF NEW-TYPE OFFSHORE BREAKWATER ON A REAL COAST

To evaluate the effectiveness of new-type offshore breakwaters on a real coast, the Ministry of Construction has been experimentally constructing slit-type offshore breakwaters on the Suruga Coast in Shizuoka Prefecture.

In this chapter, we briefly summarize this experimental construction and the first practical use of Flexible-Mound.

1. PBS offshore breakwater on the Suruga Coast in Shizuoka Prefecture.

The Suruga Coast is located at western shore of Suruga Bay, its total length is 18km from Yaezu-city to Haibara-cho, Haibara-gun (Fig.4). On this coast, coastal protection works of sea wall, wave dissipating works and groins, have been advanced as the project by Ministry of Construction since 1964.

But this coast is typical erosional beach in Japan, especially at the coast neighboring Ohigawa-Port, the recession of shoreline attained to over 100m in 10 years.

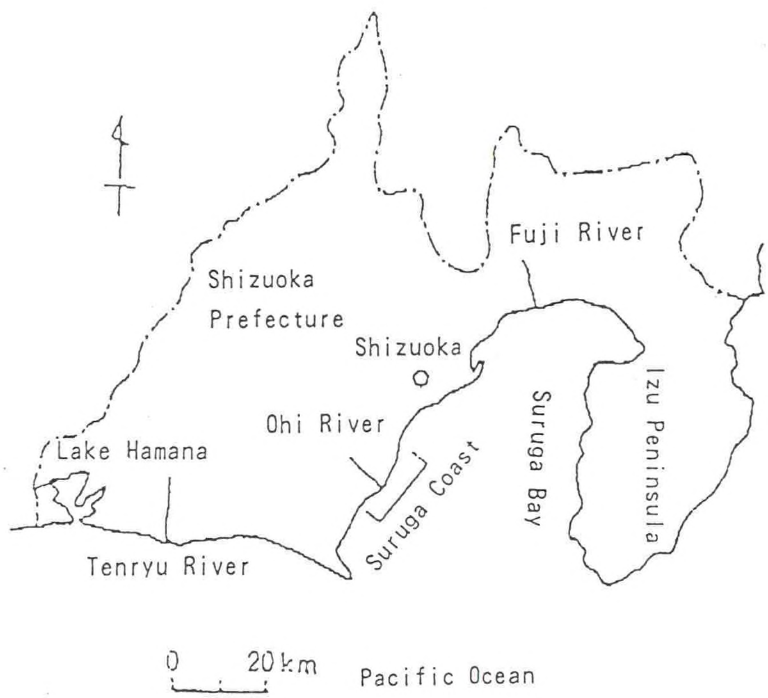


Fig. 4. Location of the Suruga Coast

For shore protection against erosion, the construction of PBS (Piles and Blocks Structure) offshore breakwaters began in 1987. The reasons to adopt new-type offshore breakwaters are as follows:

① Since the seabed slope is very steep (1/7), it is difficult to maintain conventional detached breakwater.

② It is expected to create wide calm sea area behind new-type offshore breakwater at more deep sea area, compared with conventional detached breakwater.

③ New-type offshore breakwater is expected to have the function as a fish reef.

One PBS offshore breakwater was completed in 1990, and the second breakwater is now under construction (Fig.5). Calming of waves due to the installation of the structure has been observed at the beach, and the shoreline has gradually advanced (Fig.6). The installation is also expected to be beneficial in attracting fish.

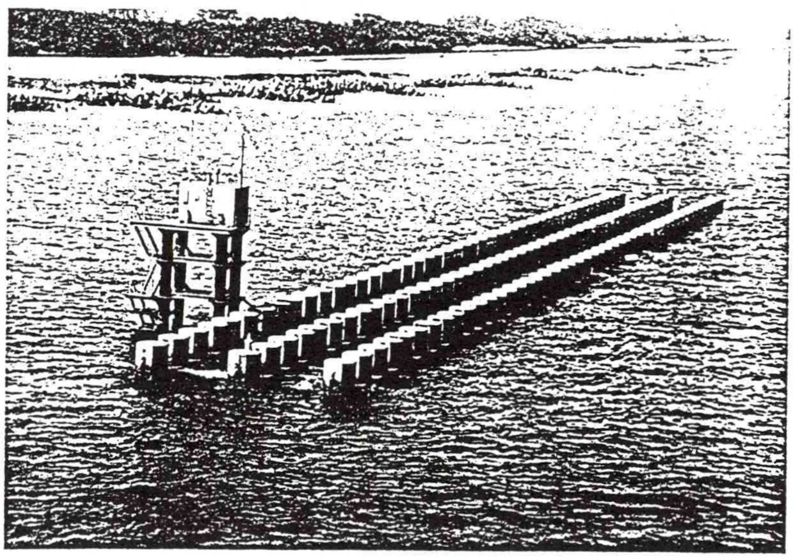


Fig. 5. Slit-type large-scale offshore breakwater (PBS method); the Suruga Coast

2. Flexible-Mound at the HOUSE TENBOS in Nagasaki Prefecture.

Flexiblel-Mound was constructed at the mouth of the harbor in 1991, as part of the improvement of HOUSE TENBOS, in Sasebo-city, Nagasaki Prefecture.

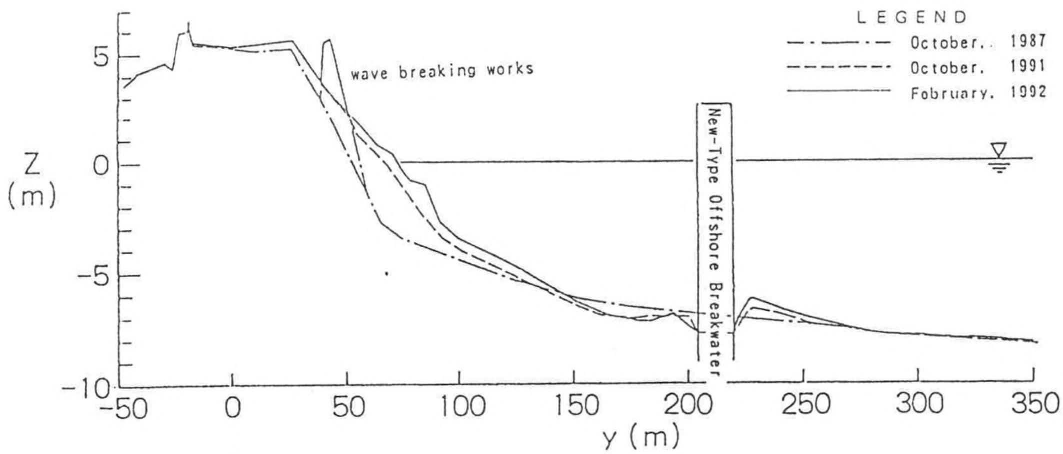


Fig. 6. Advance of shoreline due to the installation of slit-type offshore breakwater

Flexible-Mound is to be in a deflated form during normal wave conditions so as not to obstruct navigation of water craft and be filled with sea water at rough wave times such as typhoons season so as to dissipate wave.

Since this structure is deeply submerged underwater, it does not disturb scenic views, and it is safe for navigation by water craft and leisure activities of people.

V. CONCLUSION

As part of the project presented in this paper, the " Manual for Planning of MMZ Project" was published in 1992. The manual summarizes the research results and describes the practical aspects of the MMZ project and items related to the design of various structures and execution of construction.

The Ministry of Construction will implement the MMZ project as part of its shore protection works. For the time being, it will continue the experimental construction on the Suruga Coast and will select the sites for installation of offshore breakwaters in coastal zone facing the open sea. On-site investigation and evalution of effects will be continued.

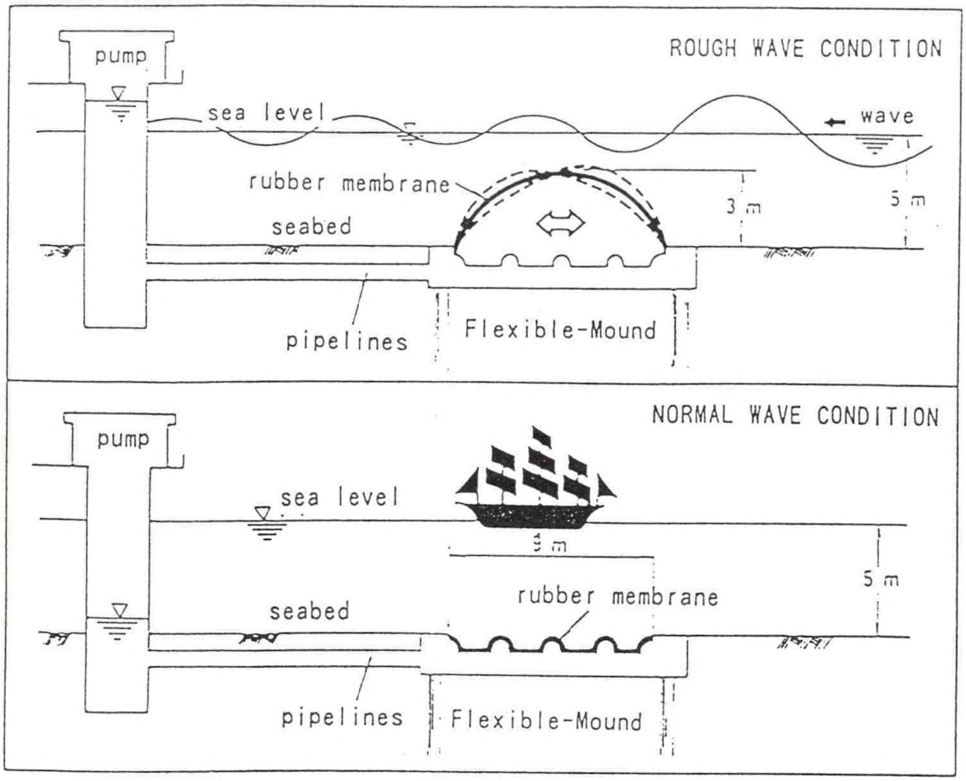


Fig. 7. Function of Flexible-Mound

Ocean Measurement, Assessment, and Environmental Protection

SHIPS AND OCEANOGRAPHIC OBSERVATIONS

Hajime INOUE

Ship Research Institute, Japan

ABSTRACT

The present state of marine environment indicates an urgent accumu-lation and analyses of detailed data and information, both oceanographic and biologic. In addition to the satellite-derived oceanographic information, commercial vessels through their ordinary navigations, as well as research vessels, can provide numerous useful data. A possible role of the vessels important for understanding the nature of the ocean is described.

1. INTRODUCTION

Ever since ancient times when the human being had no particular intention to make dangerous expeditions into the unknown regions in the world, ships have been playing an important role to gain useful information of the seas. Most of the information of the sea and the ocean had been accumulated through the experineces of navigation and fisheries, and they formed emperical guidances for navigation.

Geographers in classical times knew that the earth is round and the knowledge, which is essential for interests and understanding of the sea and ocean, was lost and forgotten in the Middle Ages. By the 15th century, however, it had again become an axiom with scientists and geographers. Saliors gradually learned to sail on the oceans, and since then to recognize their winds, currents and tides on more scientific bases. The numerous voyages of explorations and historic expeditions in 15th century and from this time on have accelerated the accumulation of the knowledge and understandings of the nature of the ocean.

Scientific and technological necessities for navigations of the vessels and ocean and deep-sea fisheries surely made a foundation of climatology, oceanography, geology, and biology.

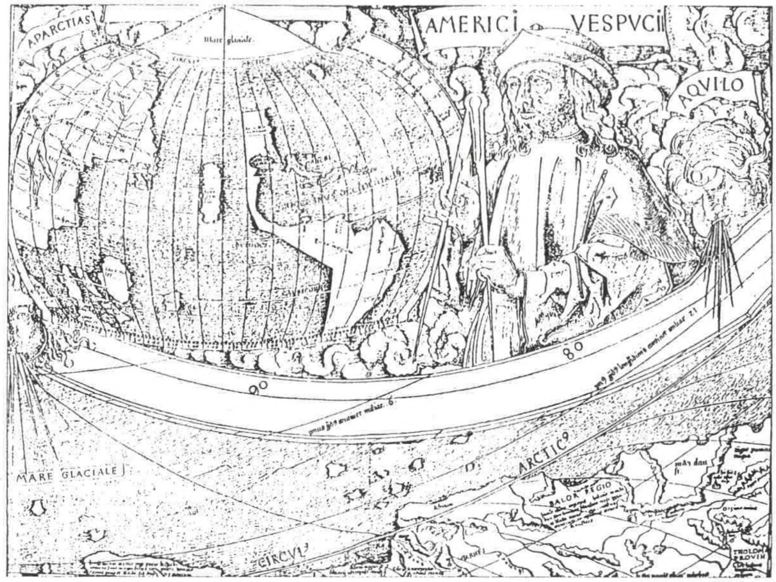


Fig. 1 Maps in the Days of Columbus[1]

2. HYDROGRAPHIC CHARTS

Great effort has been made to obtain geographic, hydrographic and geological data of in- and off-shore regions, where water depth and current velocity as well as shore lines have been of common measurements, and hydrographic charts have been provided mostly for navigation of the vessels. In the early time, the surveys were eventually limited in the maritime provinces, and then expanding to the outer seas.

In those days, scientific information of the ocean was poor and too imperfect to rely on it. Instrumentation, however, for hydrographical survey has been developed and the past data have been successively replaced by accurate information obtained by newly developed instruments and methods of measurement. Numbers of crafts and relatively small ships well served for the hydrographical survey. Experiences through navigations of various ships in various waters also constituted valuable contributions to the hydrography. Echo-sounding and alternative instruments aboard provided geographical and geological data of the sea bottom. In the 1900s, deep submergibles operated in the deep water and improved accuracy of oceanographic and geographic data of the deeps. It will be said that continuous activities on hydrographic charts established a basis of the modern oceanography and added important contribution to the development of physics of the earth.

3. METEOROLOGICAL OBSERVATIONS

Marine users want and require both oceanographic and climatographic data. Partly for the marine users benefit, meteorological observations have been conducted by making use of the ships designed for this particular purpose. To benefit society, meteorological information has been strongly requested, which has priority over oceanographic one. Most of the countries, which have maritime provinces and shore-lines, have built ships for meteorological obsevations and relatively few ships for oceanographic research.

The primary objective of the meteorological observation ships is obviously to serve the society particularly through provinding weather forecast and related information. Some of reasonable requests of scientists on oceanography had been often declined. It is evident, however, that the data and information gathered with those ships are useful for understanding the nature of the ocean and opening the gateway to the modern oceanography.

Daily observations made by commercial vessels and log data have also contributed effectively to collection of global information of the ocean.

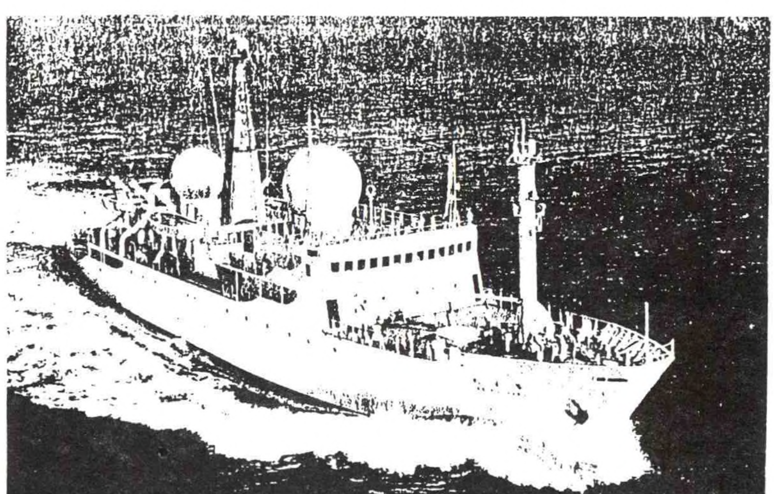


Fig. 2 Meteorological Observation Vessel, "KEIFU-MARU"

4. OCEANOGRAPHIC RESEARCH VESSELS

Necessity of oceanographic research vessels is quite obvious to improve accuracy and reliability of the information and to investigate the seas in minute detail, and to cover the waters as well, where no commercial navigation has been made. As science and technology advanced, information of more physical characteristics and more minute structures of the ocean has been requested and required. To meet scientific requirements, oceanographic research vessels have been constructed in many countries. Through the construction and operation of those vessels, methodology and instrumentation of observations and measurements have rapidly been developed and improved, with the marked advancement of electronics.

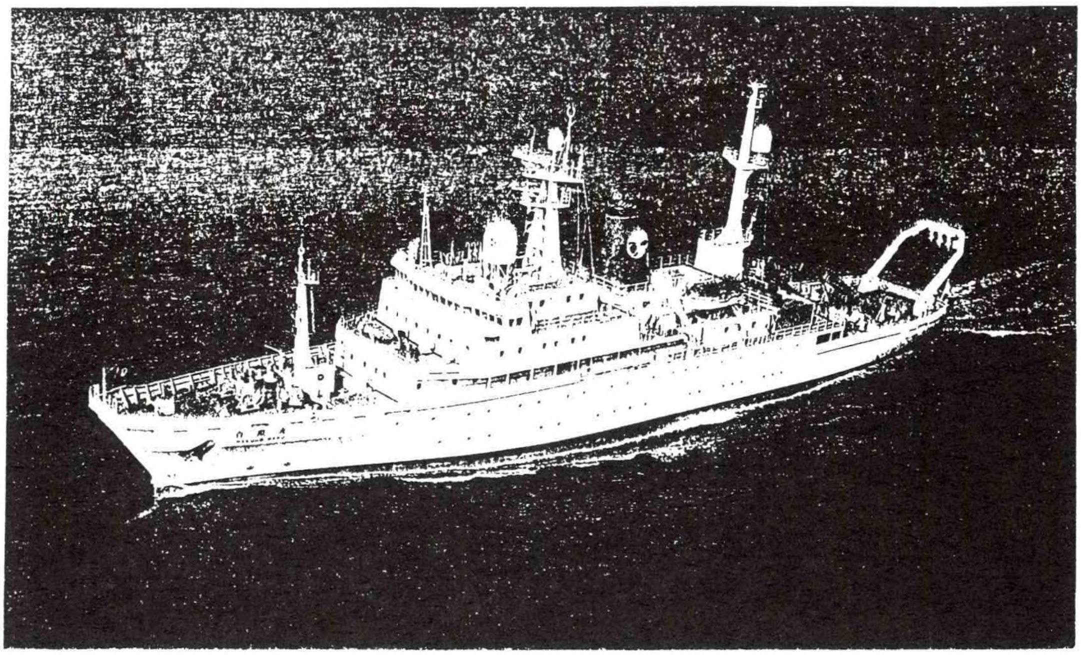


Fig. 3 Oceanographic Research Vessel, "HAKUHO-MARU"[2]

It is natural that the worldwide increase in number of oceanographic research vessels led to international collaborations and setting up of international committees and international data centres of oceanographic information. International organizations have been gradually establised panels in UNESCO, etc., such as IOC, SCOR, IAPSO, ICES. For instance, to improve accuracy of measurements of density and salinity of sea water, Joint Panel on Oceanographic Tables and Standards studied and recommended new procedures for their determinations which have been effective since 1982.

Every data should be collected and stored in a central computerized data base so that rapid evaluation and dissemination of the data are possible. MIAS, Marine Information and Advisory Service of the U.K., is another example, which has collected and analyzed wave data from various observation sites in the world. MIAS is performing an international information service and diffusion of wave data. In Japan, the Japan Oceanographic Data Center was set up in the Hydrographic Department of Maritime Safety Agency and is performing various oceanographic information services.

It is rather a time-consuming job to obtain various oceanographic data by conducting observations and measurements at sea or from the air. For saving time and utilizing the accumulated data effectively, the UNESCO IOC has recently provided the international exchange system and common format of oceano-graphic data which is well known as GF-3 Format. Parameters reported in the format are observation conditions, wind, gust, wave, current, physical parameters of sea water, etc. Wave data, for instance, are expected to consist of wave direction, significant wave height, maximum wave height, wave spectrum including its higher moments, spectrum width, mean wave period, RMS value of surface elevation, etc.

5. RESEARCH VESSELS IN A NEW ERA

The hydrosphere covers 72 % of the earth surface. Most of the oceanographic parameters have to be measured yearly, monthly, daily and even continuously. The present activities with oceanographic reaserch vessels are therefore far from the ideal, although numerous international cooperative projects for oceanographic observations have already been being performed, such as the WOCE, to improve the efficiency of the activities. There have been an earnest worldwide request for increase of number of well-designed and well-instrumented research vessels.

5.1 REQUIREMENTS FOR RESEARCH VESSELS

Constructions of well-equipped research vessels with the advanced electronics and technologies will surely be the first step toward improvement in accumulation of oceanographic data with minute accuracy. The vessels should have the highest possible performance in operation which assures measurements with satisfactory accuracy. The vertical structures of the ocean in detail are one the most highlighted research targets, and measurements is to be made as deep as up to the sea bottom and as high as up to the ionosphere. Observations and measurements aboard should easily be carried out of meteorology, hydrography, pollution, geology, geophysics, ocean dynamics and biology as shown in Table 1.

Some requisites for novel research vessels will be as follows:

1) Most of measurements are to be conducted periodically and automatically, using remote sensing techniques to the fullest extent.
2) Measured data will be analyzed on board and transmitted to an international data centre through satellites.
3) Data information necessary for judgement and operation of measurements will be supplied and exchanged to and from the data center.
4) Tethered vehicles, such as underwater sliding vehicle(USV) and manned or unmanned submersibles are to be installed. One of the submersibles can hopefully go down deeply up to 2,000m. They should have their own gateways at the stern and ship bottom.
5) Recoverable transponders will be utilized for operation of the submersibles, etc.
6) Recoverable instrumented buoys.
7) Radiosondes or the alternaives are to be operated indoor.
8) EWS and graphic displays.
9) Most of biological research activities will also be enjoyed indoor.
10) Non-ferrous laboratory(compartment).
11) Cold test room as low as 30°C below freezing point.
12) An aquarium of reasonable size.
13) Well-equipped meeting rooms.
14) Comfortable accomodations.
15) System for satellite communications.

Table 1 Items and parameters in measurements

METEOROGY Upper air observations Incident radiation Air-sea interface studies Ice observations HYDROGRAPHY SURFACE & NEAR SEA FLOOR Temperature Salinity PHYSICAL Vertical profiles(STD/CTD) Sub-surface measurements Mechanical bathythermograph Bathythermograph-expendable Sound velocity Transparency Optics Diffusion(dynamic) CHEMICAL Oxygen Phosphates Phosphorus(total) Nitrates Nitrites Silicates Alkalinity pH Chlorinity Radioactivity Isotopes Dissolved gases DYNAMICS Current meters Current, measured from ship drift GEK(Geomagnetic Electro-Kinetograph) Drifters Bottom drifters Tidal observations Sea and swell POLLUTION Suspended solids Heavy metals Petroleum residues Chlorinated hydrocarbons Other dissolved substances Thermal pollution Waste water(BOD, Nitrates, Microbiology, others) Discoloured water Bottom deposits Contaminated organisms	GEOLOGY, GEOPHYSICS Sea floor temperature Acoustical properties of the sea floor Engineering properties of the sea floor Magnetic properties of the sea floor Gravimetric properties of the sea floor Radioactivity Motion picture of sea floor Bathymetry-wide & narrow beam Side scan sonor Seismic reflection & refraction Gravimetry Magnetism Sediments, physical & chemical Paleothermy Paleomagnetism & rock magnetism Paleontology Geothermy Geochronology Mineral & fossil resources Littoral zone studies BIOLOGY Primary productivity Phytoplankton pigments Seston Particulate organic carbon Particulate organic nitrogen Dissolved organic matter Bacterial & pelagic micro-organisms Phytoplankton & Zooplankton Neuston & Nekton Invertebrate nekton Pelagic eggs & larvae Pelagic fish Amphibians Benthic bacteria & micro-organisms Phytobenthos & Zoobenthos Commercial demersal fish Commercial benthic crustacean Attached plants & algae Intertidal orgainsms Borers & Foulers Birds Mammals & Reptiles Deep scattering layers Acoustic reflections on marine organisms Biologic sound Bioluminescence Vitamin & Aminoacid concentrations Hydrocarbon & Lipid concentrations ATP-ADP-AMP & DNA-RNA concentrations Taggings

16) Helicopter on board: for airborne measurements and transportation.

17) Instrumentation for airborne observations and measurements.

18) Pollution-free design in every environmental aspect.

19) Well-designed hull form suitable for observations and measurements.

20) Multi-steering system(fore, port & starbord sides aft)

21) Auto-positioning system.

22) Fixed-point turning.

23) Trim and heel adjustment system.

24) Vibration-free and noise-free laboratory.

25) Pollution-free design.

For instance, hull form, particularly bow form, of the research vessels has been seldom designed for the measurement of encounter waves. Generation of spray often has unfavourable influence on the measurement of dynamic swell-up at the bow, and there will be some hull form to counteract the influence.

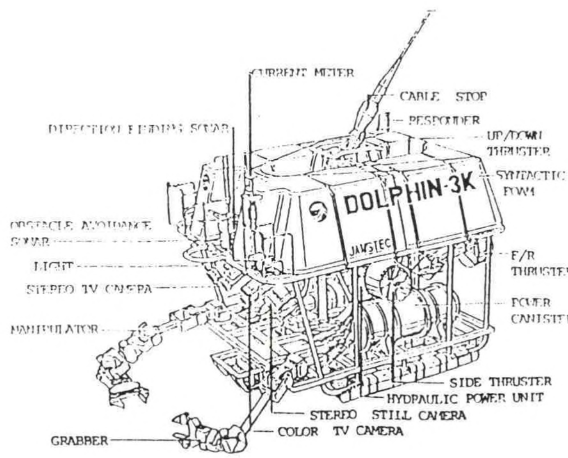
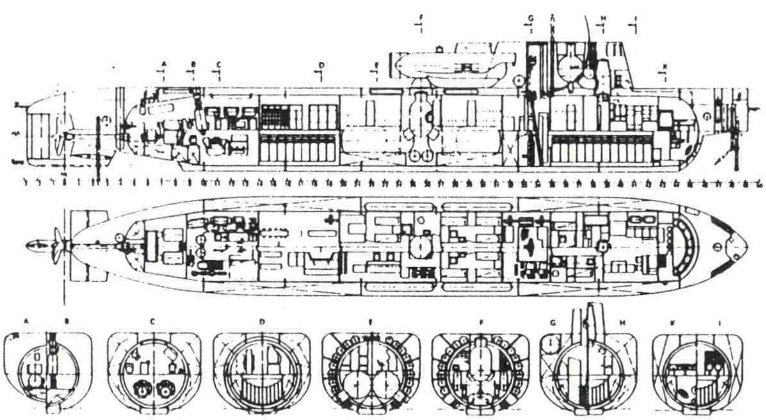


Fig. 4 DOLPHIN-3K(JAMSTEC) [3]



AUTONOMOUS SUBMARINE, TOURS 520

Fig. 5 Autonomous Submarine TOURS 520/500 [4]

The novel research vessels will be mostly operated under international cooperations. Scientists and engineers from various countries will join together on board, and forums and workshops can be held on board effectively.

It is obvious that in the near future, remote sensing data obtained by satellites will play a much more major role in supply of information of the ocean and the atomosphere than in today. The in-situ data, however, obtained through operations of the vessels, will still be vital to the validation of the satellite-derived information. Some of the remote sensing techniques are only applicable to the measurement in relatively short range, and ship borne sensing, ship borne lidar as an example, will be one of the solution. Marine creatures are often sensitive to the microclimate and its change. It is then important to find out appropriate marine creatures and organisms such as a phytoplankton, through which macroscopic information of the physical ocean will be gathered. Those data will be effective to identify useful biologic response measures. The vessels are indispensable for understandings of deep sea and minute structures of the ocean and biological measurements.

Drifting and measuring will be of another possible type of research vessels, or floating structures. One of the typical examples will be drifting manned ice stations. They will be an economic solution for increasing number of research vessels, which will be designed and built at great cost. Some supporting system, by air or sea, will be required for supplement of goods and materials for daily consumption and changing crew and scientists.

5.2 POLAR RESEARCH VESSELS

The polar regions, arctic and antarctic, have long held a fascination for scientists and explores of various countries. Despite the numerous voyages of exploration, the nature of the central arctic had been unknown up to the beginning of the 20th century.

The sea ice in the polar regions has a great influence on global climate of the earth. In the regions, operations of research vessels with icebreaking capability will be a fair working solution of lack of data. There have been numerous problems on, in and under ice covers.

Fig. 6 WOCE Observation Lines[5]

Large-scale and mesoscale phenomena as well as small scale processes in the polar ocean should be clarified.

Similar requisites have to be filled for polar research vessels as those in ice-free waters. In ice-infested waters, however, most of the oceanographic and biologic data cannot be easily obtained. Thickness of ice, for instance, varies with the time and place, and measurements of physical properties and structures of ice are hard and time-consuming work. The polar research vessels should therefore have capabilities of both microscopic and macroscopic observations and measurements to improve the efficiency of their research activities.

For the microscopic measurements, it will be the most important to save total time for the measurements. Time for preparation of measurements, in particular, should be saved as short as possible. This will be done mostly by carefully designed systems and refined procedures. Highly instrumented containers with sufficient insulation will be helpfull to the efficient measurements.

For the macroscopic purposes, various sensors can be applied and installed. For instance, three-component loadcells flush-mounted on the hull surface of icebreaking research vessels will give a continuous information of mechanical properties and structures of ice. Records of thrust and torque of propellers or even fuel consumption rate will also contain much useful macroscopic information of ice. In this sense, the vessel will act as a giant sensor and instrument.

6. UTILITIZATIONS OF COMMERCIAL VESSELS IN PROSPECT

Even if considerable numbers of new research vessels are constructed and in service, recent trends in global climate change on the earth will surely show an urgent necessity of accumulation of much more information of the ocean, biological and oceanographical.

Meteorological observations of commercial vessels have a long history and have made a substantial contribution of permanent value to understandings of the ocean. Except for oil tankers, LNG carriers and other types of ships which carry sensitive goods and materials to electric sparks, oceanographic and biologic measurements through ordinary commercial navigations will be performed if some compact packages of sensors and data acquisition systems, or modules can be provided. And most of fishing vessels have different navigation and operation waters from general cargo carriers. Data from the fishing vessels and the general cargo carriers will cover the information of considerably wide area of the ocean. Fishing vessels, some of which may already have certain equipments for biological survey, will be suitable for collection of biological data.

The compact package for measurements are to be of automatic operation, or at least, of easy operation such as a system with a few push buttons or switches which necessitates no particular training.

Unfortunately, such compact packages have never been developed yet. The technologies to be develped will be as follows;

1) power supply unit: light and compact, long-life,
2) sensor technologies: compact and reliable,
3) storing or transmission of data in short and long distances: improvement of storage capacity to long-term deployment, etc,
4) modularity of the unit.

The scientists and engineers are to be requested to dedicate their individual and organized efforts to develop those compact measuring systems.

Navigation recorders have been proposed to install on commercial vessels to monitor the wave loads and ship responses, etc. Those recorders as well will provide useful data.

6. CONCLUDING REMARKS

The efficient management of rapidly increasing quantities and qualities of satellite-derived oceanographic data together with numerous in-situ data surely poses a major challenge for the immediate future.

Discussions of remote sensing technologies in a new perspective will suggest further insistent necessity for in-situ data available through operations of research vessels and navigations of commercial ships. The in-situ activities should be carried out by international cooperations and frameworks.

Firstly, advanced technologies of shipbuilding as well as highly developed electronics and instrumentation will be expected to effectively apply to novel oceanographic vessels. Secondly, to accelerate data accumulation, compact instrumented packages will be hopefully developed and installed on various types of ships.

There is a need to answer the questions on the marine and estuarine environment. Determination of the threshold of the marine quality or identification of óceanographic and biological response measures is one of the most urgent subjects. A complete and objective determination requires understanding of the structural and functional relationships between every biotic and abiotic component of an ecosystem under the influence of the physical conditions of the ocean. The vessels can make a valuable contribution to this.

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CONTROLLING POLLUTION AT SEA

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The Carderock Division of the Naval Surface Warfare Center, formerly called the David Taylor Research Center, has become a major developer of antipollution technology and equipment. This has stemmed from the Carderock Division's mission to provide research and development through fleet support in the area of surface and undersea vehicles for the United States Navy and the maritime industry. Today, environmental technology and engineering is the fastest growing segment of this 4,600 employee organization which grossed over $700M in fiscal year 1992. This paper will highlight several of the products emerging from the Carderock Division laboratories.

Pollution control aboard ship is both essential and complex. A large ship is, in effect, a small city with virtually all of its environmental problems. In times past, the solution to problems of waste disposal was easy—simply dump everything overboard. The oceans were vast regions not owned by anyone in particular, and, as such, there was no one to complain about their abuse.

A naval ship can pollute the environment in many ways (Fig. 1). Trash and garbage are produced in abundance. Hazardous materials (paints, heavy metals, etc.) from workshops and storerooms are plentiful. Human wastes from lavatory and shower drains and, perhaps even more odious, medical wastes from sick bay drains are ever present. Photo-chemical laboratory drains, laundry drains and the considerable commissary and galley drains all add their contributions to the unsavory trail of the warship through the sea. Oil and fuel find their way to the

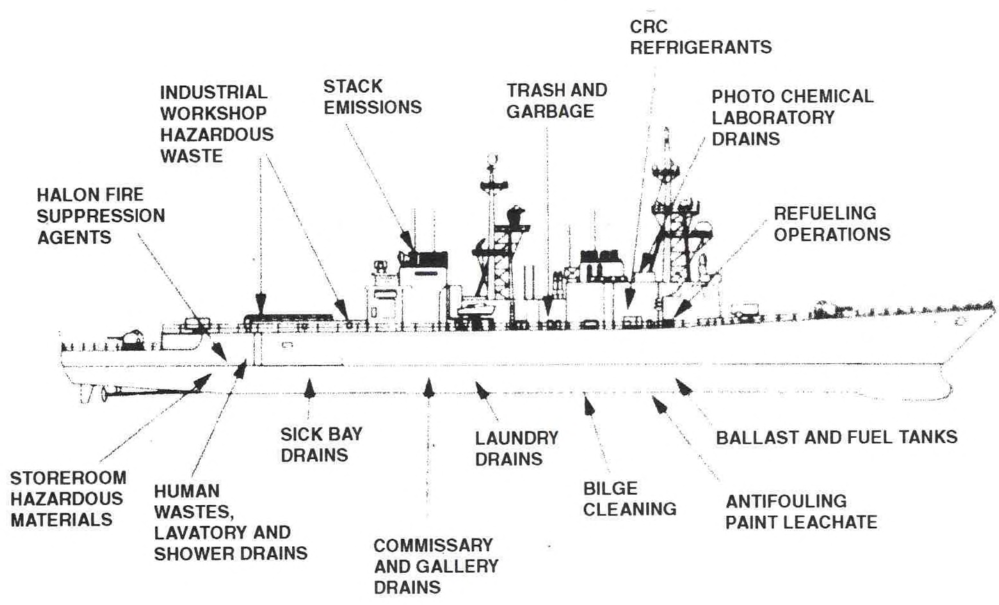


Figure 1. Typical ship air and water pollution problem areas.

ocean from bilges, ballast and fuel tanks and, also, during at sea refueling operations. Even antifouling paint leachate from the ship's hull is hostile to marine life. And above the sea surface, stack emissions and the substantial presence of halon fire suppression agents and air conditioning and refrigeration machinery loaded with ozone layer depleting chlorofluorocarbons (CFC) as the working fluids complete the pollution picture.

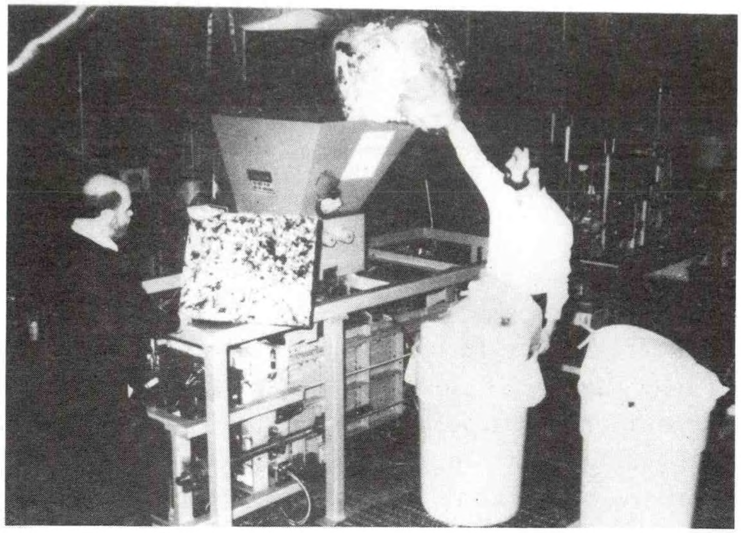


Figure 2. Prototype shipboard plastic waste processor.

The magnitude of this waste is considerable. A sailor aboard a naval ship generates in excess of three pounds of solid waste per day. For a large aircraft carrier with a crew of 6,000, this amounts to 18,000 pounds per day. Approximately seven percent of this is plastics. The remainder is broken down to 41 percent food waste, 35 percent cardboard and paper, and 17 percent metal, glass and other wastes.

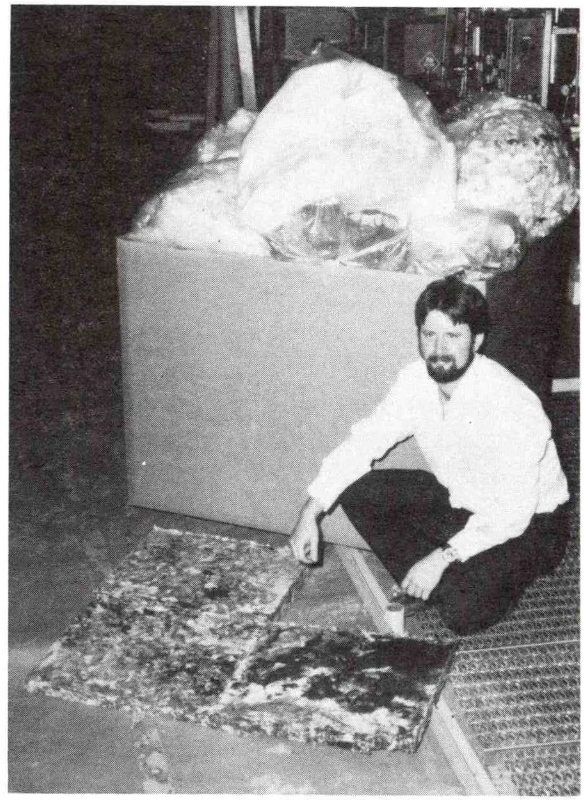


Figure 3. Thirty-to-one compression of plastic waste.

Elimination of plastic waste disposal is a particularly tough problem. However, the Navy has no choice in this matter. The United States Congress has mandated that the Navy must eliminate plastics disposal at sea by 1994. A brute force solution to the problem is to hold and store all plastic waste aboard the ship for the duration of its cruise and then off-load it when the ship enters port. This presents many problems, the most notable being finding the space to store the plastic debris and coping with large quantities of food-contaminated material in hot and humid environments. An aircraft carrier generates about 1200 pounds of plastic waste per day occupying approximately 700 cubic feet of volume. About 50 to 60 percent of this waste is contaminated by food.

The Carderock Division has developed a shipboard machine (Fig. 2) that shreds plastic waste and then compresses it with the addition of heat into a large brick form. This brick (Fig. 3) results in a thirty-to-one reduction in volume. Additionally, the food contamination is both cooked and encapsulated within the brick to produce a product that is sterile and safe for extended storage. The bricks are stacked in appropriate spaces until removed when the ship has entered port. This machine, now in advanced prototype form, will undergo shipboard tests this year with fleet installation scheduled to start in 1996. A further refinement of this process is the ability of the Navy to sell the bricks to manufacturers who produce plastic "lumber" for park benches, picnic tables, car stops, decking, forklift pallets and other recycled products. A pilot project conducted by the Carderock Division and several manufacturers has demonstrated the feasibility of the concept (Fig. 4).

A shipboard vertical trash compactor (Fig. 5), another product of the Carderock Division laboratory, is further advanced in the development cycle. This rugged, simple-to-operate and maintain machine has successfully completed evaluation aboard the destroyer USS *O'Bannon* and will begin deployment throughout the United States Navy in 1993. Glass bottles, cans, paper and cardboard are processed by the compactor into negatively buoyant slugs. These slugs, weighing 30 to 50 pounds each and packaged in cloth, are readily transportable by hand for onboard storage or can be easily discharged overboard in unrestricted areas.

Elimination of wastes that are readily biodegraded will be accomplished through the employment of an advanced solid-waste pulper (Fig. 6) that is in the final stages of development by the Carderock Division. This unique shipboard pulper will process approximately 75 percent of the wastes produced aboard ship, including the considerable volume emanating from the ship's galley. It operates on saltwater producing a biodegradable slurry for discharge overboard from paper, cardboard, galley disposables and even classified documents. It has throughput in excess of 500 pounds per hour and can be operated 24 hours a day aboard ship. It is extremely rugged in construction being designed to receive and collect nonpulpables such as eating utensils, wrenches, hand tools, and even something as substantial as lengths of chain without damage to the machine. These nonpulpables are diverted to a holding compartment for removal by the ship's crew. Even plastics, due to their light weight and inability to absorb water, are rejected in the centrifugal action of the machine for future removal. Like the vertical trash compactor, the shipboard pulper is simple to operate and maintain. It recently completed tests aboard the USS *Lexington* and is scheduled for comprehensive evaluation aboard the aircraft carrier USS *Theodore Roosevelt* this year. Installations aboard United States Navy ships will commence in 1994.

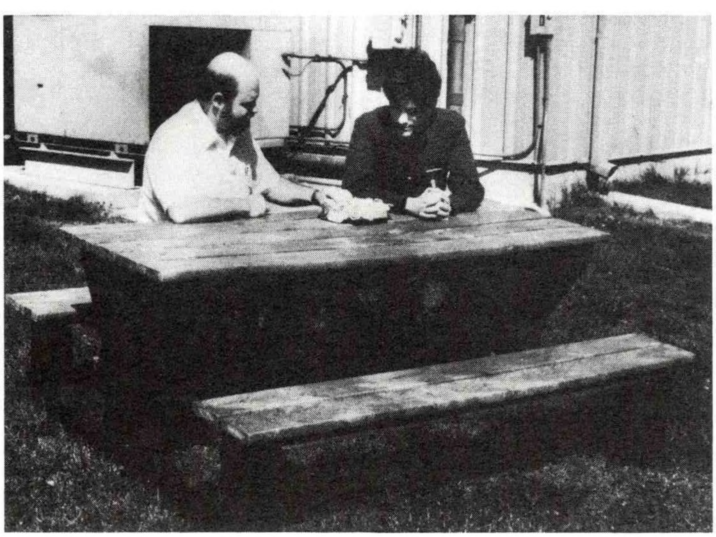
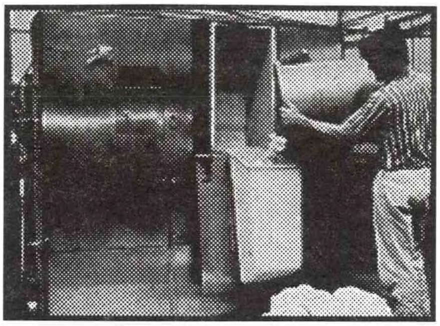


Figure 4. Picnic table and benches, product of shipboard plastic waste at Carderock Division Annapolis, Maryland, laboratory.

Discharge of oil or oil-contaminated bilge water into ports and harbors or at sea is a growing environmental problem. International treaties have been put into effect that limit oil concentrations of ship discharge to 20 parts per million in port and 100 parts per million in the open sea. A family of gravity, parallel-plate oil/water separators (Fig. 7) are being evaluated and further developed by the Carderock Division for a variety of shipboard and shore facility applications. These devices utilize gravity separation and coalescence to remove oil from the denser water. These sys-



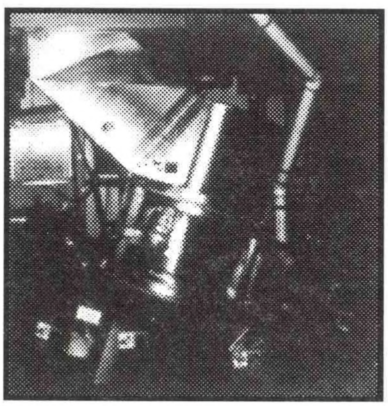
SPECIFICATIONS

- COMPACTOR PROCESSES PAPER, METAL, AND GLASS INTO SELF-CONTAINED, NEGATIVELY BUOYANT SLUGS SUITABLE FOR DISCHARGE BEYOND 25 NM OF SHORE FOR RETENTION AND STORAGE IN RESTRICTED DISCHARGE WATERS
- 150 LB/HR PROCESSING RATE
- ACHIEVES 9:1 VOLUME REDUCTION FOR ONBOARD RETENTION AND STORAGE OF PLASTICS
- NAVY-OWNED, SUPPORTABLE AND MIL-SPEC

PLANS:

- INSTALLATION ABOARD ON SURFACE SHIPS BEGINNING IN FY92

Figure 5. Shipboard vertical trash compactor.



SPECIFICATIONS

- PROCESSES PAPER, CARDBOARD BOXES, FOOD WASTE, AND CLASSIFIED DOCUMENTS COMPOSING 76% BY WEIGHT OF ALL SHIP'S SOLID WASTE
- > 1000 LB/HR PROCESSING RATE
- PRODUCES A WET SLURRY FOR OVERBOARD DISCHARGE WHEN > 3 NM FROM SHORE
- NAVY-OWNED, SUPPORTABLE AND MIL-SPEC

PLANS:

- SHIPBOARD EVALUATION OF IMPROVED PREPRODUCTION PROTOTYPE ABOARD USS THEODORE ROOSEVELT (CVN-71) IN FY92
- LIMITED PRODUCTION OF SWP IN FY93
- INSTALLATION OF SWP ABOARD ALL MEDIUM AND LARGE SURFACE SHIPS BEGINNING IN FY94

Figure 6. Shipboard solid-waste pulper.

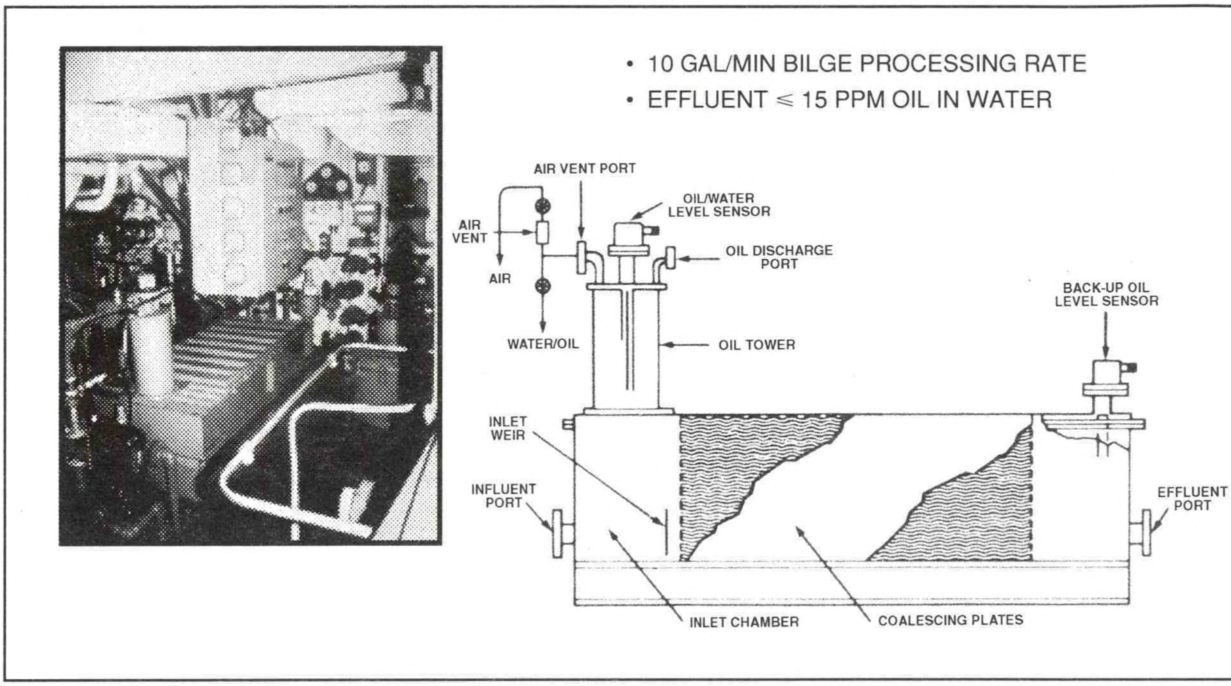


Figure 7. U.S. Navy 10NP Parallel Plate, Gravity, Oil/Water Separator

tems are simple with virtually no moving parts, easy to maintain and highly effective. Oil which has been separated from the water is stored in tanks for future recycling. About 70 percent of the ships of the United States Navy are currently equipped with these separators. By 1995 separators will be installed in virtually every ship in the Fleet.

Human sewage from water closets and urinals (blackwater) poses serious logistical as well as environmental problems for ships, particularly in operation in ports or within three nautical miles of coastlines where blackwater discharge is not permitted. In these areas, all blackwater must be held in tanks for eventual transfer to shore facilities. The Carderock Division has developed shipboard vacuum collection systems that require only 10 percent of the water of conventional gravity systems to flush out the system. This vacuum collection technique drastically reduces the blackwater holding requirement of naval ships.

The above developments underway at the Carderock Division are major elements in a comprehensive program to eliminate or substantially reduce pollution and environmental damage from ships at sea. Not described in this paper are significant Carderock Division programs in elimination of harmful CFC's from air conditioning and refrigeration plants (the United States Navy operates more than 3,000 such units employing CFC's), hazardous waste control and development of environmentally benign antifouling hull coatings. Further, the Carderock Division is engaged in extensive research supporting new ship hull designs such as advanced double hull concepts that are resistant to leakage of contaminates, i.e., oil or fuel, into the sea when the hull is ruptured due to groundings or collisions.

The application of this technology has progressed well beyond the shipboard environment. The Carderock Division today consults for a variety of customers ranging from Naval shore facilities to small cities and resorts. With the growth of the world's population, particularly in the littoral regions of our planet, this technology will play an ever-increasing role in the centuries to come.

THE TECHNOLOGY OF REMOTE ECOLOGICAL MONITORING OF THE SEAFLOOR - REMOTS®

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INTRODUCTION

Pollution of the near-shore marine environment involving bays, estuaries, rivers and off shore sites for dumping has reached epidemic proportions in all of the industrialized nations as well as many developing third world countries. Increasingly, environmental resource managers at regional, State, and Federal levels are placed in the position of having to make decisions governing the management and regulation of ocean waste disposal sites when they lack either technical or financial in-house resources to carry out the necessary monitoring studies designed to insure compliance or detect environmental impact.

Utilization of the results of monitoring studies has often been compromised because of several related difficulties. Monitoring studies have historically been relatively inefficient and therefore expensive resulting in sampling tasks that are that very specific and do not encompass a total problem area. The result is that the acquired data may not directly lead to unequivocal management decisions. Further, the data return from traditional monitoring studies has been so slow that the data are rarely used to make real-time management decisions.

In order to maximize the utilization of site monitoring data for effective management decisions it is essential to use sampling techniques that provide rapid data return. For the last several years, SAIC has been continuing the development and successful use of such a technique that can be applied to both open-water dumped dredged material monitoring and problems associated with organic enrichment of coastal waters receiving urban sewage effluents, agricultural run-off, and increased sedimentation or organic mater from mari-culture systems as well as from industrial operations such as pulp mills. This technique is REMOTS® (Remote Ecological Monitoring of the Seafloor) and capitalizes on the efficiency and advantages of sediment profile imaging and image analysis. This paper will provide an overview description of the REMOTS® systems and its uses as well as planned near term capability improvements.

TECHNICAL DESCRIPTION

REMOTS® technology was developed by SAIC to provide a rapid and cost effective method for mapping changes in the surface of the seafloor. This innovative optical technique is used to image, measure, and analyze physical, chemical, and biological parameters in aquatic environments. A unique combination of sediment profile photography and computer image analysis allows rapid mapping of bottom processes over large areas of the seafloor.

Many seafloor processes can be reconstructed from sedimentary and biological features found in the upper 20 cm of the seafloor. The unique design of the REMOTS® camera allows high resolution imaging of these features even in the most turbid water conditions. Sediment-profile photography is done **in situ** by lowering the instrument to the seafloor. An optical prism automatically descends from the deployment frame and vertically sections the bottom. Working like an inverted periscope, the prism serves as an optical corer. The knife-sharp edge at the bottom of the prism and slow penetration rate insure that the imaged profiles of the seafloor are as undisturbed as is possible. **Figure 1(a)**. illustrates the method of deployment while **1(b)** shows the principal system elements.

The camera consists of a wedge-shaped prism with a camera mounted horizontally above the prism in a watertight housing (Fig. 1b). The prism is filled with distilled water with light provided by an internal strobe. Because the object to be photographed is directly against the face plate, turbidity of the ambient seawater is never a limiting factor. The prism assembly is moved up an down by producing tension or slack on the winch wire. Tension on the wire keeps the prism in the up position. A piston ensures that the prism enters the bottom slowly and does not disturb the sediment-water interface. Unlike conventional free-fall corers and grabs, delicate

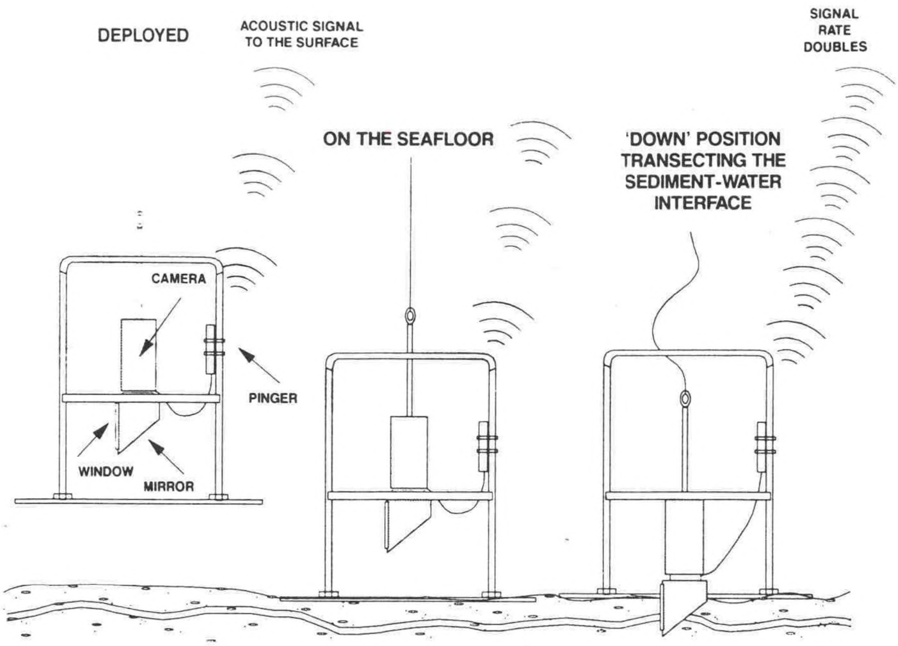


Figure 1(a). REMOTS deployment sequence left to right. As the instrument is lowered to the bottom, tension on the winch wire maintains the optical prism in an "up" position. Once on the bottom, the area of the bottom below the optical prism is undisturbed because the pressure wave generated by the prism is located far from the sediment surface. Once the winch wire slackens, the prism descends slowly (ca. 6 cps) into the bottom, the window is wiped, a photo is taken, the ping rate doubles, the camera is withdrawn from the bottom by the winch (window is wiped again), and the system is redeployed for subsequent replicates. Bottom time is ~ 13 seconds.

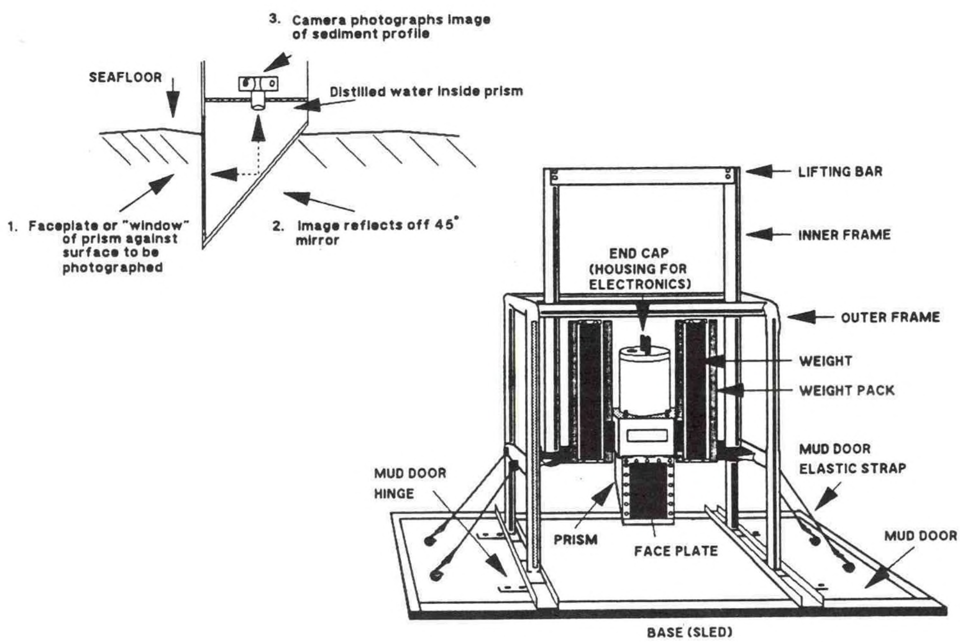


Figure 1(b). Principal elements of the REMOTS system.

surface features such as flocculent surface layers and small scale surface features are preserved by the REMOTS® System. On impact with the bottom, a trigger activates a 13 s time delay on the shutter release; once the prism comes to rest within the sediment, a photograph is taken.

When the camera is raised (it only has to clear the sediment), a wiper blade cleans off the faceplate; the film is advanced by motor drive, the strobe is recharged, and the camera can be lowered for another image. After each image is taken, the camera is raised two or three meters off the bottom and redeployed for taking another image ("sample"). Typically, five replicate images are taken at each station within a period of about 5 minutes. An array of other measurement devices may also be attached to the frame to efficiently obtain information about water column properties (salinity, temperature, oxygen).

Typically, 100 to 220 photographs can be collected in one survey day, depending on water depth and transit time in between stations. Complete analysis, interpretation, and reporting can be accomplished with one to four weeks, depending on the size of the survey.

DATA MEASUREMENTS

Back in the laboratory, measurements of all physical parameters and some biological parameters are measured directly from the film negatives using a video digitizer and computer image analysis system. Negatives or slides are used for analysis instead of positive prints to avoid changes in image density that can accompany the printing of an enlarged, positive image. The image analysis system can discriminate up to 256 different gray scales, so subtle features can accurately be digitized and measured.

The REMOTS® negatives are analyzed rapidly by a computer image analysis system. SAIC's proprietary software allows rapid measurement and storage of a wide variety of imaged features.

Twenty-one different variables are measured or computed and stored for each REMOTS® image. Variables of interest can be compiled, sorted and retrieved for display and statistical comparison. A data sheet, containing the various parameters for each replicate, can be printed. The following describe some of the principal measurements of the system.

Sediment type determination

Sediment grain-size major mode and range are visually estimated from the photographs by overlaying a grain-size comparator. Grain-size classes on the comparator range from 4 phi to -1 phi with intervals of 1 phi. Textural classes (sand, muddy sand, sandy mud and mud) are identified and used to generate a subtidal sedimentary facies map.

Apparent redox potential discontinuity (RPD) depth

On REMOTS® images, aerobic near-surface marine sediments present a higher reflectance value than underlying hypoxic or anoxic sediments. The boundary between the high reflectance ferric hydroxide surface sediment and the grey to black reduced sediment below is called the apparent redox potential discontinuity (RPD). The RDP depth gives an estimate of the depth of pore water exchange, usually through bioturbation. the apparent RPD depth is usually deeper than the true RPD as measured with microelectrodes. In the absence of bioturbating organisms, the high reflectance surface layer typically will be about 2 mm thick (Rhoads, 1974). In the presence of bioturbating macrofaunal the thickness of this layer may extend several centimeters into the sediment column.

The apparent RDP depth is measured on each REMOTS® images by using the 256 grey-scale density slicing. The average value for each station is used to produce a contour map of RPD depth distributions.

Organism - Sediment Index (OSI)

A multi-parameter REMOTS® Organism-Sediment Index (OSI) has been constructed to characterize habitat quality. Habitat quality is defined relative to two end-member standards. The lowest value is given to those bottoms which have low or no dissolved oxygen in the overlying bottom water, no apparent macrofaunal life, and methane gas present in the sediment. The REMOTS® Organism-Sediment Index for such a conditions is -10. At the other end of the scale, an aerobic bottom with a deeply depressed RDP, evidence of a mature macrofaunal assemblage, and no apparent methane gas bubbles at depth will have a REMOTS® Organism-Sediment Index of +11. The organism Sediment Index is calculated automatically from the software after completion of all measurements from each negative.

This index has been found to be an excellent parameter for mapping disturbance gradients and documenting ecosystem recovery after disturbance.

Other parameters

From each REMOTS® image, other data are available such as successional stage (pioneering versus late assemblages) and salient structural features of organism-sediment relationships. The presence and origin of small-scale boundary roughness (ripples versus biological structures) are noted and measured, as well as mud clasts (number, size, shape, oxidation state). These structures allow one to make inferences about relative levels of kinetic energy (Germano, 1983). Processes of methanogenesis, occurring at extreme levels of organic-loading, can be detected by the presençe of imaged methane bubbles in the sediment column. The gas-filled voids are counted and measured when present in REMOTS® images (see Rhoads and Germano, 1982 and 1986 for more detailed information on interpretation of REMOTS® images). **Figure (2)** shows examples of REMOTS® images typifying extremes of bottom conditions.

TYPICAL RESULTS

Geographic Information System (GIS) database construction

A geographic information system can be used to effectively present the collected data. For example, we have used the Geographic Resource Analysis Support System (GRASS 3.1), a public domain system developed by the U.S. Army Corps of Engineers, Construction Engineering Research Laboratory. This GIS, running on a UNIX Sun System provides for extensive data storage, retrieval and powerful analytical routines.

Gradient (contour) maps of the physical and biological parameters (continuous variables) are produced from field data. These maps are then digitized using ROOTS 4.0 software and transferred to GRASS (vector format), where they are converted into a raster format. These steps result in GIS database of the following map layers: 1) Bathymetry, 2) Bottom salinity (+ 40cm), 3) Surface salinity (50 cm), 4) Sediment type, 5) Near-bottom dissolved

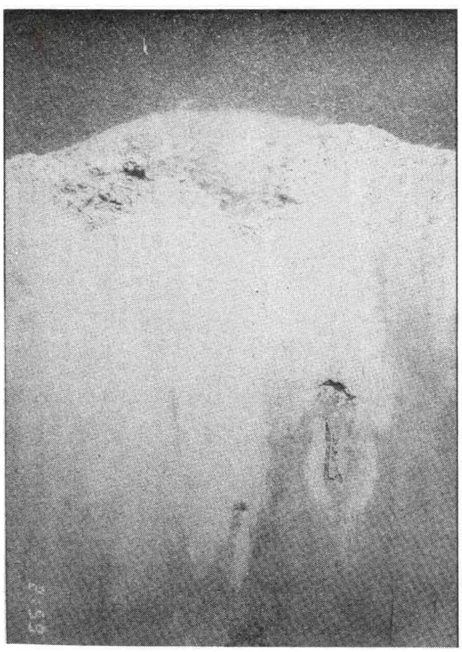


Figure 2. Typical end-member sediment profile images of a pristime unpolluted bottom (left) versus a highly enriched, sulfitic, and methanogenic sediment (right). Note the high reflectance of the pristine bottom imparted by the presence of oxidized sediment particles (ferric hydroxide) caused be intensive sediment stirring and ventilation (bioturbation) by bottom organisms. This represents a bottom where organic detrital inputs are balanced with their consumption and oxidation. The dark optical reflectance of the enriched sediment is imparted by a high inventory or reduced organic substrates including methane gas and iron sulphides. This is typical of organically enriched bottom areas near sewage outfalls that are devoid of macrobenthos. Scale: image measures 15 x 20 cm.

oxygen concentrations, 6) Apparent RPD depth, and 7) Selected bottom biological species counts within the sediment. Various overlay programs within GRASS were used to generate new map layers (e.g. weight analysis, combine, mathematical expression programs and area statistics) (see Krieger and Mulsow, 1990) that allow identification of pollution stress areas.

The protocol used in this method of data collection to GIS database construction is summarized in **Figure (3)**.

A typical example of how REMOTS® data are used together with other types of benthic data to identify estuarine pollution "hot spots" and areas-at-risk are shown in **Figure (4)**. This example comes from a one week survey of Narragansett Bay (Rhode Island, USA).

Combinations of mapped parameters are used to identify existing gradients in habitat quality. For example, **Figure 4(a)** is a ranking of benthic habitat quality based on three mapped layers: near bottom dissolved oxygen, REMOTS® RPD depth, and C. perfringens counts. A high weighting value was given to those parts of the seafloor representing poor habitat quality (dissolved oxygen below ≤ 3 mg/l, apparent RPD depths ≤ 3 cm, and enteric bacterial spore counts ≥ 1000 colony forming units (CFU's)/gm wet wt. of sediment. **Figure 4(b)** is an interpretive map showing how benthic habitat quality (Figure 3a) is related to enrichment sources. High sewage input areas are inferred from shallow or low values (cm) in the apparent redox boundary (high sediment oxygen demand) and high concentrations of enteric bacterial spores in sediments (high Cp counts). Relatively clean or non-eutrophic bottom areas, on the other hand, are inferred from deep apparent RPD values (**high** numerical depth values) and low concentrations of enteric bacterial spores. **Figures 4(a)** and **4(b)** give the status (and inferred causality) of organic enrichment of the Bay floor at the time of the survey. **Figure 4(c)** defines areas of future risk from benthic eutrophication. This interpretive map is based on a combination of a mapped data layer called "particle sinking potential" (not shown here) and the habitat quality map (Fig. 4a). Particle sinking potential is highest in an estuary where fresh water mixes with saline water. If current nutrient discharge rates continue or increase, those areas at greatest risk for further degradation are those bottom areas that are already stressed in regions of high particle sinking potential. Conversely, these are the same areas that are expected to experience the greatest improvement following future sewage abatement. This type of interpretive map is used to establish a parsimonious grid of long term monitoring stations for assessing future trends in an estuary following remediation/mitigation practices.

FUTURE DEVELOPMENT OF THE REMOTS® SYSTEM

At the present time, chemical measurements of the sediment with the REMOTS® System are indirect and limited. Inferences about anthropogenic contamination of sediments is based on imaged methane gas bubbles and shallow RPD depths commonly associated with high inventories of labile organic matter and sulphides. Science Applications International Corporation is conducting a feasibility study to enhance the direct chemical sensing capabilities of the REMOTS® system. This includes modular sensors to measure concentrations of polycyclic aromatic hydrocarbons (PAH's) or contaminant metals. Fluorescence imaging and quantification of contaminants within the sediment column would permit rapid field screening of sediments in real time. The spatial distribution of these contaminants within a sediment profile may allow one to determine if the pollutants are surficial, patchily distributed throughout the sediment column, or uniquely associated with dredged material layers. These types of data are critical for developing cost-effective sampling programs for follow-on sampling based on traditional laboratory methods. The field screening data themselves will allow us to add chemical REMOTS® parameters to GIS map overlays. It has been SAIC's experience that this type of "quick-look" technique, based on sediment time-integrative measures of pollution, addresses many of our clients needs to gain rapid insight into patterns and processes. Once this first-order information is available, efficient measurement and monitoring programs can be designed for efficiently addressing a wide range of management problems.

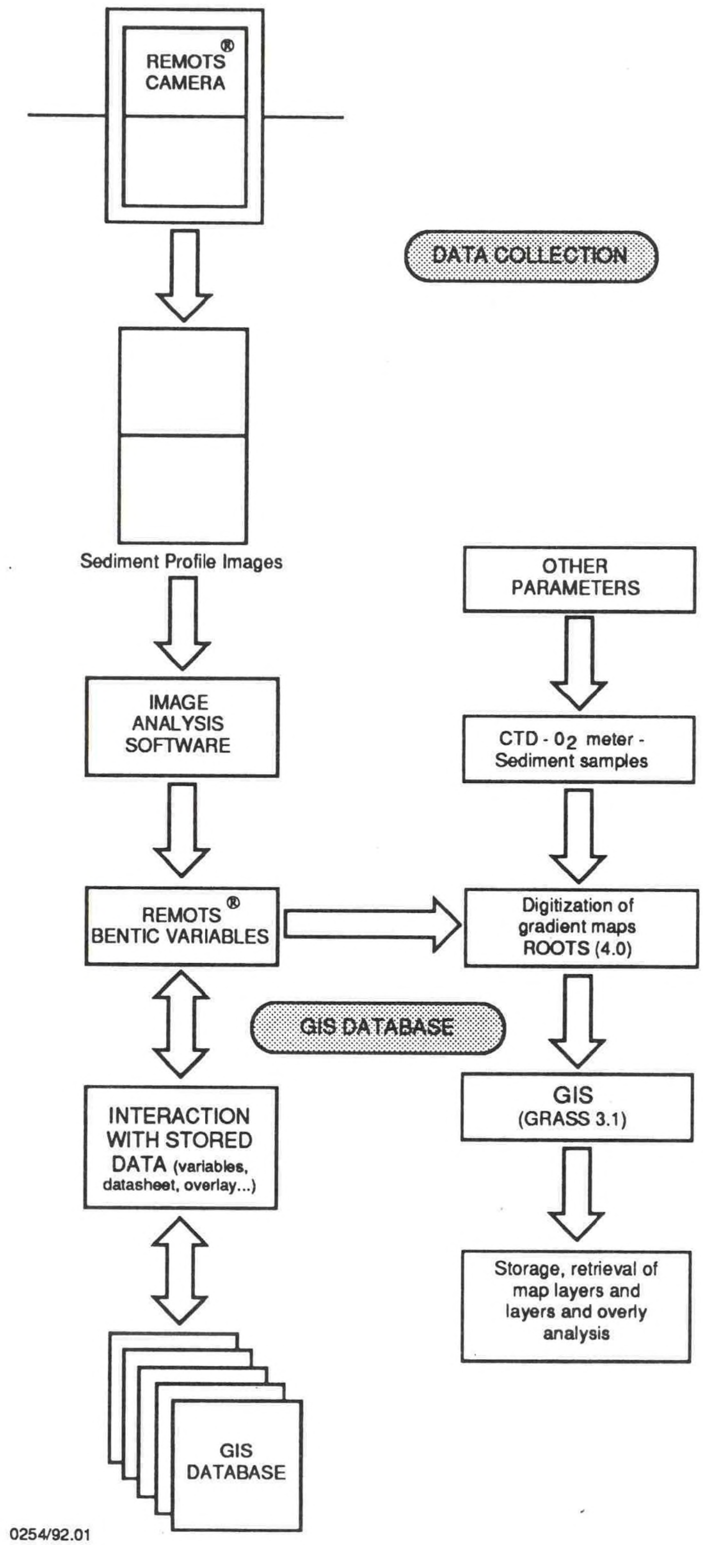
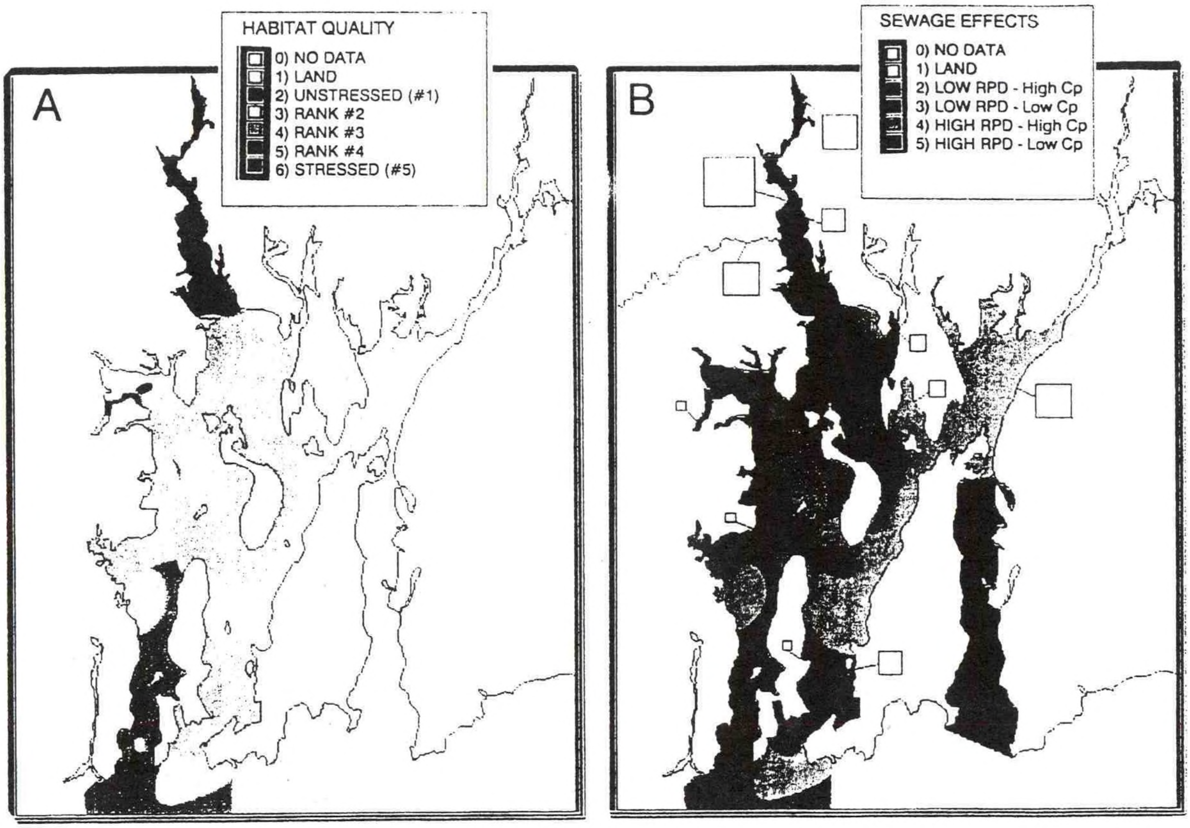
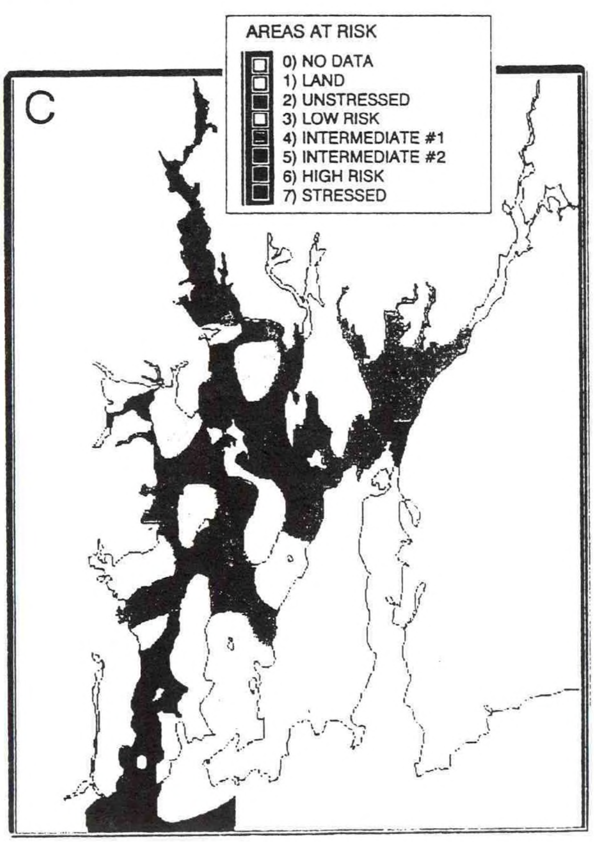


Figure 3. Protocol for pollution impact assessment: Integration of Image Analysis (REMOTS ® technology) and GIS. Computer storage of REMOTS ® benthic variables and GIS map layer allows the user to interactively retrieve and display information of interest.





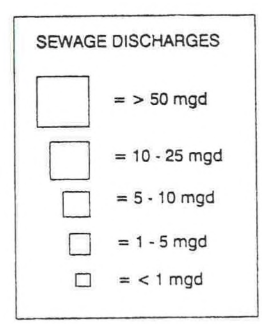


Figure 4. Example of GIS display and analysis of REMOTS® as well as other benthic data for management evaluation (from Krieger, Mulsow, and Rhoads, 1990) A.) Status of benthic habitat quality in Narragansett Bay based on three mapped GIS layers; bottom dissolved oxygen, depth of the apparent RPD, and sediment spore counts of an enteric bacterium C. perfingens. B.) Sewage versus non-sewage effects. C.) Areas of future risk from continued chronic organic loading. This map is derived from GIS overlays of particle "sinking potential" and the benthic habitat map (3A). See text for further discussion. (NOTE: Original data map was prepared in color for ease of graphic interpretation. Color is not reproduced here but will be shown in the paper presentation.)

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NEW SEAFLOOR SWATH MAPPING TECHNOLOGY
AT TEXAS A&M UNIVERSITY

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Abstract

In the Spring of 1991, the Geodynamics Research Institute (GRI), with support from the U.S. Navy and the John E. Chance Company, completed development of a new multispectral long-range side scan sonar system which simultaneously images and maps the bathymetry of the seafloor. Named [TAMU]^2 — Texas A&M University Topography and Acoustic Mapping Undersea System — it is designed for operation aboard ships of opportunity and requires only electrical power, cooling water and deck space.

The three major physical components are the towfish, launch and retrieval system, and the data processing and recording laboratory. The towfish contains 11/12 kHz and 72 kHz sonar arrays, can be towed at speeds up to 10 kts and to water depths of 500 m, and collects data in swaths ranging from 100 m to 30 km in width.

Data binning is selectable up to 8,000 pixels per ping (swath). Bathymetry is obtained by phase interferometry using complex demodulation of the received signal, which produces 12 bit 'inphase' and 'quadrature' values for each of two channels on either side of the fish at the rate of 20 k sets per second. The shipboard processor reduces these data to range, depth and intensity for each pixel. Processed and compressed raw data, plus fish operational data and navigation are all logged on optical disk. Slant-range and ship's-speed compensated processed imagery and bathymetry are displayed in real time on grey-scale recorders.

Further processing of the digital data may be done either aboard ship or on shore. GRI employs a 4D/VGX340 Silicon Graphics power workstation and a versatile software system for data enhancement, geo-referencing, mosaicing, 3D image production and interactive seafloor "flyovers." The processing system employs an integrated package of NASA's ELAS and Silicon Graphics' Explorer software.

Introduction

Descriptions of [TAMU]^2's design, operation and development have been previously reported on by Hilde et al. (1991a,b) and Carlson et al. (1991). This report provides a brief review of the system's operation and a discussion about the system's potential range of applications.

System Operation

The [TAMU]^2 towfish is 19 feet long, 4.4 feet high, 3.9 feet wide and weighs almost three tons. Buoyancy is provided by syntactic foam and two large electronics bottles located in the top half of the fish. The massive sonar arrays are located in the lower half of the fish, and the large separation of the centers of mass and buoyancy give the fish a large righting moment and great stability as it is towed. The towfish is slightly buoyant and is depressed to desired tow depths by adding variable amounts of lead weights to the tow cable 20 to 100 meters forward of the fish. An acoustically transparent plastic skin encases the fish in a streamlined design. Roll, pitch and yaw rarely exceed one-half degree.

The hydraulically actuated launch and recovery system also serves as a storage and maintenance cradle for the [TAMU]^2 towfish. This system consists of a sliding tilt bed with a powerful hydraulic winch mounted on its forward end (Fig. 1). The winch accommodates 1500 meters of standard 0.680 inch armored co-axial tow cable that serves as the electrical and mechanical connection to the fish. Electrical connection to the topside telemetry system is provided through slip rings mounted on the winch.

During launch and recovery, the tilt bed is extended into the water so that the fish can be smoothly deployed and recovered. The launch and recovery system is operated through a set of electromechanical controls mounted in a portable console so that the operator can, if necessary, launch and/or recover the towfish single-handed.

The towfish houses 11/12 kHz (port and starboard) and 72 kHz sonar arrays, and the system is capable of supporting a third set of arrays with an intermediate operating frequency. In addition to its multispectral capability, the three-row configuration of the system's 11/12 kHz arrays is also unique to [TAMU]^2; using the outside rows as receivers reduces the sensitivity of the system to interference. The fish also houses environmental sensors to record heading, roll, pitch, fish depth and acoustic velocity.

Complex demodulation is used to produce 12-bit 'inphase' and 'quadrature' values for each channel. The sampling rate for the combined inphase and quadrature data is 160 kHz. While this rate is highly redundant for single frequency operation (20 kHz for each inphase or quadrature signal), it is required for multispectral operation because the full sampling rate must be partitioned between the 11/12 and 72 kHz subsystems.

The [TAMU]^2 topside processor computes both imagery and bathymetry from the inphase and quadrature data using an algorithm very similar to the procedure recently developed by de Monstier (1991). Based on a flat seafloor approximation, bathymetry and imagery for each ping are 'binned' into pixels. The system will support up to 4096 pixels per side (8192 pixels per swath). Navigation (preferably GPS or STARFIX), environmental data, and processing parameters are logged onto optical disk in ping headers that are followed by the imagery and bathymetry data for each ping. Also recorded on disk are 'compressed' interferometric data in a sufficiently primitive form to facilitate reprocessing. Monitor records of imagery and bathymetry are written on grey-scale recorders. The processor uses the navigation data to compensate for over-the-ground ship speed variations to produce spatially correct real-time records.

Applications

[TAMU]^2 surveys to date provide a good basis for evaluating the system's performance and considering its possible range of applications. Subtle and small scale features are sharply resolved in imagery and bathymetry at both frequencies, and multispectral operations reveal distinctive frequency dependent seafloor backscatter characteristics.

Examples of [TAMU]^2's resolution

include imaging a 4" diameter semi-submersible drill rig anchor cable lying on the seafloor at 1000 m water depth (Fig. 2), resolving details in both bathymetry and imagery of a small canyon cut into an escarpment which went undetected in an earlier multibeam survey of the escarpment, and consistently obtaining sharp correspondence between changes in slopes and backscatter amplitudes.

Based on existing data collected from shelf, slope and basin depths in the Gulf of Mexico and the Sovanco Fracture Zone/Explorer Ridge region of the Northeast Pacific, [TAMU]^2 is capable of sharply resolving a wide range of small scale geologic features. Figure 3a shows imagery and bathymetry, combined in 3-D, produced on GRI's Silicon Graphics VGX340 workstation. Imagery and bathymetry were binned into 3,000 pixels across the swath as the data was recorded. Post collection processing includes correction for water velocity variations and application of a 3x25 boxcar filter to the bathymetry. The same data is pictured in Fig. 3b, viewed from a different perspective and with bathymetry contours added.

Because [TAMU]^2 simultaneously collects co-located high resolution imagery and bathymetry (Fig. 3b) with contours, a more comprehensive knowledge of the sea floor is gained than with swath systems that collect only imagery or only bathymetry or that collect both but do not collect the imagery and bathymetry at comparable resolutions (Fig 3a). This is obviously important for basic geological studies. It seems likely that marine engineering activities, such as placing drill rigs, laying pipelines and communication cables, etc., can also be accomplished with reduced risk and greater efficiency where the seafloor has first been mapped in the detail that [TAMU]^2 provides.

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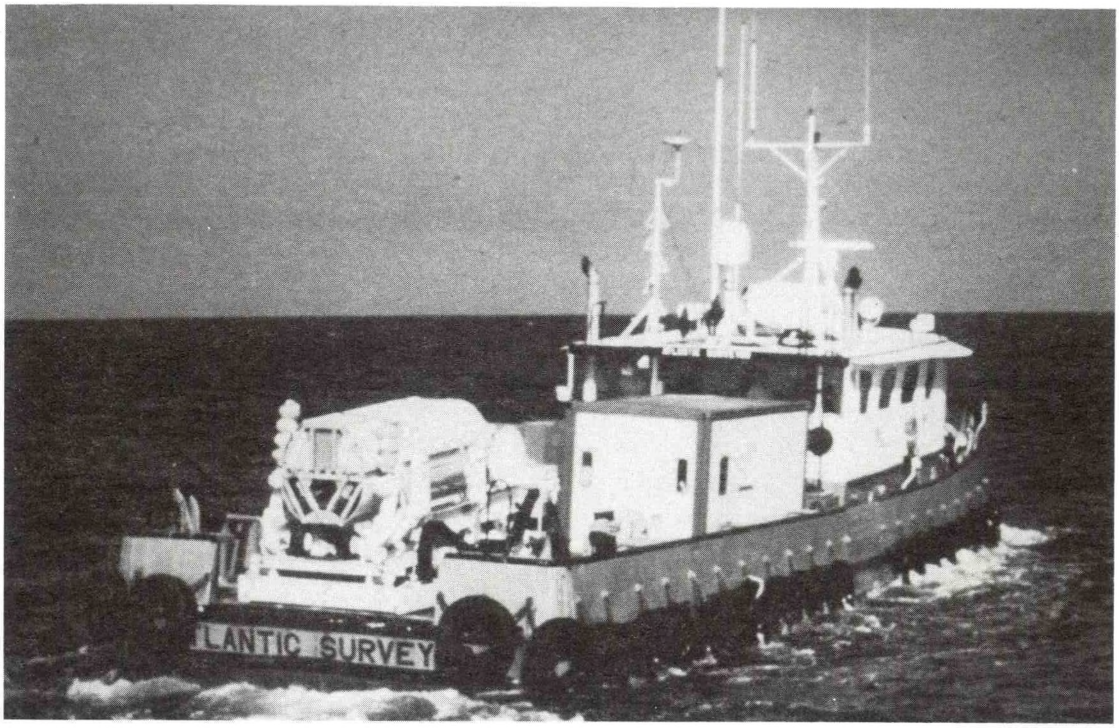

Figure 1. [TAMU]^2 system, aboard the JECA ATLANTIC SURVEYOR, underway to a survey site.

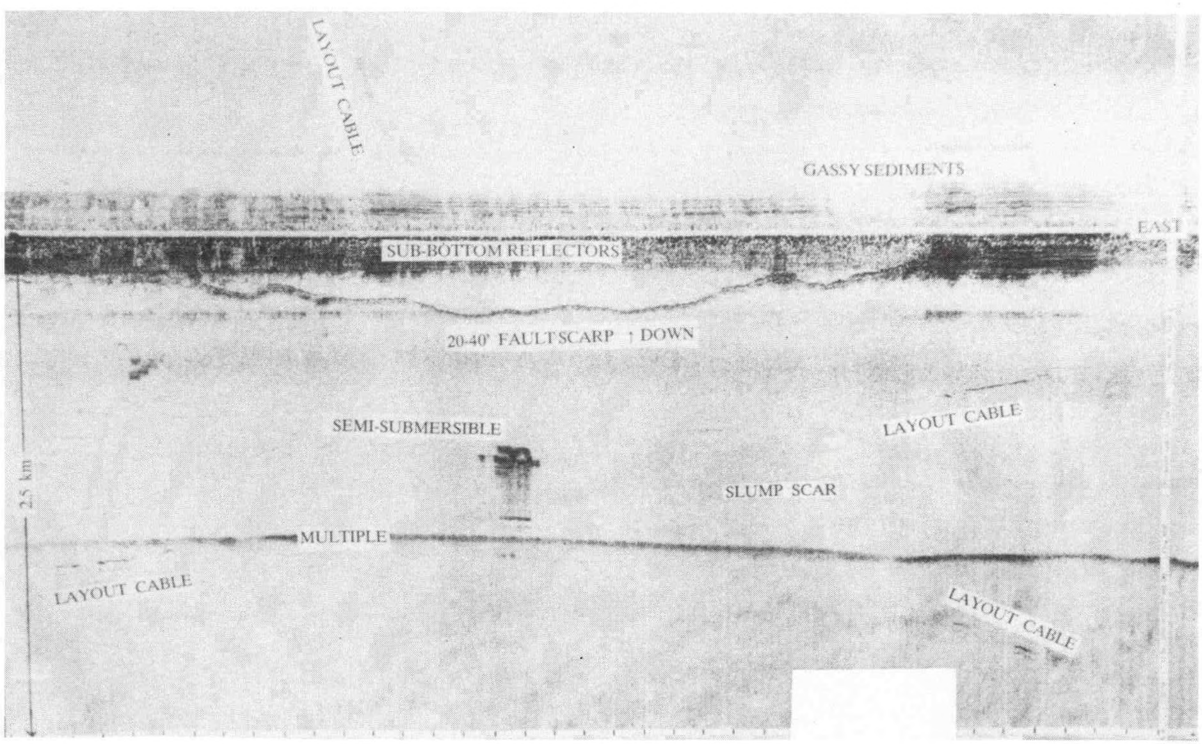

Figure 2. Part of a 11/12 kHz monitor record for a 5 km wide swath of seafloor beneath a Shell Oil Company semi-submersible drill rig located on the east margin of Mississippi Canyon. Water depth is about 1000m. Note the 4" diameter layout cables.

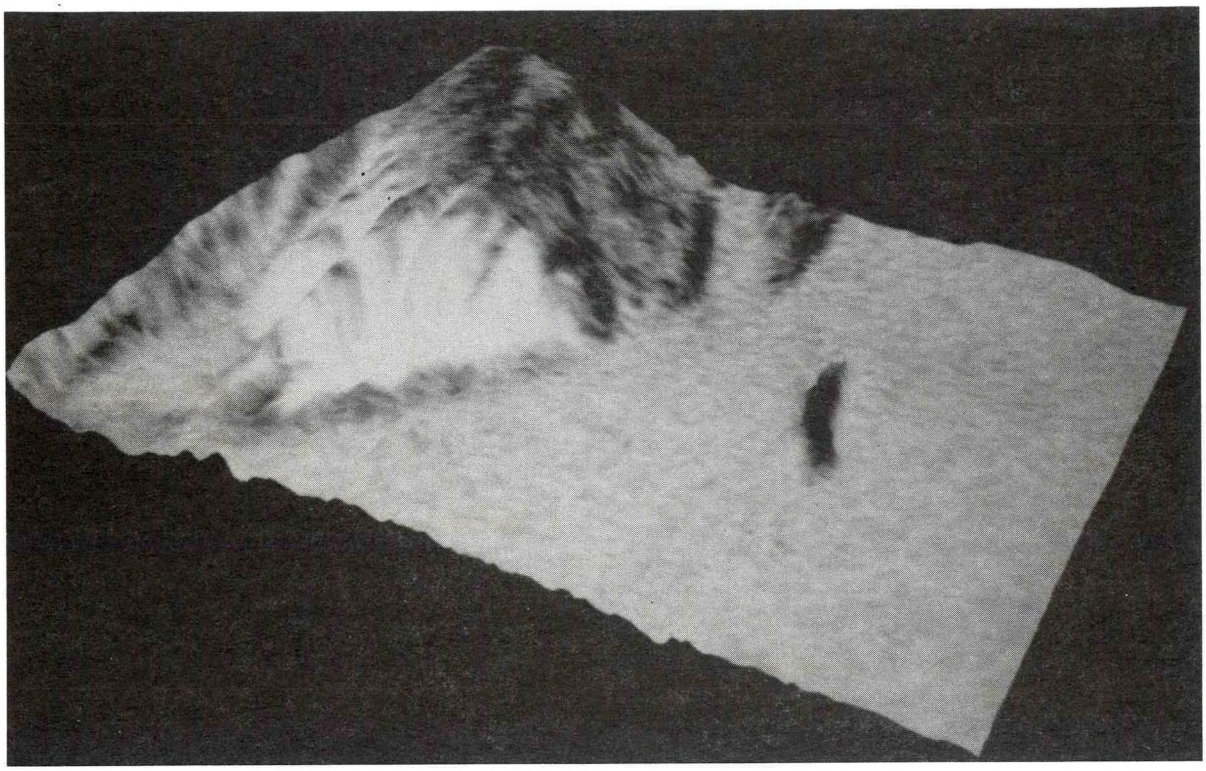

Figure 3a. An approximate 1x1½ km portion of Juan de Fuca Canyon, offshore from Washington State. Imagery and bathymetry combined in 3D, produced on GRI's Silicon Graphics VGX340.

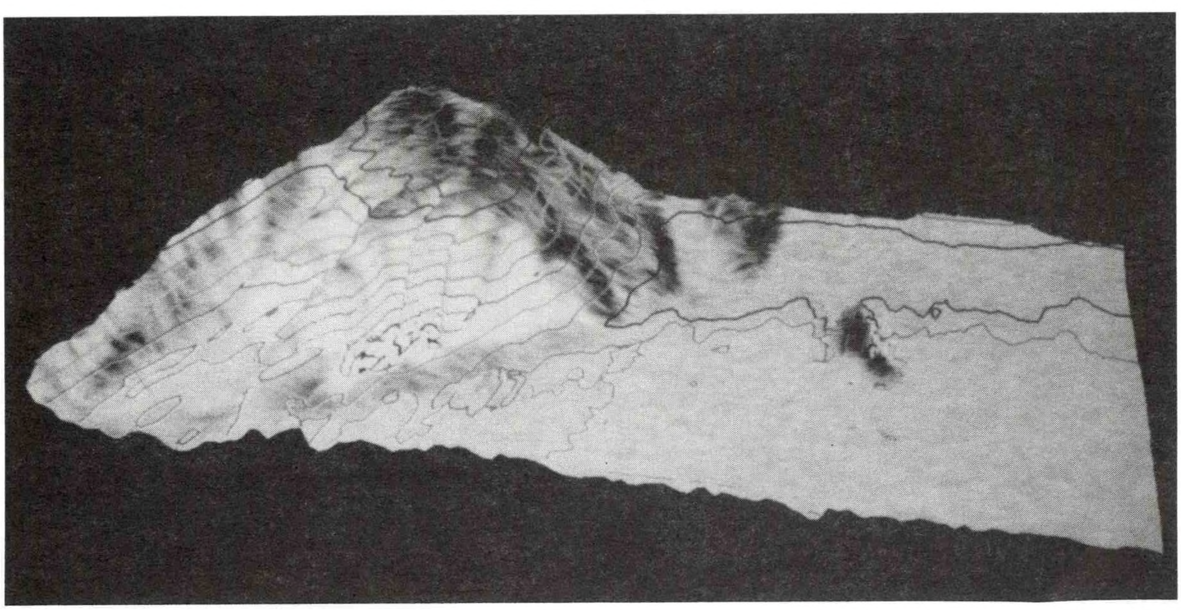

Figure 3b. An approximate 1x1½ km portion of Juan de Fuca Canyon, offshore from Washington State. Imagery and bathymetry combined in 3D with contours, produced on GRI's Silicon Graphics VGX340.

Supercritical Water Oxidation - Technical and Economic Assessment

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ABSTRACT

This paper describes the technical and economic aspects of a supercritical water oxidation (SCWO) treatment system. There is a need for a process capable of destroying toxic organic substances and biological sludges. The SCWO system has the potential of meeting these criteria; because the system can be designed to produce the desired liquid and gaseous effluents, as well as a highly oxidized ash.

Since early 1980's several companies, universities, and national laboratories have demonstrated that the concept of SCWO for wastewater treatment is technically sound and promising. Operating parameters for SCWO are dependent on several interrelated factors: heat release and loss, and heat transfer; reaction temperature, pressure and residence time; flow rate and velocity; waste reactivity, kinetics, transformation product development and destruction; and both liquid/solid and liquid/gas separations. The viability of SCWO must be evaluated on each waste separately.

Progress is being made in the technical and economic assessment of the SCWO processes. The body of knowledge involving reaction chemistry and kinetics, mixing characteristics, solids separations, corrosion-erosion, catalysis and heat transfer continues to grow. Examples are provided describing the breakdown of carbon/nitrogen compounds via oxidation. Similarly, a kinetic database and its relationship to global kinetic models is presented. Other physical/chemical considerations such as oxygen mixing, salt separation, materials selection, catalysts usage and heat transfer are presented.

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INTRODUCTION

There is more to SCWO of toxic wastewaters and sludges than implied in recent articles. Reference is made to such articles as, can "molecular charisma" vanquish toxic waste? Even the Wall Street Journal (Jan. 15, 1992) editors have joined a flurry of popularized SCWO news releases. Articles and letters to the editors have been numerous (Chemical & Engineering News, Dec. 23, 1991, Jan. 27 and March 9, 1992; R&D Magazine, Feb., 1992; Pollution Engineering, Apr., 1992).

As is so often the case, there is some truth in every statement. The test is simply a question of engineering do-ability. Stated in another way: is the science supportive of the concept? Is there a sufficient body of knowledge available to support an effective engineered design? Is the resulting treatment process constructable, operable, efficient and economical? Is the process needed? Is it acceptable to the public?

Obviously, the magnitude of the toxic waste and sludge problem is illustrated by a recent *EPA report: Annual Toxic Chemical Release Inventory* . In 1989 industries in Texas either released or stored toxic wastes amounting to nearly 793 million pounds.

There appears to be some light at the end of the treatment tunnel. The SCWO research at The University of Texas at Austin is one of several efforts dedicated to totally destroying toxic materials and reducing the non-organic substances to acceptable ash in a completely enclosed system. The objective is heavily oriented to obtaining engineering design data. This research can have a significant environmental and economic impact on the costly waste problem.

This survey paper briefly describes the SCWO progress, several technical assessment elements, and four economic considerations.

SUPERCRITICAL WATER OXIDATION (SCWO)

SCWO is a thermal process for the destruction of organic compounds in wastewaters and sludges. The SCWO process utilizes the unique properties of supercritical water. The critical point of water occurs at (374.2°C and 221 bar).

Supercritical fluids exhibit remarkable and abnormal physical properties near or above their critical points. For example, density, viscosity, and dielectric constant decrease sharply across the critical point, while heat capacity approaches infinity at the critical point. For example, at a pressure of 250 atm and temperatures from 25°C to 450°C, water density changes from 1 g/cc to 0.1 g/cc and dielectric constant of water changes from 80 to 5. Under similar conditions, hydrocarbon becomes completely miscible with water and inorganic solubility in water becomes virtually zero.

Supercritical water is an excellent medium for the oxidation of most organic compounds. Organics that are normally insoluble in water can become completely, or nearly completely miscible with supercritical water (Connolly, 1966). Supercritical water provides an excellent oxidizing environment since oxygen becomes completely miscible. Thus, the gas-to-liquid mass transfer is greatly enhanced (Japas and Franck, 1985). Compounds are oxidized rapidly into mostly carbon dioxide and water.

The concept of using SCWO for wastewater treatment appears to have been first disclosed in 1970s (Thiel et al., 1979). SCWO research and development activities accelerated in mid 1980s. The early work demonstrated that SCWO might be applicable for nearly all classes of organic pollutants. Even thermally stable compounds such as polychlorinated dibenzodioxins and polychlorinated dibenzofurans could be destroyed to a level of greater than 98% (Shafi and Blaney, 1991).

It was demonstrated that the operating conditions for a SCWO reactor system could be adjusted to composite for almost any desired degree of organic compound destruction. Chemical oxygen demand removal efficiencies could be in excess of 99.99%. Destruction of organic contaminants is largely dependent on residence time, reaction temperature and reaction pressure, and these parameters are interrelated. The minimum residence time, temperature, and pressure required to achieve the desired degree of organic compound destruction must be determined through laboratory and pilot-plant studies.

TECHNICAL ASSESSMENT OF SCWO

Technical assessment of SCWO can be divided into the following areas: reaction kinetics, solids separation, corrosion, catalytic enhancement, oxygen mixing, heat transfer, and process modeling. All of these areas have been explored at the SCWO Research Laboratory, UT-Austin. Results from these investigations and from other researchers are briefly discussed below.

Reaction Chemistry

Numerous reactions occur during the initial stages of a SCWO process. The pathways for the transformation of complex compounds into more stable entities are influenced by many factors. As one example, in addition to temperature, pressure and reaction time, the reaction pathways appear to be highly susceptible to the catalytic influence of the media and containment system. The complexity of the wastewaters undoubtedly provides an opportunity for alternative pathways.

Previous studies on reaction mechanisms and product analysis of subcritical water oxidation have indicated that short-chain carboxylic acids, ketones, aldehydes and alcohols are the major oxidation intermediates (Taylor and Weygandt, 1974; Conditt and Sievers, 1984; Keen and Baillod, 1985; Baillod et al., 1982; McGinnis et al., 1983; Hurwitz et al., 1965; Teletzke et al., 1967; Fisher 1971; Foussard et al., 1989). Acetic acid has been found to be a major by-product in SCWO of sludges, wastewaters, and model compounds (Shanableh, 1990; Tongdhamachart, 1990; Lee, 1990). Reactions may involve peroxy radicals attacking at the α-carbon of high molecular weight alcohols, ketones, aldehydes, and carboxylic acids. Similarly, other mechanisms involving the rupture of a C-C bond (β or γ) may also produce low-molecular weight compounds.

For nitrogen-containing organic compounds, nitrogen gas is confirmed to be the predominant SCWO end product, regardless of the oxidation state of nitrogen in the starting material (Killilea et al., 1991; Hong et al., 1987; Takahashi et al., 1989). This observation agrees with thermodynamic and kinetic calculations. The formation of ammonia and nitrous oxide has been reported in SCWO of various nitrogen-containing organic compounds and wastewaters (Timberlake et al., 1982; Shanableh, 1990; Hong et al., 1987; Killilea et al., 1991). Ammonia is usually a hydrolysis product of nitrogen-containing organic compounds (Timberlake et al., 1982; Tiffany et al., 1984), and nitrous oxide is a partial oxidation product of ammonia. At higher temperatures, 560°C to 670°C, the formation of nitrous oxide is more favorable than the formation of ammonia (Hong et al., 1987; Takahashi et al., 1989). At low temperatures near 400°C, nitrogen remains in solution as ammonia or ammonium ion (Fisher, 1970; Takahashi et al., 1989; Gamer, 1986).

The reaction chemistry involving SCWO of nitrate and nitrate-methanol mixture has recently been studied (Dell'Orco, 1992). The objective is to use nitrate as a source of oxygen to convert coexisting organic compounds. An understanding of nitrate reaction pathways could assist in developing treatment methodologies for propellant wastes and mixed radioactive wastes.

Tests were conducted at temperatures from 450°C to 525°C, a constant pressure of 30.9 MPa, and residence times from 5 seconds to 18 seconds. Under these conditions, methanol destruction efficiencies ranged from 31% to 85%, which were comparable to the literature data obtained using oxygen as the oxidant. On the other hand, 15% to >99% of nitrate were reduced to gaseous by-products such as nitrous oxide (N_2O) and nitrogen.

At 500°C and above, ammonia appeared to be the primary nitrogen by-product. Below 500°C, nitrate was the predominant nitrogen species. A nitrate pyrolysis run was also conducted. At 525°C and 12.6 second residence time, a maximum nitrate conversion (to nitrite) of 36% was observed. No ammonia was detected in nitrate pyrolysis at 525°C. For all experiments, mass recoveries for nitrogen and carbon have been good, generally ranging from 90% to 110%.

Little information exists about the competing reactions in water other than oxidation. Antal et al. conducted a series of studies on the dehydration of ethanol in supercritical water. The dehydration rate constant involving an acid-catalyzed E2 mechanism was reported to be 7.48 liter/mol/sec (Xu et al., 1990). Recent studies on hydrolysis and pyrolysis in supercritical water by Huppert et al. (1989) and Wu et al. (1991) reported a first-order rate constant for the disappearance of guaiacol of 8.03×10^{-4} sec^{-1} at 383°C. Tiffany et al. (1984) reported that the conversions via hydrolysis of quinoline and isoquinoline in supercritical water were about 30% at 400°C and about 70% at 500°C for a reaction time of 48 hours. At these conditions, benzonitrile and tetralin, respectively, were converted to benzene and naphthalene. Lee (1990) showed that more than 50% acetamide conversion occurred as a result of hydrolysis during SCWO.

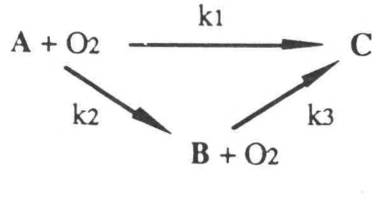
Reaction Kinetics

Global kinetic models have been widely reported and successfully used within the stated experimental conditions to describe SCWO of organic compounds, wastewaters, and sludges. A kinetic database including activation energy, frequency factor, reaction order, initial reactant concentration, and reaction conditions, has been initiated (Li et al., 1991). Most kinetic studies have been conducted at a nominal pressure of about 25 MPa. The oxidation rates in this pressure range appear to be first-order and zero-order with respect to the reactant and oxygen concentrations, respectively. Under SCWO conditions, pressure variation can greatly affect water density, and in turn can change the reactant concentration. However, it has been shown that temperature, as compared to pressure, exhibits a strong effect on reaction rates (Lee et al., 1990).

A generalized SCWO kinetic model is available (Li et al., 1991). The model uses a simplified reaction scheme involving the formation and destruction of rate-controlling intermediates. The assumption is made that as WO reactions proceed, the initial compounds are converted to (a) oxidation end products, (b) unstable intermediates, and (c) relatively stable intermediates. Conversion of all intermediates to the oxidation end products requires a number of parallel and consecutive reactions. Quantification of the SCWO reaction mixtures requires the treatment similar to that used in the kinetic lumping technique (Hutchinson and Luss, 1970; Astarita, 1989; Aris, 1989).

Since the global SCWO rate depends on the final product formation rate, as well as the formation and destruction rate of stable intermediates, it is necessary to identify key rate-controlling reaction intermediates. Comparison of kinetic parameters for different organic compounds can assist in identifying rate-controlling components. The refractory nature of acetic acid and its validity as a key SCWO intermediate are elaborated elsewhere (Li et al., 1991).

The proposed reaction scheme for SCWO of organic compounds can be illustrated as follows:



where

C = [Oxidation end products];

B = [Rate-controlling intermediate]; and

A = [Initial and intermediate organic compounds other than **B**].

Application of this generalized reaction scheme requires the definition of Group **A** and identification of Group **B**. Three classifications of organic compounds which are characteristic of many organic waste streams, are defined as follows:

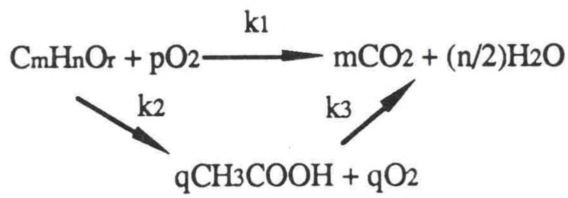
Category I - hydrocarbons and oxygenated hydrocarbons;

Category II - nitrogen-containing organic compounds; and

Category III - chlorinated organic compounds.

Both categories II and III may or may not contain oxygen.

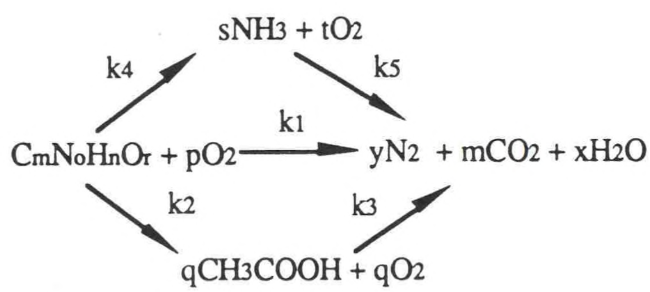
For category I organic compounds, it is assumed that acetic acid is the key rate-controlling intermediate. In this case, the reaction scheme becomes,



where $C_mH_nO_r$ is a collective term including the initial compounds and unstable reaction intermediates.

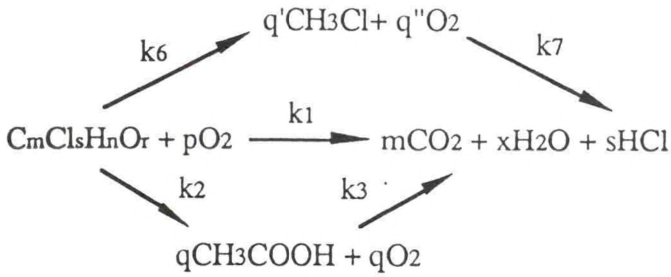
Using the same notations given in the generalized reaction scheme, three groups of organic substances can be further specified. Group **A** includes the initial organic compounds and all unstable intermediates except acetic acid, Group **B** contains the refractory intermediates represented by acetic acid, and Group **C** is designated as the oxidation end products (carbon dioxide and water). The concentrations of Groups **A** and **B** may be expressed in terms of total organic carbon (TOC), chemical oxygen demand (COD), total oxygen demand (TOD), or biochemical oxygen demand (BOD). The concentration units for these measurements are expressed in mass per unit volume (usually mg/L). The mass concentration measurements are particularly useful and convenient for quantifying organic contents in wastewaters and sludges.

For nitrogen-containing organic compounds (category II), nitrogen conversion rate may depend on ammonia formation and destruction rates. Therefore, a simplified SCWO reaction scheme for nitrogen-containing organic compounds can be written as,



where $C_mN_oH_nO_r$ is a collective term including the initial compounds and unstable intermediates with or without nitrogen. If Group **A** represents the compounds containing primarily the trinegative state nitrogen, then organic nitrogen concentrations can be monitored using the Kjeldahl nitrogen and ammonia nitrogen methods.

A similar reaction scheme can be shown for chlorinated organic compounds.



Methyl chloride is a representative reaction intermediate among short-chain chlorinated hydrocarbons which are likely to be produced. The abundance of water in the SCWO environment enhances fast hydrolysis of these intermediates to alcohol's. Therefore, in addition to acetic acid, methanol and ethanol may be used as rate-controlling intermediates for SCWO of chlorinated organic compounds. Finally, the key rate-controlling intermediates identified for use in the generalized model and the reported kinetic parameters for these compounds are summarized in Table 1.

Table 1. Kinetic Parameters for Key Rate-Controlling Intermediates

Organic Compound Category	Key Intermediate (Alternative)	Oxidation End Product	Kinetic Parameters* Condition (Water)	k (1/sec)	E_a (kJ/mol)	Reference
I	CH_3COOH	CO_2, H_2O	Subcritical	4.40×10^{12}	182	(Foussard et al., 1989)
			Supercritical	2.55×10^{11}	172.7	(Wightman, 1981)
			Supercritical^	2.63×10^{10}	167.1	(Lee, 1990)
II	NH_3	N_2, H_2O	Supercritical	3.16×10^{6}	157	(Webley et al., 1991)
	(N_2O)		Not available	-	-	
III	CH_3Cl	HCl, H_2O	Not available	-	-	
	(CH_3OH)		Supercritical	2.51×10^{24}	395	(Rofer and Streit, 1989)

* Pseudo-first-order reaction model using oxygen.
^ Using hydrogen peroxide.

By solving the rate equations of **A** and **B**, the following simplified expression can be obtained,

$$\frac{[A+B]}{[A+B]_0} = \frac{k_2}{k_1+k_2-k_3} e^{-k_3 t} + \frac{(k_1-k_3)}{k_1+k_2-k_3} e^{-(k_1+k_2)t} \qquad (1)$$

where $[A + B] = [A] + [B]$; $[A + B]_0 = [A]_0 + [B]_0$; and $[\ ]_0$ and $[\ ]$ are the reactant concentrations at time = 0 and t, respectively. The three rate constants, k_1, k_2 and k_3, require further description. If k_2 is much smaller than k_1, the organic compounds in the waste stream may be oxidized more easily to the end products. If k_2 becomes larger, more acetic acid will be formed. Values of k_1 may be determined from the initial reaction rate data based on lumped parameters, such as, COD and TOC; because Group **A** is a collective term encompassing the initial compounds as well as unstable intermediates. Conversion of Group **A** to acetic acid does not change effluent COD or TOC concentration significantly. Therefore the kinetic parameters based on COD or TOC are directly related to k_1. The existing kinetic parameters for acetic acid can be substituted for k_3. Values of k_2 may be derived from further treatment of equation 1.

Since the SCWO of Group **A** can be considered as a parallel reaction system, the point selectivity, α_I, is defined as the formation rate of acetic acid to that of carbon dioxide, the oxidation end product, from Group **A**. If first-order reactions are assumed, the following relation may be obtained for α_I,

$$\alpha_I = \frac{r_2}{r_1} = \frac{k_2[A]}{k_1[A]} = \frac{k_2}{k_1} = \frac{k_2^o}{k_1^o} e^{-\frac{(Ea_2 - Ea_1)}{RT}} \qquad (2)$$

The global reaction rate depends on activation energy levels for the three step reactions. Since acetic acid is a refractory intermediate, Ea_3 is greater than either Ea_1 or Ea_2. For most organic wastes, Ea_2 should approximately be equal to Ea_1; because Groups **B** and **C** represent series degradation products all derived from similar reactions. For this reason, α_I should be a weak function of temperature, and merely become a ratio of the frequency factors of the two parallel reactions. The value of α_I for a feed stream matching the above assumptions falls in between 0 and 1 (Li et al., 1991). If the concentration of short-chain organic compounds, including those with two carbon atoms, other than acetic acid, such as ethanol, is high in a wastewater, the value of α_I may be large. Similar selectivity correlations may be obtained for organic compounds of the categories II and III. The values of α generally can be used to characterize the "strength" of the waste stream in a SCWO process.

Oxygen Mixing

Although oxygen and water can form a single phase above the critical conditions, mixing between oxygen and water takes a certain amount of time. Oxidation occurs only after an oxidant is supplied in a form that allows the chemical reaction(s) to proceed. Since several mass transfer processes must occur before oxygen is available for reaction, mixing characteristics of oxygen in near critical water must be established for optimal reactor and mixer designs.

Research on oxygen mixing in critical media is underway at UT-Austin. Dimensional analyses are used to assist in evaluating oxygen mixing in supercritical carbon dioxide. Correlations based on dimensional analysis, have been developed to predict oxygen mixing characteristics in near critical water (Riojas and Gloyna, 1991).

This research is significant to SCWO in several areas, including the interpretation of experimental kinetic data and design of full-scale reactors. In fast reactions, the mass transfer step is often rate-limiting. One of the advantages of SCWO over other treatment methods is the rapid rate of oxidation of most organic compounds. The variability in published kinetic data can, in part, be attributed to improper or non-ideal mixing in an experimental setup. The results of this research will be useful to assess turbulent mixing and oxygen availability for reaction in annular and tubular reactors.

Solids Separation

A solid separation model can be used in the design of an operational SCWO process. Erosion, corrosion, clogging and fouling may occur at transfer devices located down-stream from the reactor.

Two types of solids are generally encountered in SCWO environments: metal oxides and inorganic salts. Separation of the first type has been studied in conjunction with hydrocyclones attached to the UT's SCWO pilot-plant. Test results involving micron sized SiO_2, TiO_2, and ZrO_2 have been reported (Dell'Orco, 1991). Separation efficiencies can be enhanced by increasing water temperature from subcritical to supercritical regions.

Correlating the gross efficiency with the inlet Stoke's Number results in the following equation,

$$E_G = 1 - A(St)^B \quad \text{and} \quad St = \frac{C d_{pg}^2 v_i(\rho_p - \rho_g)}{9\mu d_c}$$

where E_G is the gross efficiency; A and B are adjustable parameters; St is the hydrocyclone inlet Stoke's Number; C is Cunningham slip correction factor; d_{pg} is the mean mass particle diameter; v_i is the gas inlet velocity; ρ_p and ρ_g are densities of particle and gas, respectively; μ is the gas viscosity; and d_c is the feed port diameter. The adjustable parameters have been established at a pressure of 25 MPa, temperatures from 20°C to 425°C, and flow rates from 100 lb/hr to 370 lb/hr. The model predictions and test results were generally in good agreement .

The low solubility of inorganic salts in supercritical water have been studied (Dell'Orco et al., 1991). Salt separation studies have been conducted through a cooperative project between UT and Los Alamos National Laboratory. For the preliminary stage of this research, salts were processed in a SCWO reactor equipped with a salt separator (Dell'Orco et al., 1991). This processing resulted in the concentration of salts into a concentrated brine stream. The separability of the salts was assessed at different temperatures (400°C to 500°C) and a constant pressure, 29.8 MPa (4200 psi). From the partitioning of the salt in different process stream (effluent, brine, reactor rinses, solids), it was possible to observe the chemical behavior of the salts. Mass balances were performed on all constituents. Some results are shown in Table 2.

Table 2. Results from Salt Separation Studies

Salt in Feed Solution	Temp.*	Residence Time	Feed Conc.	Effluent Conc.	% Removed
	(°C)	(s)	(mg/L)	(mg/L)	(%)
2 wt% $NaNO_3$	507	52			
Na^+			5690	183	96.8
NO_3^-			14000	452	96.8
Cs^+			24.7	0.5	98.0
NaCl	509	52			
Na^+			380	119	68.7
Cl^-			615	180	70.7
Na_2SO_4	509	118			
Na^+			217	6.0	97.2
$SO_4^=$			391	2.6	99.3
Cs^+			22.7	11.0	51.5
$NaHCO_3$	509	50.0			
Na^+			191	17	91.1
HCO_3^-			537	68.7	87.2
Cs^+			23.3	21.3	8.6

* Average temperature of salt separator. All experiments conducted at 29.8 MPa.

Initial studies demonstrated the feasibility of salt separation from supercritical water. Separations were achieved near the solubility limit of sodium chloride and sulfate. Some salts were more difficult to process. Corrosion of stainless steel was chromium selective in the presence of an oxidant, and non-selective without an oxidant.

Solids separation study is being continued. A cross-flow filtration project is funded jointly by National Science Foundation and Texas Advanced Research Program. Solid separation tests will be performed on the pilot plant. The model predictability of the performance relating to process conditions will be verified. Further considerations will include: (1) particle cut size vs. separation efficiency; (2) particle size distribution; (3) fluid-surface interactions.

Corrosion

SCWO creates an environment which is conducive to corrosion. Extremes in pH, high concentrations of dissolved oxygen, ionic inorganic species, and abnormally high temperature-pressure variations enhance the corrosion problem. Specifically, corrosion products in the effluent may cause two problems. First, metals such as chromium in the reactor effluent, might affect the quality of the effluent and the ash. Second, excess corrosion products, usually metal oxides, are likely to plug up pressure regulating devices. Studies have been undertaken to evaluate a variety of corrosion resistant alloys, corrosion rates, and corrosion by-product formation (Thomas, 1990; Matthews, 1991).

Thirteen alloys including different grades of Stainless Steel, Hastelloy, Inconel, Titanium, and Monel have been tested. Generally, the highest corrosion rates occurred at the subcritical temperature (300^{o}C) and the lowest pH condition (2.1). The higher corrosion rates at subcritical conditions might be explained by the large amount of disassociated ions in solution and the higher dielectric constant.

Additionally, the corrosion rates increased, regardless of pH condition, at high temperatures (500^{o}C). The higher corrosion rates at 500^{o}C reinforce the temperature dependence of the electrochemical and chemical reactions which occur during the corrosion process. As the temperature is increased the rate of the chemical reactions involved in the corrosion process also increase.

At the subcritical temperature (300^{o}C) the properties of water appear to facilitate electrochemical corrosion. Inorganic ions are free in solution and the dielectric constant of water permits electrochemical reactions At supercritical conditions (400^{o}C and 500^{o}C), the inorganic solubility and the dielectric constant of water drop off markedly. Therefore, above the critical point, the HCl, NaCl and NaOH which made up the test solutions may not become disassociated into free ions. At supercritical conditions chemical corrosion may be the dominant form because of the extremely low dielectric constant of water. As the temperature is increased beyond that of supercritical water, the corrosion reactions proceed at a faster rate.

Catalytic Enhancement

Catalysts have been used in SCWO to (a) enhance the conversion of complex organic compounds, (b) shorten reaction time, and (c) lower required reaction temperature. Initial work in catalytic SCWO has been based on wet air oxidation (WAO).

In the presence of hydrogen peroxide, copper salts were reported to be the most active catalyst (Imamura et al., 1982). The chemical oxygen demand (COD) reduction of raw municipal wastewaters was more than doubled in a WAO reaction catalyzed by $CuSO_4$ and $Fe_2(SO_4)_3$ in conjunction with H_2O_2 (Chowdhury and Ross, 1975). The conversion of acetic acid and ammonia, respectively, increased two and eight fold, respectively, when copper (II) nitrate was added (Imamura et al, 1986). Addition of ferric sulfate [$Fe_2(SO_4)_3$] in the WAO of softwood and hardwood increased the percentage of volatile acids (formic acid and acetic acid) relative to the total acid formed in the effluent (McGinnis et al, 1983).

A recent study of homogeneous catalysts in SCWO has shown that manganese (II) chloride, manganese (II) acetate, and copper (II) tetrafluoroborate exhibited little effect on the rate of oxidation of *p*-chlorophenol in supercritical water (Yang and Eckert, 1988). The disadvantage of homogeneous (water soluble) catalysts reportedly is the potential toxicity of metal ions and subsequent post-treatment requirements.

Mn/Ce composite oxide has been shown to exhibit higher activity than homogeneous copper (II) nitrate in the WAO of acetic acid, poly(ethylene glycol), pyridine, and ammonia (Imamura et al., 1986). The rate of oxidation of *p*-chlorophenol in supercritical water was enhanced more by increasing the surface-to-volume ratio of the reactor (Inconel 600) than by adding copper (II) tetrafluoroborate (Yang and Eckert, 1988).

Of the precious metals, such as ruthenium, rhodium, palladium, iridium, and platinum when supported by cerium (IV) oxide, ruthenium has been the most active catalyst in WAO of n-propyl alcohol, n-butyl alcohol, phenol, acetamide, poly(propylene glycol), and acetic acid (Imamura et al., 1988). The catalytic activity of copper oxide and manganese oxide immobilized on a γ-Al_2O_3 carrier has been studied in the WAO of phenol (Sadana and Katzer, 1974). Of the most refractory compounds, acetic acid has been catalytically oxidized by various metal salts including Co-Bi complex oxides (Imamura et al, 1982) and ferric oxide (Levec and Smith, 1976). Similarly, WAO of ammonia catalyzed by cerium-based composite oxides (Imamura and Doi, 1985), and WAO of many oxygen- and nitrogen-containing organic compounds catalyzed by cobalt (III) oxide (Ito et al., 1989) have been reported. These studies have shown that most heterogeneous catalysts have increased the rate of organic conversion.

The non-catalytic and catalytic destruction of acetic acid under SCWO conditions has been studied. Acetic acid was chosen as the compound primarily due to its high level of chemical/thermal stability, which is the rate-limiting compound in SCWO. The catalyst studied was MnO_2/CeO_2 on alumina. Oxygen was the oxidant. All experiments were performed on a laboratory-scale, batch reactor. For non-catalytic SCWO a kinetic model which was first order with respect to acetic acid concentration and the activation energy was found to be 103 kJ/mol. Destruction of acetic acid catalyzed by MnO_2/CeO_2 on alumina showed reaction rates about 30 times faster than uncatalyzed rates. A first-order kinetics was found. The activation energy was 42.5 kJ/mol, much lower than that for uncatalyzed reactions.

Heat Transfer

In an SCWO process, heat transfer is an important design aspect. It is necessary to achieve efficient energy recovery and utilization. Because of the marked changes in water properties near its critical point, heat transfer in supercritical water must be evaluated.

A heat transfer study has been conducted to evaluate individual and overall heat transfer coefficients in a concentric-tube SCWO reactor system (Michna, 1990). Heat transfer to water is enhanced for bulk temperatures just below the pseudocritical point. Increased natural convection effects due to the extremely low kinematic viscosities of water near the critical point are believed to be partly responsible for such enhancement. The heat transfer coefficient rises rapidly with increasing bulk temperature as the pseudocritical temperature is approached.

Deterioration in heat transfer occurs for bulk temperatures just above the pseudocritical temperature. Deterioration in heat transfer is believed to be largely the result of variations in the physical properties between the fluid at the surface of the tube and the bulk fluid. Therefore, deterioration is greatest for pressures close to the critical pressure where the physical properties change most rapidly. Secondary flows in the annulus, enhanced by the strong dependence of density on temperature, and pseudofilm boiling may also be responsible for this deterioration in heat transfer.

ECONOMIC ASSESSMENT OF SCWO

A SCWO economic model might consist of four parts:

1. heat balance required to establish the mass flow rate (reactor dimension, wastewater characteristics and exothermic output);
2. power requirement for fuel pumps;
3. external heat requirements; and
4. energy consumption per unit volume of waste treated.

The heat produced from the oxidation reaction in a continuous-flow SCWO system is utilized to heat the influent waste stream to supercritical conditions. Relatively dilute wastes are capable of generating sufficient energy for the system to operate without supplemental heat (Shanableh et al., 1990). The flow rate of the waste establishes a heat balance within the reactor system. The heat content of the waste feed is important; however, the waste can be either diluted or fortified to help obtain the desired temperature profile within the reactor.

As an example, a deep-shaft reactor is capable of self-sustained operations with wastes containing heat values of only 50 Btu/lb (Smith and Raptis, 1986; Smith et al., 1986). The energy use in deep-shaft SCWO reactor and an incinerator has been compared (Stanford, 1991). This simplified model estimates the external heat required to achieve self-sustaining conditions and the energy consumption for the deep-shaft SCWO reactor system. The amount of energy required for the destruction of a waste may be quantified for specific wastewaters and prescribed reactor dimensions. The cycle time is defined as the length of time the reactor can operate without maintenance.

The SCWO model has four parts: (1) establishment of a heat balance for the prescribed reactor dimensions and wastewater characteristics to determine the mass flow rate necessary to provide a self-sustaining reaction; (2) calculation of the power required to drive the feed pumps; (3) calculation of the amount of external heat and pumping energy required to achieve the desired operating conditions; and (4) estimation of the energy consumption per unit volume of waste treated.

The EPA developed an incineration model consisting of two algorithms. This model estimates the energy consumed by the incineration of wastewaters and sludges (USEPA, 1985). The first algorithm estimates the energy necessary to dewater wastewaters and sludges sufficiently for incineration. It is assumed that a recessed plate filter press is utilized. The second algorithm estimates the supplemental heat and electrical requirements for the operation of a multiple hearth incinerator.

The dewatering model irequires the following input data: the annual sludge volume, the suspended solids concentration, the sludge specific gravity, the hours per day the process is operated, the days per year the process is operated, the cake solids content, and the filter cycle time.

The incineration model is particularly sensitive to the suspended solids content in the dewatered sludge. Dewatering requires less energy than the supplemental fuel requirement for incineration, but the volume reduction impacts the overall energy consumption. In reality, the cake solids content of the dewatered sludge depends on the process used, the initial solids content of the waste, and other waste characteristics. In the Stanford comparison, the solids content after dewatering of each waste was assumed to be the same. The dewaterability of each specific waste was not considered. The energy consumption for any waste depended on the heat content of the waste and the actual cake solids content that was achieved for the waste by dewatering.

The energy consumption for treating a particular waste with either SCWO or incineration system depends on a number of factors. A comparison of the two models shows, for the assumed wastewater characteristics and operating parameters, that a deep-shaft SCWO system, as compared to incineration, has more efficient energy usage. Energy savings between 20 to 90 percent may be realized for relatively concentrated wastes (hazardous liquids and industrial sludges) by utilizing the SCWO deep-shaft system. In the case of primary sludges and digested sludges, the possible energy savings are even greater. Primary sludges consume only 3 to 33 percent as much energy as incineration depending on the reactor depth and cycle time. For digested sludges a deep-shaft SCWO reactor may use from 1 to 12 percent of the energy required for incineration. The actual energy consumption depends on the depth and operating cycle of the SCWO reactor. Generally, energy savings will be the greatest for wastes with low heat contents, though actual savings will depend upon specific wastewater characteristics.

Finally the SCWO model developed herein can be used to approximated various economic considerations and reactor designs. Estimates of the optimum designs can be determined by varying system parameters such as effluent exit temperature, reactor flow areas, and reactor depth.

PROCESS DEVELOPMENT

UT research is cooperating with the development of a SCWO pilot-plant. Eco Waste Technologies (EWT), Austin, TX, has provided funding for a 40 gal/hr SCWO facility. This pilot plant facility has been in operation for more than one year.

SUMMARY AND CONCLUSIONS

Nowhere is the "not in my backyard" syndrome more prevalent than in the case of toxic waste destruction, site remediation, and sludge management. New approaches must be found to assist in the management of the growing sludge and toxic waste problems. The ultimate goal of the U.S. Environmental Protection Agency (EPA) for hazardous waste management is to achieve selected organic destruction efficiencies up to 99.99+% in an acceptable enclosed treatment facility.

Key technological issues relating to SCWO of organic compounds, wastewaters, and sludges, such as reaction pathways and kinetics, oxygen mixing, solids separation, corrosion, and heat transfer, have been addressed.

An economic model has been proposed to compare the energy usage by a deep-shaft SCWO reactor and an incinerator. According to this study, there is a potential for significant energy savings by using SCWO.

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ON DATABASE OF WINDS AND WAVES OF THE NORTH PACIFIC

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1 INTRODUCTION

Wave climate data in the ocean is most crucial factor not only in designing ocean going vehicles but also scheduling and selecting safer and economical ocean routes for shipping. Ship Research Institute has been putting great efforts for a long time to collect and complie such information for naval communities. After ten years since the last publication in 1980 of the wave statistics of the North Pacific Ocean, it became necessary to assemble new kinds of wave climatic chart to meet requirement by new design method of marine vehicles. Taking these conditions into account, a three year research program was launched in 1989 by SRI under the joint collaboration with the Japan Ship and Ocean Foundation. The work was completed this March and the final output of data base system and publication of wave climate chart are now open to public.

This paper presents brief summary of the final report(refer to Appendix for contents) and how the collaboration between USA and Japan under this panel has contributed to this program.

2 OVERVIEW OF THE PROJECT

The objective of the project is to build comprehensive database system on wave climate of the North Pacific Ocean based on as many data sources as obtainable. Wave reports from oceangoing vessels and offshore buoys constitute the main part of the data source, as well as hindcast time history of waves in the ocean. Compilation of statistical tables on winds and waves is made after careful verification and correction of the data.

Data base system for wave and wind in the North Pacific is set up to include these statistical tables and time histories, based on these two kinds of information. The final report will be made in a form of PC version database complised of the core part of the statistical tables, in addition to publication of the results, so that users may have easy access to valuable information.

3 DATA COLLECTION

Three kinds of data were collected in this project to compile long-term wave climate of the North Pacific.(Fig.1) One is the weather report from ocean going vessels, another is report by offshore buoys deployed by JMA and NOAA in the offshore areas. The third one is numericaly generated time history on waves based on the past weather in the ocean through computer simulation, known as wave hidcasting.

3.1 Ship Reports

Thousands of voluntary ships in service report weather, wave and other meteorological information at their point to meteorological agencies which are responsible for data collection assigned by WMO. Japan Meteorological Agency (JMA) is the responsible body for the data collection in the North West Pacific Ocean and NOAA is responsible for the North East Pacific.
Athough the accumulated data have been analyzed for regular publication by the organizations, further analyses are necessary for the engineering purposes to get long-term wave climate for use of the ship design and so forth. In this project data covering the entire North Pacific in the period of 1974 to 1989 stored in JMA and NOAA were made use of. Support from US members of this Panel contributed very much in getting NOAA data.
Those items essential to present purpose are selected out of reported information with respect to wind, wave and atmospheric climate.
Collected ship data covering the entire North Pacific during the period of 1974 to 1989 amount to more than 5 million data for 15 years. Fig.2 shows number of ship reports on waves by zones.

3.2 Buoy Data

Wave measurement by offshore buoys has been thought to be one of the most accurate means to know wave characteristics in the ocean. There are a buoy system operated by JMA in the vicinity of Japan and another large buoy network in the North Eastern Pacific Ocean operated by NOAA. The data from both buoy systems are included into our inventory.

More than half a million data from 5 JMA bouys and 13 NOAA buoys during 1978 to 1989 are in the database. Locations of all the buoys of which data taken are shown in Fig.3.

3.3 Hindcasting

Hindcasting is a powerful tool to get information on waves in the otherwise unavailable areas. It is free from such regional restrictions as buoy and ship reports have. indcasting for the entire North Pacific Ocean in the past ten years.(1980-1989) With recently revised wave model and wind data, the simulation was made at more than 1000 mesh points covering the North Pacific as shown in Fig.4 at every 6 hour interval. Total number of generated wave data is more than 11 million for simulated time.

4 DATA VERIFICATION

In order to make ship data more reliable, it is indispensable to check and verify them with some more reliable ones.
Checking process for ship data is shown in Fig.5. One of our scheme to check reliability of derived ship reports is to see if the reports are contaminated by noise. By plotting the consecutive reports of the same ship, we have found that the data with excessively steep waves are not reliable since such data appears as a spike (isolated high wave) in the most cases.

5 WAVE DATABASE

The present system, as is explained in Fig.6, consist of two parts. One part is assigned to store basic data such as individual ship reports, buoy time reports or hindcast. The other part stores statistically analysed tables of various items. The tables are created in the system through users may have a access to both parts of database on command.
The statistical data may be retrieved under various options. They may be looked up in one or grouped zonal categories on monthly , seasonally ,annually or all time period bases. Although primary concern to the database are statistically analyzed distribution or histogram of wave, wind and other climatic information, the data base gives us on command an easy access to basic information.

6 PC version DATABASE

The statistically analysed tables are of immediate use for engineers. It would help them great if data can be handled on PCs. A subset database working on PCs was created to meet this demand. The tables on winds and waves may be provided to users packed in several diskettes. The users can easily make use of them ifa program called Lotus123 is installed on their PCs.

7 EXAMPLE OF RESULTS

Vast amount of useful information can be extracted out of the database. As an example, several points will be taken up here so as to demonstrate how the system works. Fig.7 shows zonal mean wave height(all season) by ship reports. Corresponding mean wave height by hindcast is shown in Fig.8. It is seen both figures show high wave zones near the International date line.

Newt Let us examine whether data taken independently correspond each other. Fig.9 shows the monthly variation of mean values from different data sources in zone W07. This is where NOAA buoys(46005,46010,46036) are located. Wave height and wind speed are drawn in sequence. The figure shows that the ship reports, hidcasting and buoy reports are in good agreement each other. It is to be noted in the figure that the curves show gradually increasing trends both in wave height and wind speed. It amounts to 5cm per a year for the wave height. It is thought due to a kind of global weather change but further studyis necessary before definite conclusion will be drawn.

Ships may experience different wave condition according to routes. The database system can tells us easily such information. Fig.10 shows probability distribution between wave height and period from ship data along the higher lattitude route between Japan and America as is shown in the map of hte figure. Fig.11 shows the diagram along the lower lattitude route. Comparison of both figures shows clear difference of the routes.

8 CONCLUDING REMARKS

The project was done successfully as planned. Final report summerizes useful and newly derived statistical characteristics of waves and winds in the North Pacific. PC version database will help engineers make use of these results. However, There are much more information to be uncovered. Researches will be continued using the database to extract further information useful not only to naval engineers but also to those interested in the wave climate in the North Pacific.

We would like to express our gratitude of supports given by Mr. Joseph Vadus and other members of the Panel who supported us in locating and make available of ship and buoy data. We are also gratitude for supports extended by JMA. We know that there are lots of data to be added and supplement this database so that it could cover longer time and details of wave climate. Further supports by the Panel members will be appreciated in this context.

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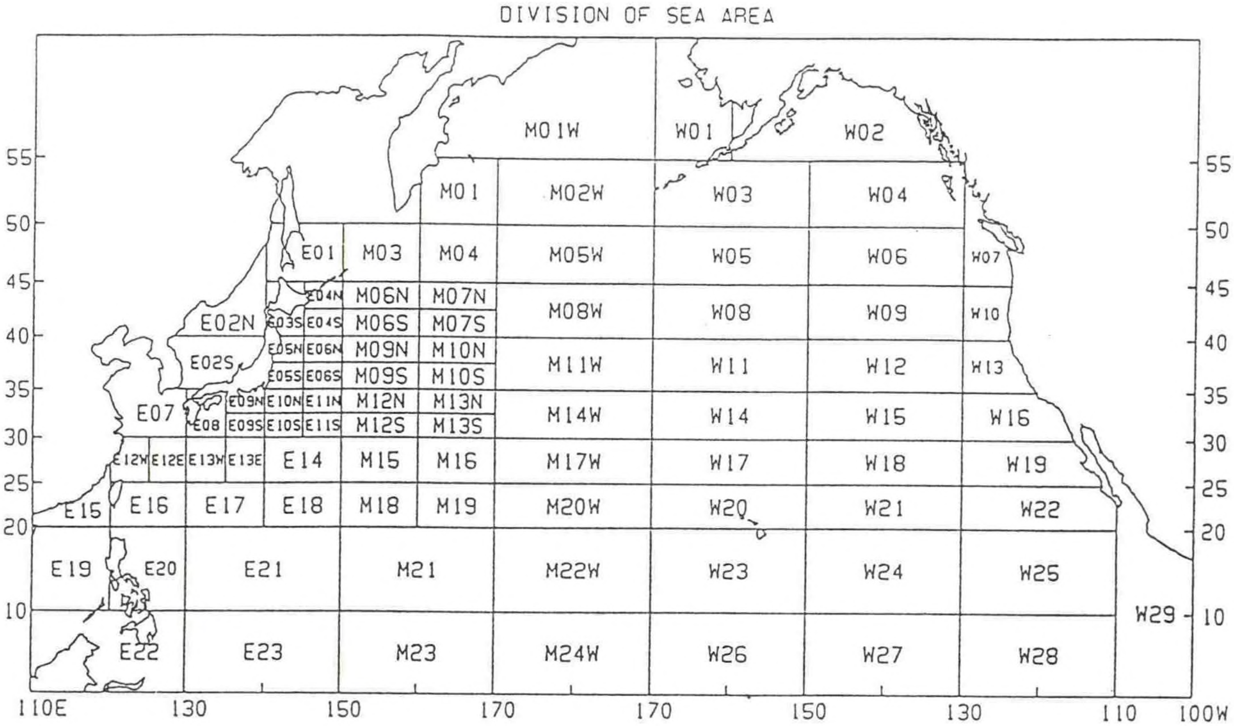


Fig.1 Zoning of the North Pacific for Wave Statistics

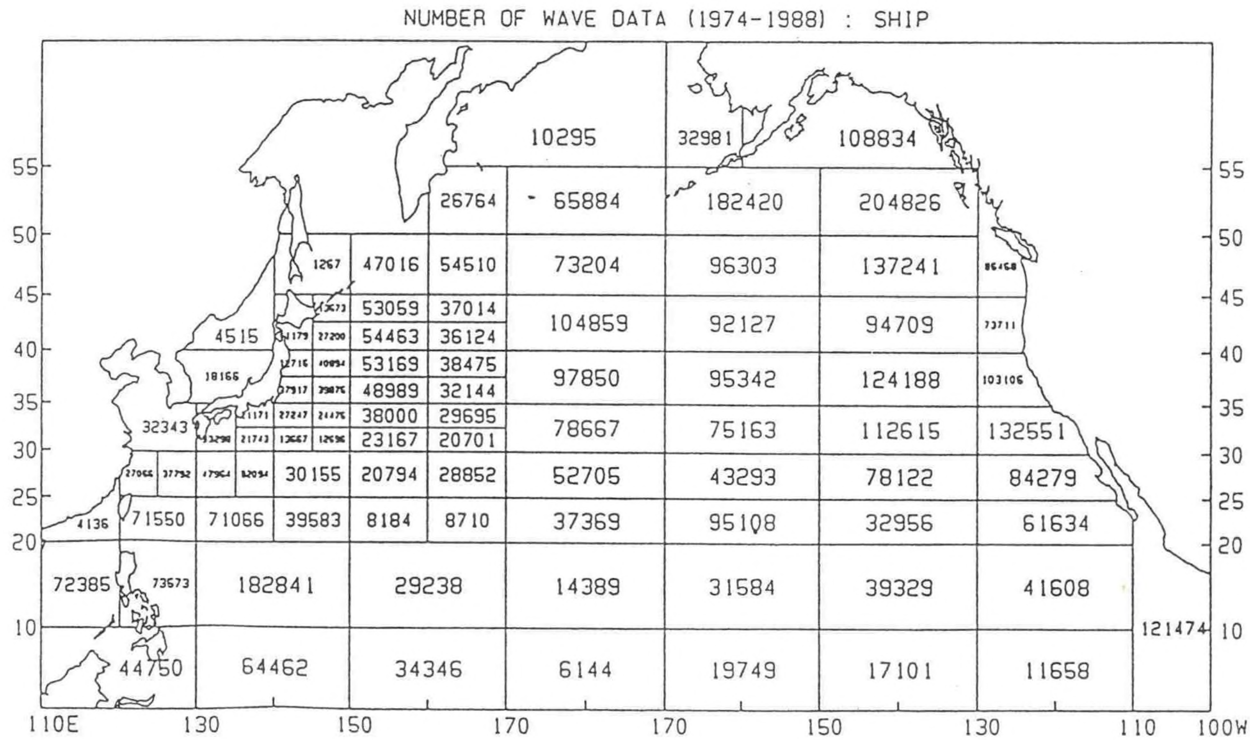


Fig.2 Number of Ship Reports by zones

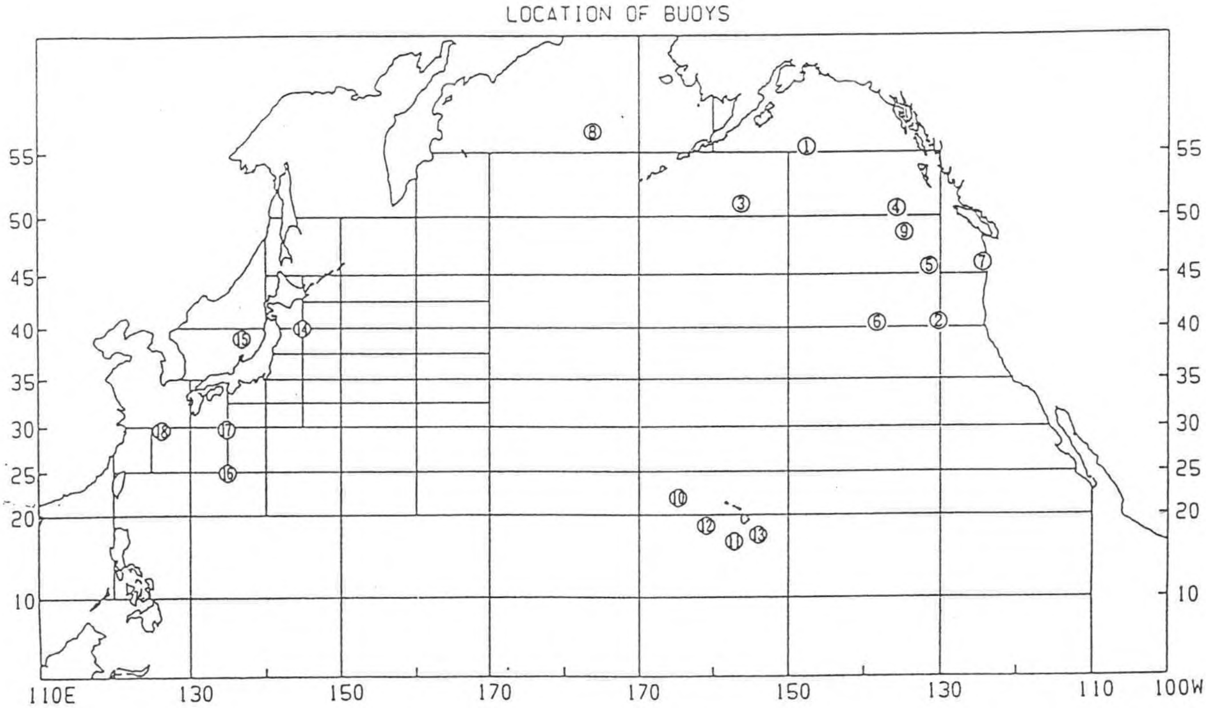


Fig.3 Location of Offshore Bouys

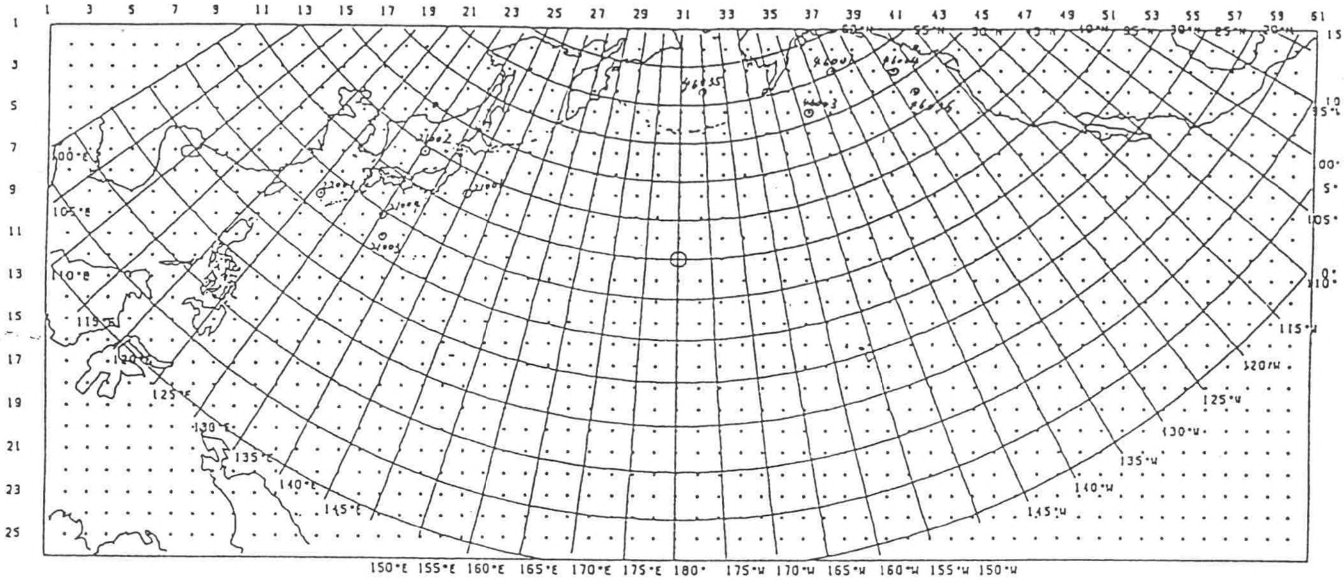


Fig.4 Grid Plan of Hindcast

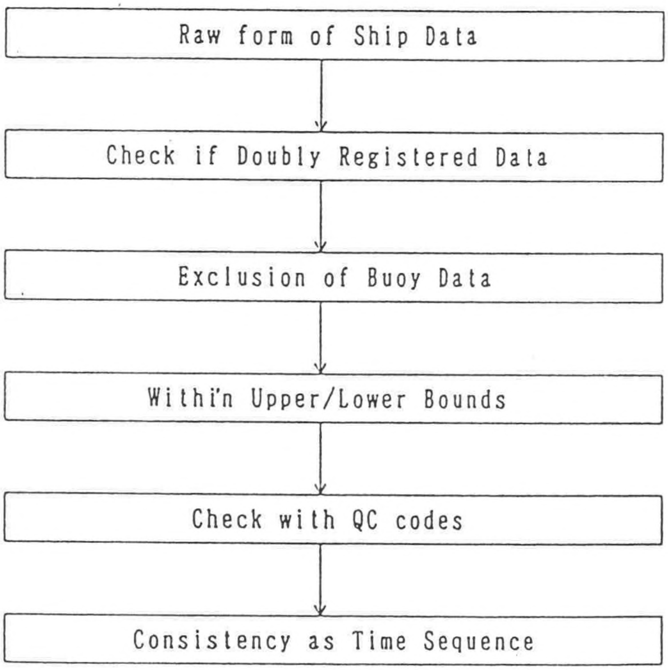


Fig.5 Checking Process of the Ship Data

General Diagram of Wave Data Base System

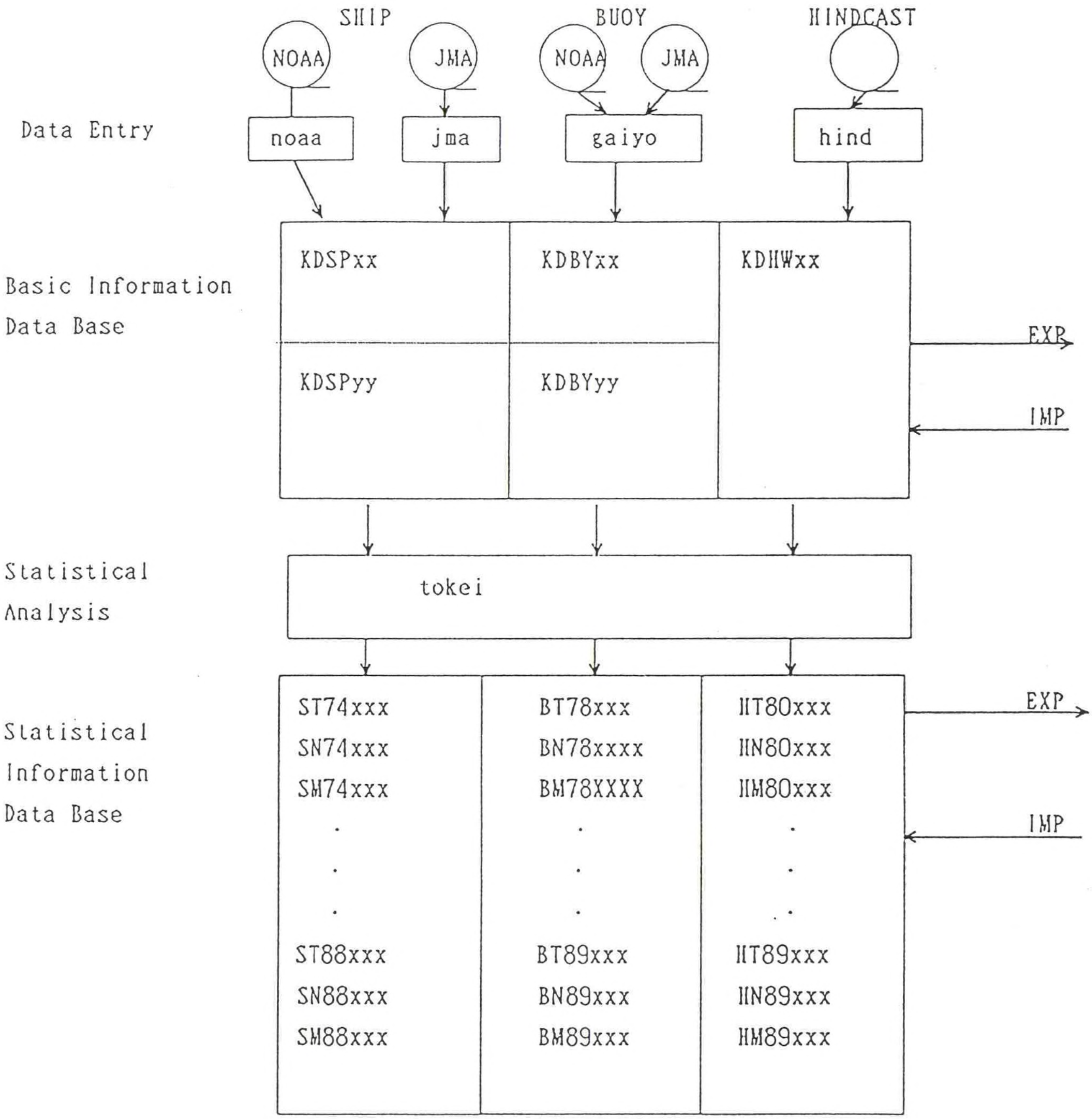


Fig.6 General View of the Wave Database System

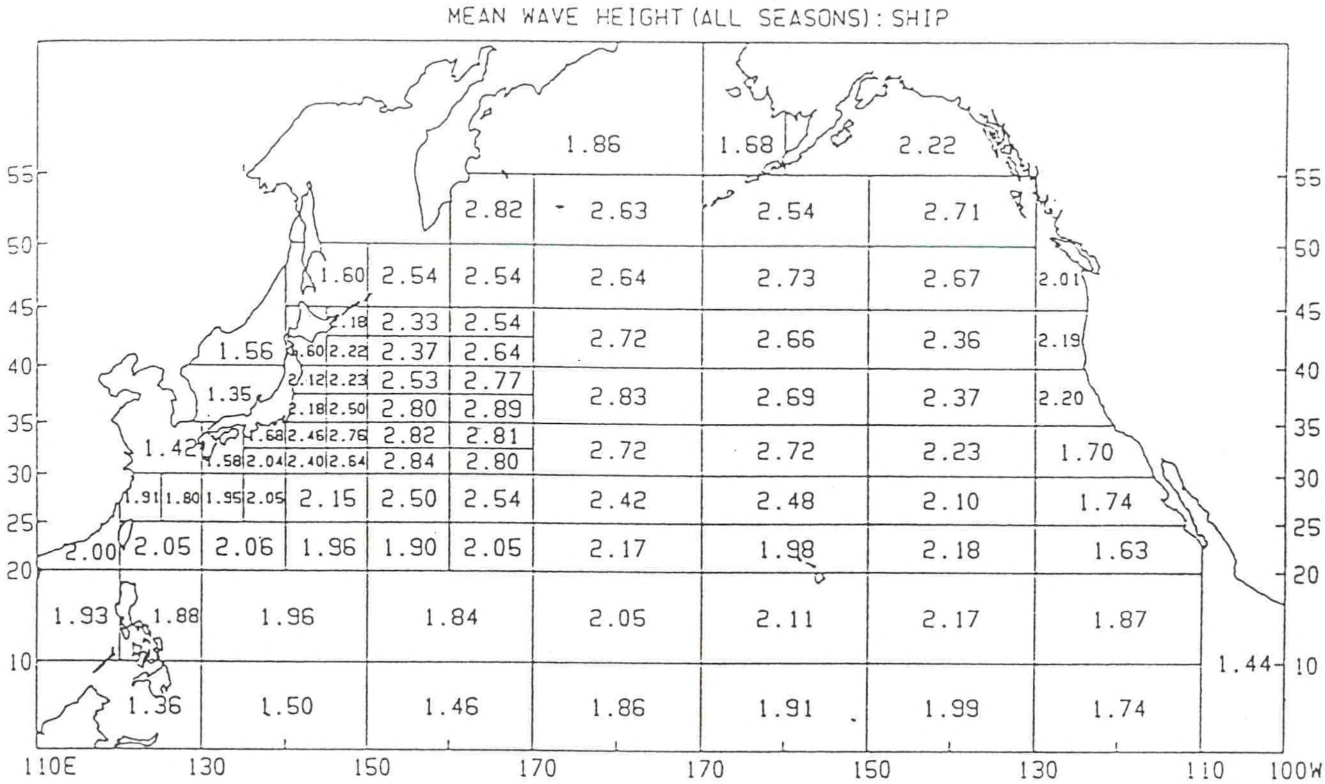


Fig.7 Mean Wave Height by Zones from Ship Data

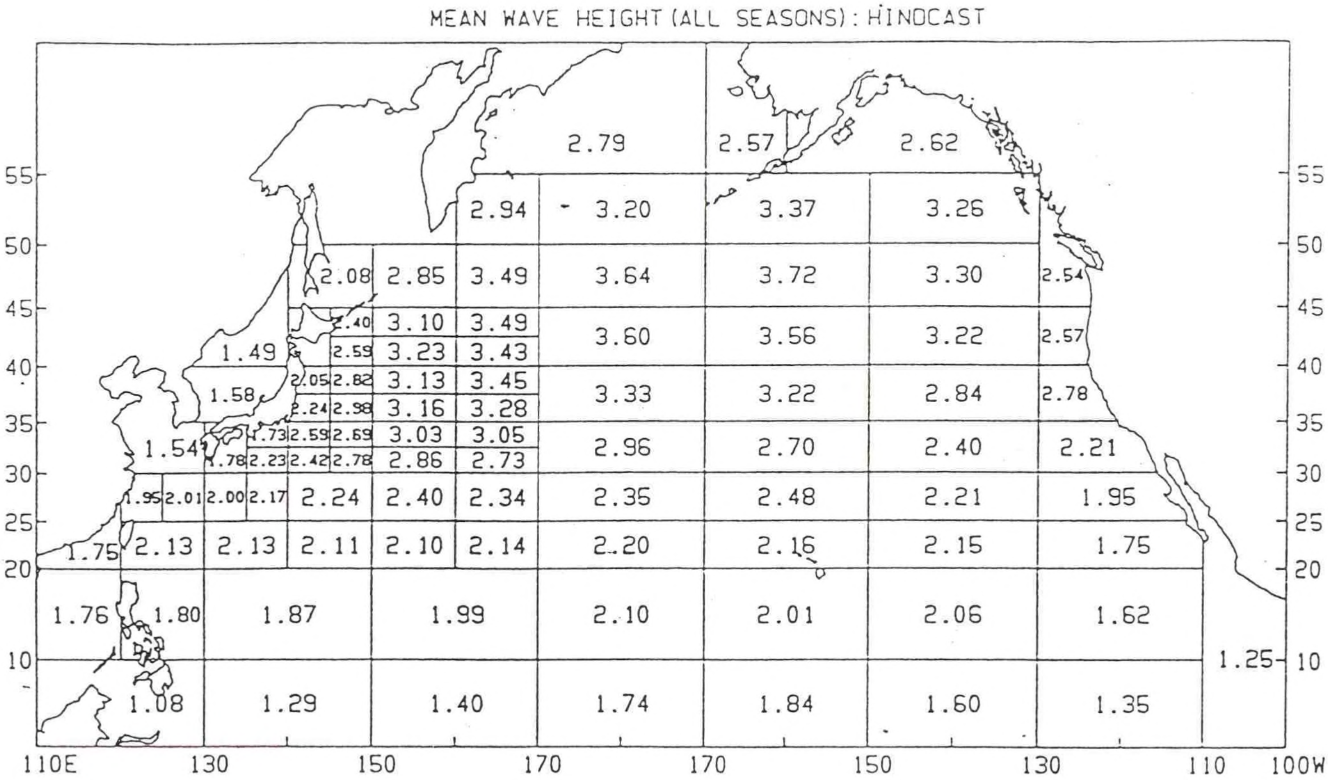
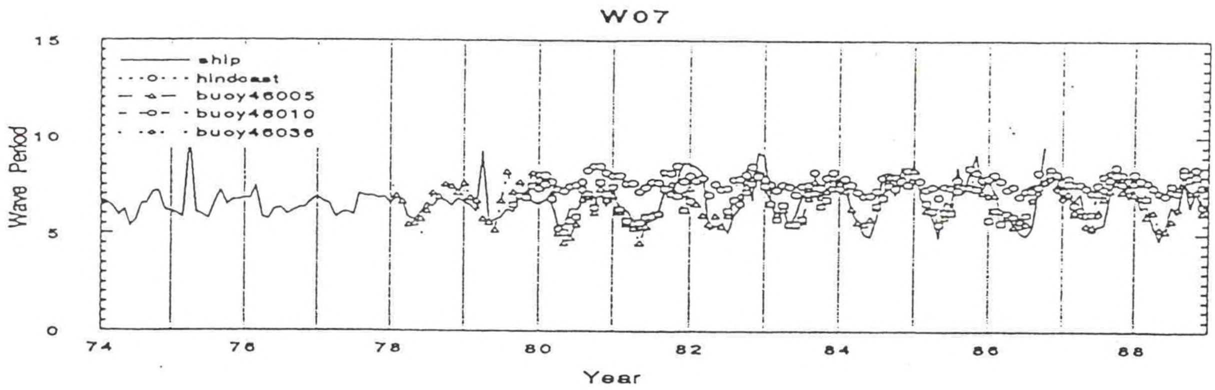


Fig.8 Mean Wave Height by Zones from Hindcast Data



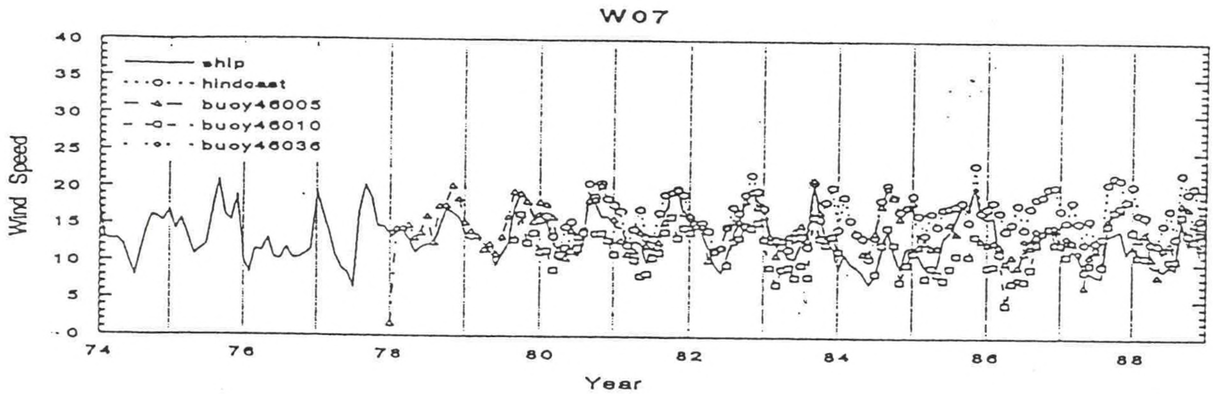


Fig.9 Monthly Variation of Mean Wave Height and Wind Speed

1980-1989 All seasons

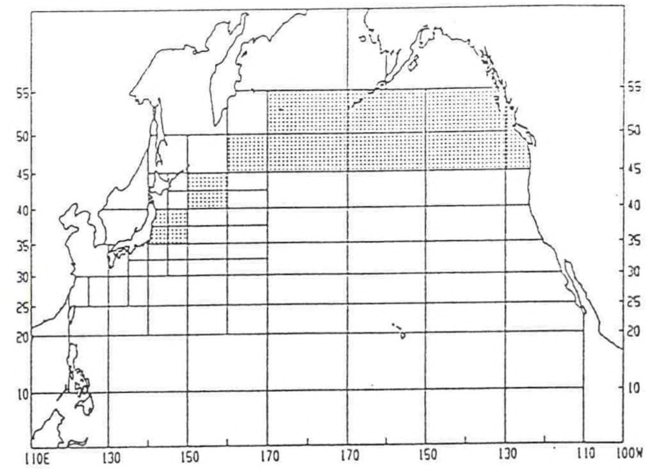
MULTIPLE AREA

MEAN OF WAVE HEIGHT 2.56 M
MEAN OF WAVE PERIOD 6.79SEC

PERIOD (SEC)

HEIGHT (M)	0-	5-	6-	7-	8-	9-	10-	11-	12-	13-	14-	TOTAL
14.75-		4	1	2	1	1	23	6	12	3	13	66
13.75-	1	1			4	2	5	2	5	3	10	33
12.75-		1	2	1	9	2	17	4	25	2	14	77
11.75-	3	5	4	4	34	17	84	12	39	9	37	248
10.75-	8	4	3	3	18	15	25	15	39	9	60	199
9.75-	7	9	75	57	137	106	252	62	183	54	160	1112
8.75-	5	5	88	70	186	126	245	99	176	53	218	1271
7.75-	3	9	120	145	435	268	536	169	407	97	373	2562
6.75-	11	21	1270	732	1323	813	1390	377	886	206	729	7758
5.75-	212	419	897	1154	2408	1553	2991	816	1663	411	1010	13544
4.75-	553	1110	2107	2872	6236	3852	6019	1479	2758	522	1037	28545
3.75-	1609	3463	7651	10093	18210	9611	10855	2145	3344	629	1210	68820
2.75-	6330	13245	25568	27242	32967	11675	10658	2235	2956	659	1322	134857
1.75-	33786	42509	51052	33707	29576	8610	8318	1468	2185	568	1377	213156
0.75-	84109	37425	25533	12978	10641	3085	3445	606	1021	289	656	179788
0.00-	24895	3082	1335	525	599	211	252	65	27	7	12	31020
TOTAL	151532	101312	115706	89595	102784	39947	45135	9560	15726	3521	8238	683056
MAX	14.00	15.00	16.00	17.00	15.00	17.00	20.00	20.00	17.00	17.50	20.00	

DATE (MAX HEIGHT) 06h 05-JUL-80



1980-1988 Spring

MULTIPLE AREA

MEAN OF WAVE HEIGHT 2.69 M
MEAN OF WAVE PERIOD 7.01SEC

PERIOD (SEC)

HEIGHT (M)	0-	5-	6-	7-	8-	9-	10-	11-	12-	13-	14-	TOTAL
14.75-						1	4	2	5	2		14
13.75-					1	1	1		4	1	2	10
12.75-					2			4	11		4	21
11.75-	1		2		10	1	27	1	14	1	13	70
10.75-	2			1	5	2	8	3	8	6	21	56
9.75-	1	4	11	18	33	29	91	9	35	15	53	299
8.75-			22	19	46	48	58	26	47	17	58	341
7.75-	1	3	24	46	137	70	147	46	127	33	123	757
6.75-	2	4	347	215	346	249	384	106	267	61	210	2191
5.75-	41	119	241	278	706	475	832	228	485	109	248	3762
4.75-	131	268	550	832	1781	1192	1787	434	759	153	315	8202
3.75-	466	950	2058	2958	5380	2763	3093	616	953	189	334	19660
2.75-	1671	3755	7303	7825	9537	3374	3169	632	835	180	407	38688
1.75-	8922	10969	12743	8535	8133	2405	2460	449	642	184	416	55858
0.75-	18524	8208	5392	2790	2589	788	849	157	270	68	152	39787
0.00-	4826	588	222	88	130	56	54	17	6	2		5989
TOTAL	34588	24868	28915	23505	28836	11454	12964	2730	4468	1021	2356	175705
MAX	12.50	10.00	12.00	11.00	14.00	17.00	20.00	20.00	15.50	17.50	14.00	

DATE (MAX HEIGHT) 18h 15-APR-80

1980-1988 Summer

MULTIPLE AREA

MEAN OF WAVE HEIGHT 1.89 M
MEAN OF WAVE PERIOD 5.90SEC

PERIOD (SEC)

HEIGHT (M)	0-	5-	6-	7-	8-	9-	10-	11-	12-	13-	14-	TOTAL
14.75-			1	1			5		1		1	9
13.75-					1		2				1	4
12.75-							1			1		2
11.75-	2				3		7					12
10.75-			1		1			1	1		11	15
9.75-	1		3	3	5	4	5	1	4	1	6	33
8.75-	1	1	5	4	4	5	9		2	1	6	38
7.75-		2	7	6	8	15	17	7	10	2	15	89
6.75-	2	3	45	38	54	26	63	10	25	4	37	307
5.75-	25	29	56	61	119	71	149	34	68	17	56	685
4.75-	62	122	170	233	460	245	393	86	161	28	70	2030
3.75-	212	425	919	1264	2097	1064	1080	177	273	58	116	7685
2.75-	1166	2667	5170	5524	6074	2028	1738	273	435	77	193	25345
1.75-	9892	13949	17510	11669	9132	2466	2172	333	507	132	339	68101
0.75-	38748	17956	12573	6293	4587	1281	1394	239	399	108	261	83839
0.00-	13278	1670	789	303	289	106	125	31	12	1	7	16611
TOTAL	63389	36824	37249	25399	22834	7311	7160	1192	1898	430	1119	204805
MAX	12.50	9.00	16.00	17.00	14.00	10.00	20.00	11.50	15.00	13.00	17.50	

DATE (MAX HEIGHT) 06h 05-JUL-80

1980-1988 Autumn

MULTIPLE AREA

MEAN OF WAVE HEIGHT 2.71 M
MEAN OF WAVE PERIOD 6.91SEC

PERIOD (SEC)

HEIGHT (M)	0-	5-	6-	7-	8-	9-	10-	11-	12-	13-	14-	TOTAL
14.75-		3					5		2		6	16
13.75-		1			1			1	1		3	7
12.75-			1		5	1	5		4		4	20
11.75-		2		2	13	5	19	3	6		9	59
10.75-	2	1	2		8	5	9	6	11	1	13	58
9.75-	3	3	22	20	40	24	68	19	48	21	37	305
8.75-	1		20	23	62	35	76	30	23	12	49	331
7.75-	1	1	33	43	151	84	152	43	103	22	81	714
6.75-	4	7	359	214	409	186	359	100	193	40	178	2049
5.75-	53	107	257	345	690	404	772	206	409	97	283	3623
4.75-	149	317	660	832	1696	1006	1544	362	706	133	265	7670
3.75-	425	1045	2212	2935	4882	2608	2812	560	868	155	335	18837
2.75-	1803	3593	6753	7388	8866	3153	2725	588	787	196	299	36151
1.75-	8375	10206	12486	8035	7207	2051	1952	352	509	125	293	51591
0.75-	17299	7588	5002	2673	2087	577	721	116	194	58	119	36434
0.00-	4663	561	210	82	104	28	48	7	4	3	4	5714
TOTAL	32778	23435	28017	22592	26221	10167	11267	2393	3868	863	1978	163579
MAX	11.50	15.00	13.00	12.00	14.00	13.00	20.00	14.00	17.00	11.00	20.00	

DATE (MAX HEIGHT) 00h 10-NOV-80

1980-1988 Winter

MULTIPLE AREA

MEAN OF WAVE HEIGHT 3.20 M
MEAN OF WAVE PERIOD 7.67SEC

PERIOD (SEC)

HEIGHT (M)	0-	5-	6-	7-	8-	9-	10-	11-	12-	13-	14-	TOTAL
14.75-		1		1	1		9	4	4	1	6	27
13.75-	1				1	1	2	1		2	4	12
12.75-		1	1	1	2	1	11		10	1	6	34
11.75-		3	2	2	8	11	31	8	19	8	15	107
10.75-	4	3		2	4	8	8	5	19	2	15	70
9.75-	2	2	39	16	59	49	98	33	96	17	64	475
8.75-	3	4	41	24	74	38	102	43	104	23	105	561
7.75-	1	3	56	50	139	99	220	73	167	40	154	1002
6.75-	3	7	519	265	514	352	584	161	401	101	304	3211
5.75-	93	164	343	480	893	603	1238	348	701	188	423	5474
4.75-	211	403	727	975	2299	1409	2295	597	1132	208	387	10643
3.75-	506	1043	2462	3036	5851	3176	3870	792	1250	227	425	22638
2.75-	1690	3230	6342	6505	8490	3120	3026	742	899	206	423	34673
1.75-	6597	7385	8313	5468	5104	1688	1734	334	527	127	329	37606
0.75-	9538	3673	2566	1222	1378	439	481	94	158	55	124	19728
0.00-	2128	263	114	52	76	21	35	10	5	1	1	2706
TOTAL	20777	16185	21525	18099	24893	11015	13744	3245	5492	1207	2785	138967
MAX	14.00	15.00	13.00	15.00	15.00	14.00	18.50	18.00	15.00	17.00	20.00	

DATE (MAX HEIGHT) 12h 14-FEB-81

Fig.10 Scatter diagram of Wave Height and Period along Higher Latitude route

1974-1988 All seasons

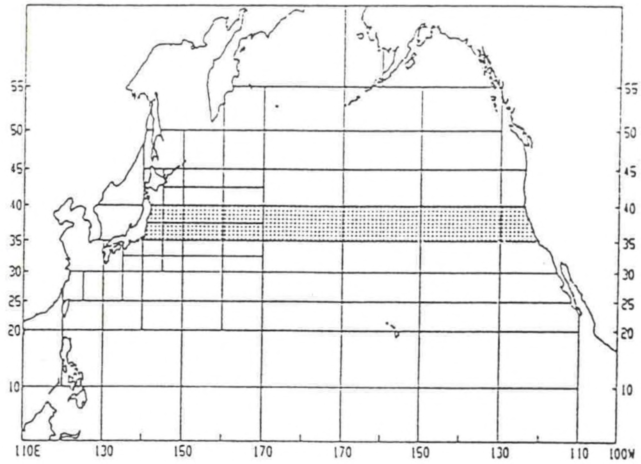
MULTIPLE AREA

MEAN OF WAVE HEIGHT 2.52 M
MEAN OF WAVE PERIOD 6.78SEC

PERIOD (SEC)

HEIGHT (M)	0-	5-	6-	7-	8-	9-	10-	11-	12-	13-	14-	TOTAL
14.75-		1	4	1	3	1	39	7	10	4	23	93
13.75-					5	8	1	5	7		6	32
12.75-				3	8	4	6	8	10	2	19	60
11.75-	1	3	3	4	15	13	125	25	33	16	44	289
10.75-	4	3	7	3	25	17	23	16	18	17	51	184
9.75-	6	11	52	56	153	98	174	73	131	58	142	960
8.75-	13	11	57	91	171	161	210	102	159	63	224	1282
7.75-	10	11	114	149	303	250	378	152	325	113	325	2131
6.75-	18	46	1536	910	1087	879	1052	389	798	255	562	7492
5.75-	124	467	857	1064	2015	1429	2134	854	1437	399	789	11568
4.75-	299	1204	1934	2553	5649	4251	5378	1653	2441	572	1155	27189
3.75-	1144	3866	7210	10664	18867	10822	10261	2506	3341	884	1449	71014
2.75-	5755	16113	25397	31157	35419	14021	11528	2598	3322	898	1714	147922
1.75-	29509	49436	50418	38735	33409	11154	9240	2092	2739	927	2366	230025
0.75-	70341	51762	26205	15339	13901	4368	4130	913	1502	575	1126	191168
0.00-	22064	4659	1124	717	755	265	351	216	17	9	14	30191
TOTAL	129288	127593	114994	102446	111791	47740	45031	11615	16300	4792	10010	721600
MAX	12.50	15.00	15.00	17.00	20.00	15.00	20.00	20.00	20.00	20.00	20.00	

DATE (MAX HEIGHT) 06h 15-NOV-88



1974-1988 Spring

MULTIPLE AREA

MEAN OF WAVE HEIGHT 2.58 M
MEAN OF WAVE PERIOD 6.84SEC

PERIOD (SEC)

HEIGHT (M)	0-	5-	6-	7-	8-	9-	10-	11-	12-	13-	14-	TOTAL
14.75-			2		1		11	3	4		3	24
13.75-					1	3		1	3		1	9
12.75-						1	1		3	1	7	13
11.75-	1	1	2	1	3	2	42	6	13	4	17	92
10.75-	3	2	3		7	3	11	2	5	4	16	56
9.75-	3	5	15	21	23	24	32	25	38	11	32	229
8.75-	3	2	19	22	42	41	54	30	40	9	43	305
7.75-	1	2	37	48	73	66	83	39	100	34	84	567
6.75-	7	18	468	229	305	211	305	110	218	75	129	2075
5.75-	37	123	256	327	501	387	568	223	376	109	173	3080
4.75-	83	326	599	712	1520	1268	1493	459	641	160	316	7577
3.75-	330	1134	2093	3042	5505	3114	2860	660	923	209	405	20275
2.75-	1575	4658	7414	8853	10731	4161	3392	806	1038	220	506	43354
1.75-	8427	14008	13507	10600	9791	3387	2806	699	893	284	842	65244
0.75-	17889	12630	6174	3892	3571	1219	1215	279	411	157	332	47769
0.00-	5034	1093	256	179	179	69	83	47	7	2	3	6942
TOTAL	33393	33392	30845	27926	32253	13956	12956	3389	4713	1279	2909	197611
MAX	12.50	12.50	15.00	12.00	15.00	14.00	20.00	16.50	20.00	13.00	16.00	

DATE (MAX HEIGHT) 06h 09-MAY-74

1974-1988 Summer

MULTIPLE AREA

MEAN OF WAVE HEIGHT 1.90 M
MEAN OF WAVE PERIOD 6.06SEC

PERIOD (SEC)

HEIGHT (M)	0-	5-	6-	7-	8-	9-	10-	11-	12-	13-	14-	TOTAL
14.75-				1			7			1		9
13.75-												0
12.75-								2			1	3
11.75-					1		4					5
10.75-	1		1				2					4
9.75-	1	2	4	3	2	4	11	3	1	3	5	39
8.75-	1	1	2	2	6	4	6	3	5	2	3	35
7.75-	1	1	8	6	8	3	9	5	11	3	6	60
6.75-	1	3	60	44	41	42	24	6	20	3	16	250
5.75-	14	36	76	65	107	65	70	33	56	10	49	581
4.75-	41	131	171	214	419	296	288	129	128	18	85	1920
3.75-	155	453	876	1175	1764	932	871	219	247	72	104	6868
2.75-	894	2723	4519	5237	5292	1923	1603	324	362	106	191	23174
1.75-	6835	13289	15083	11023	8734	2671	1835	380	456	157	515	60978
0.75-	26686	20570	11118	6655	5342	1603	1295	287	470	160	350	74526
0.00-	9676	2094	538	314	298	101	123	45	5	4	9	13207
TOTAL	44306	39303	32456	24739	22014	7644	6137	1436	1761	539	1334	181663
MAX	11.00	10.00	11.50	17.00	12.00	10.00	20.00	13.00	10.00	15.50	13.00	

DATE (MAX HEIGHT) 18h 07-JUN-75

1974-1988 Autumn

MULTIPLE AREA

MEAN OF WAVE HEIGHT 2.56 M
MEAN OF WAVE PERIOD 6.79SEC

PERIOD (SEC)

HEIGHT (M)	0-	5-	6-	7-	8-	9-	10-	11-	12-	13-	14-	TOTAL
14.75-			1		1		10		1	2	4	19
13.75-					4			4	2			10
12.75-				1	5	3	1	1	2		3	16
11.75-		1	1		7	5	24	3	6	2	12	61
10.75-			1	1	9	8	5	6	8	5	10	53
9.75-		4	16	8	46	28	51	12	32	18	41	256
8.75-	1	3	19	23	43	38	62	29	47	15	76	356
7.75-	2	5	24	39	75	54	89	38	58	17	85	486
6.75-	2	14	338	191	220	223	232	99	153	47	126	1645
5.75-	29	135	202	258	550	430	528	226	353	106	195	3012
4.75-	64	353	541	749	1549	1077	1397	387	637	153	301	7208
3.75-	290	1097	2034	2951	5107	2924	2826	731	931	220	357	19468
2.75-	1666	4444	7143	9232	10250	4164	3158	757	917	290	470	42491
1.75-	8300	13349	13998	10899	9301	2993	2536	564	714	260	523	63437
0.75-	17627	13085	6337	4051	3305	1008	958	203	348	132	244	47298
0.00-	5120	1084	232	160	176	65	88	78	3	2	1	7009
TOTAL	33101	33574	30887	28563	30648	13020	11965	3138	4212	1269	2448	192825
MAX	9.00	12.50	15.00	13.00	20.00	13.50	20.00	14.00	15.00	20.00	20.00	

DATE (MAX HEIGHT) 06h 15-NOV-88

1974-1988 Winter

MULTIPLE AREA

MEAN OF WAVE HEIGHT 3.15 M
MEAN OF WAVE PERIOD 7.56SEC

PERIOD (SEC)

HEIGHT (M)	0-	5-	6-	7-	8-	9-	10-	11-	12-	13-	14-	TOTAL
14.75-		1	1		1	1	11	4	5	1	16	41
13.75-						5	1		2		5	13
12.75-				2	3		4	5	5	1	8	28
11.75-		1	6	3	4	6	56	16	14	10	15	131
10.75-		1	2	2	9	6	5	8	5	8	25	71
9.75-	2		17	24	88	42	80	33	60	25	64	436
8.75-	8	5	27	44	80	78	88	40	77	37	102	586
7.75-	6	3	45	56	147	127	198	70	156	59	151	1018
6.75-	8	11	730	346	521	403	491	174	407	130	291	3512
5.75-	44	173	323	414	857	546	968	372	652	174	372	4895
4.75-	111	394	623	978	2161	1610	2200	678	1035	241	453	10484
3.75-	369	1182	2207	3496	6491	3852	3704	896	1240	383	583	24403
2.75-	1620	4288	6321	7835	9146	3773	3375	711	1005	282	547	38903
1.75-	5947	8790	7830	6213	5583	2103	2063	449	676	225	486	40366
0.75-	8139	5477	2576	1741	1683	538	672	150	273	126	200	21575
0.00-	2234	398	98	64	102	30	57	46	2	1	1	3033
TOTAL	18488	20724	20806	21218	26876	13120	13973	3652	5614	1705	3319	149495
MAX	10.50	15.00	15.00	13.00	15.00	15.00	16.00	20.00	15.00	16.50	20.00	

DATE (MAX HEIGHT) 06h 06-JAN-78

Fig.11 Scatter diagram of Wave Height and Period along Lower Latitude route

Appendix

CONTENTS of Winds and Waves of the North Pacific Ocean(1974-1988)

by I.Watanabe, H.Tomita and K.Tanizawa

(Supplement No.4, Report of Ship Research Institute, May 1992)

CONTENTS

Appendixes

A. Definition of Wave Height and Wave Period

B. Data Generation by Hindcasting

C. On Nature of Large Wave Heights in Ship Reports

D. Monthly Variation of Zonal Mean Values

E. Operation Manual of PC version Wave Data Base

TECHNOLOGY NEEDED TO ENHANCE THE GLOBAL OCEAN OBSERVING SYSTEM

Paul Kilho Park
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Washington, DC 20235-0001
Phone:(202)606-4360 FAX:(202)606-4355

INTRODUCTION

An end-to-end approach to carry out the Global Ocean Observing System (GOOS) in the 21st century is essential for the humanity to sustain and survive on earth, which is covered nearly 70% by the oceans. Vigorous participation by the ocean engineering community worldwide is especially needed now while GOOS is being developed. In addition to the coupling of engineering and science, socioeconomic consideration too must be thought and sought at the same time.

In March 1991, the Intergovernmental Oceanographic Commission (IOC) of the United Nations embarked on an ambitious project to create GOOS among 117 member nations. Both Japan and the U.S. are the leaders of this undertaking, especially Japan taking the lead role in the Pacific Ocean.

The GOOS aims to improve the understanding and prediction of the state and health of the world ocean, and the vital role of the ocean in global climate change prediction by collecting and analyzing biological, chemical and physical data from all over the world's oceans and seas. It also is an essential effort to supply the oceanic in situ data to satellite operation to calibrate and augment the powerful remote sensing tools.

In Japan both the Science and Technology Agency and Japan Marine Science and Technology Center are leading the GOOS effort, while in the U.S. NOAA has been developing the NOAA portion of the U.S. plans entitled "Globally Enhanced Oceanic Measurement, Analyses, and Production (GEOMAP)." The NOAA plans have been significantly advanced by Professor Dana Ray Kester of the University of Rhode Island while he was in NOAA, August 1990 - June 1992. Upon the departure of Professor Kester back to his university, its continued development is shepherded by Drs. W. Stanley Wilson and Melbourne G. Briscoe of the National Ocean Service, the ocean part of NOAA. For the biological component of GEOMAP, Dr. Kenneth Sherman of National Marine Fisheries Service, another part of NOAA, is developing the necessary monitoring strategy through his Large Marine Ecosystems (LMEs) concept.

THE GOOS CORE MEASUREMENTS

The GOOS must be operational and sustainable. The core sampling strategy evolving must be cost-effective and hopefully is user-friendly from early on. It must be continually improved based on the feedback from the users, be they ocean modelers, weather and ocean forecasters, and other maritime safety and resource managers. In this report I quote heavily the works of Drs. Kester and Sherman.

In March 1992, Professor Kester drafted a NOAA internal document entitled "Globally Enhanced Oceanic Measurements, Analyses and Prediction; a NOAA contribution to the Global Ocean Observing System." In it the eight basic oceanic variables to be measured initially and the rationale for measuring them are given as follows:

1. Wind velocity over the ocean Essential to develop coupled atmosphere-ocean global circulation models as well as to determine fluxes of heat, water, momentum, and gases.

2. Sea surface temperature and salinity Important to elucidate the energy and water exchanges between the ocean and the atmosphere.

3. Oceanic temperature and salinity profiles in the upper 200 meters, the main thermocline (200-1500 meters), and the deep ocean (> 1500 meters) are required to address problems of climate variations on seasonal, interannual, and decadal time scales. To provide the basis for determining the heat, salt, and water content of oceanic regions, which in turn becomes useful to observe the climate variations from seasons to decades.

4. Surface currents To understand heat, salt and water transport in the portion of the ocean that exchanges rapidly with the atmosphere. Comparison of observed surface currents with those computed from ocean circulation models can provide one strong test of the validity of the model calculations for other properties.

5. Sea level We already have more than 100 years of experience at many locations. National networks exist, and we are well on our way to a global sea-level network.

6. The extent and thickness of sea ice Sea ice, along with other portions of the cryosphere (that portion of the Earth's surface covered by ice), is a critical component of the climate system.

7. The partial pressure of carbon dioxide in the atmosphere and upper ocean determines the rate of exchange of this major "greenhouse" gas.

8. The chlorophyll concentration of surface waters A measure of phytoplankton abundance. Oceanic primary production fixes CO2 into organic carbon and transforms bicarbonate into calcium carbonate solid phases. Marine biogeochemical processes play a vital role in the Earth's climate system, in the health of coastal ecosystems, and in sustaining oceanic living marine resources.

The importance of mathematical models cannot be under-estimated, for any measurement systems are incomplete to represent the oceans in time and space. Professor Kester stresses that models are to provide a dynamically consistent context to evaluate and interpret observations. His hypothetical late 1990s Global Ocean Observing System is shown in Figure 1.

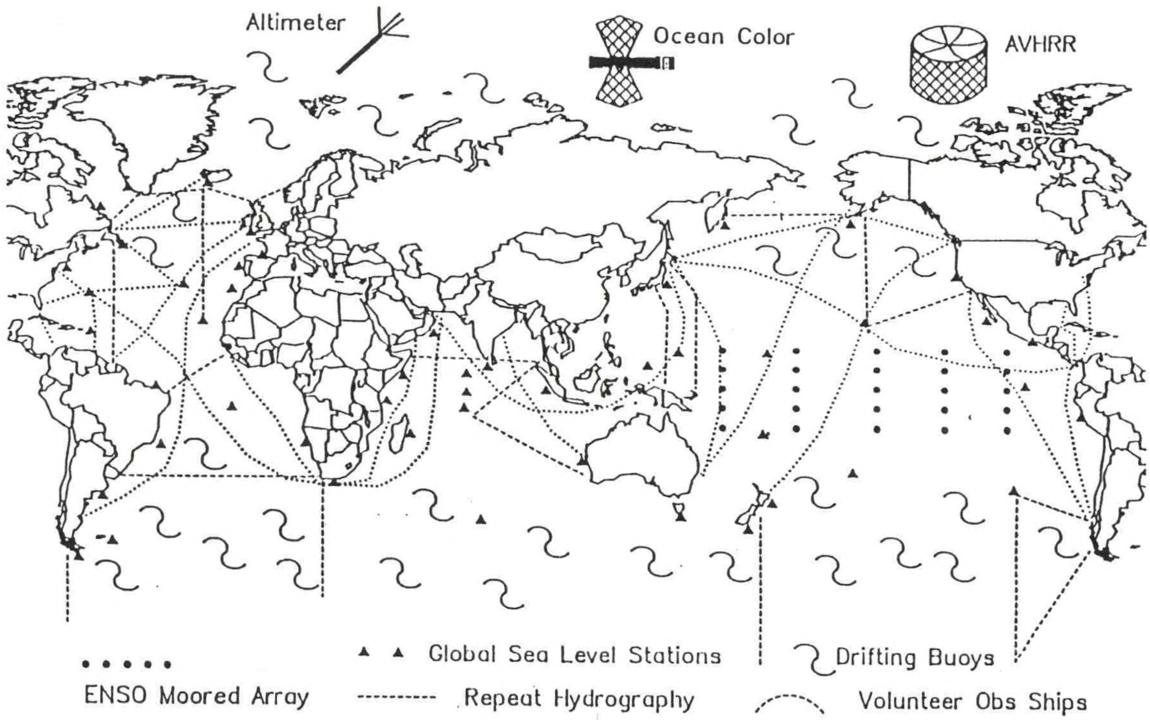

Figure 1. Schematic late 1990s Global Ocean Observing System (Kindness of Professor Dana Ray Kester)

For biological measurements, Dr. Kenneth Sherman in recent years has been advancing the Large Marine Ecosystems (LMEs) concept. He and his coworkers have delineated 49 LMEs worldwide (Figure 2).

He and his coworkers have developed a "core" monitoring strategy for LMEs as given below:

1. A Continuous Plankton Recorder/Undulating Oceanographic Recorder (CPR/UOR) to measure variability in LMEs health. The CPR/UOR sensor package measures the following:
   a. Zooplankton species composition, biomass, biodiversity, and size;
   b. Phytoplankton species composition, biomass as chlorophyll, a pump and probe sensor to measure productivity, diatom/flagellate ratios, and size;
   c. Salinity;
   d. Temperature;
   e. Hydrocarbons;
   f. Light;
   g. Oxygen.

2. A small, coastal, vessel sampling program using nets and acoustics to:
   a. Measure species abundance, biodiversity, and stock levels;
   b. Gather data on fish age, growth, size;
   c. Gather data on predator-prey interactions from stomach sampling;
   d. Make observations on gross pathology;
   e. Obtain simultaneous measurements of temperature and salinity;
   f. Sample for pollutants and photograph macrobenthos on an opportunistic basis.

3. Use of satellite images for characterizing water mass

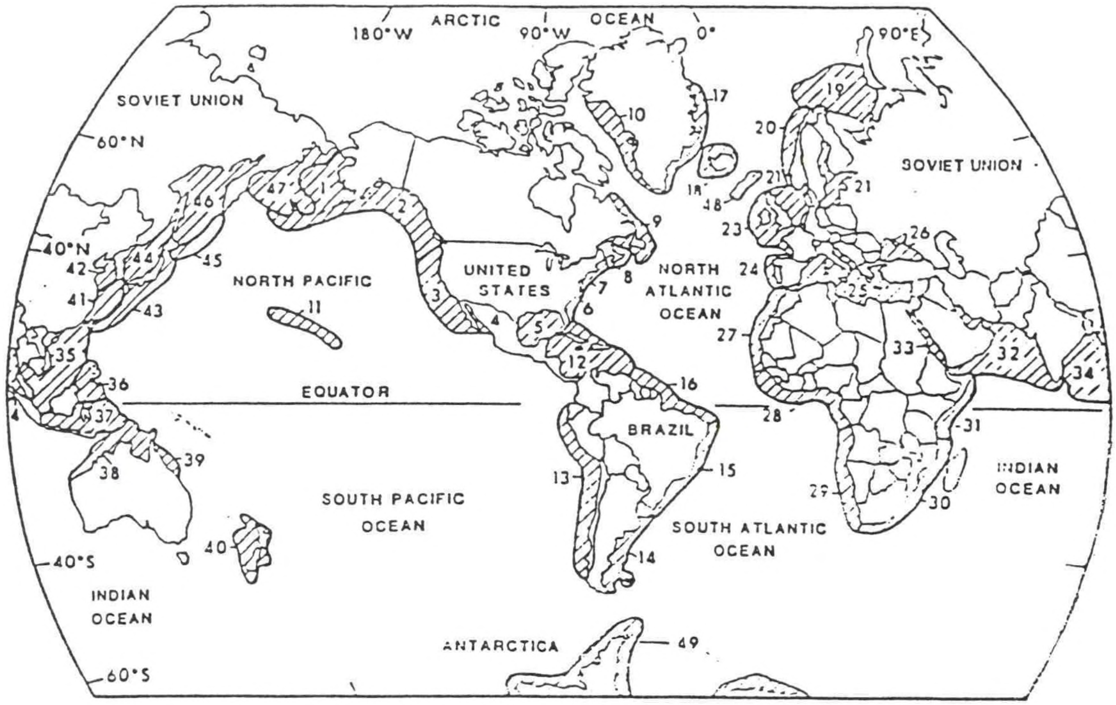

Figure 2. World map of Large Marine Ecosystems (Kindness of Dr. Kenneth Sherman)

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1. Eastern Bering Sea
2. Gulf of Alaska
3. California Current
4. Gulf of California
5. Gulf of Mexico
6. Southeast U.S. Continental Shelf
7. Northeast U.S. Continental Shelf
8. Scotian Shelf
9. Newfoundland Shelf
10. West Greenland Shelf
11. Insular Pacific–Hawaiian
12. Caribbean Sea
13. Humboldt Current
14. Patagonian Shelf
15. Brazil Current
16. Northeast Brazil Shelf
17. East Greenland Shelf
18. Iceland Shelf
19. Barents Sea
20. Norwegian Shelf
21. North Sea
22. Baltic Sea
23. Celtic-Biscay Shelf
24. Iberian Coastal
25. Mediterranean Sea
26. Black Sea
27. Canary Current
28. Guinea Current
29. Benguela Current
30. Agulhas Current
31. Somali Coastal Current
32. Arabian Sea
33. Red Sea
34. Bay of Bengal
35. South China Sea
36. Sulu-Celebes Seas
37. Indonesian Seas
38. Northern Australian Shelf
39. Great Barrier Reef
40. New Zealand Shelf
41. East China Sea
42. Yellow Sea
43. Kuroshio Current
44. Sea of Japan
45. Oyashio Current
46. Sea of Okhotsk
47. West Bering Sea
48. Faroe Plateau
49. Australia

movements and use of chlorophyll and temperature data for satellite intercalibrations.

For monitoring inshore-offshore extension of nutrients and eutrophication, systems of towed CPRs should be deployed and, where possible, moored buoys for collecting chlorophyll and productivity data.

JAPAN'S S&T POLICY

The basic science and technology policy of the government of Japan was issued by the Prime Minister's Council for Science and Technology on 24 January 1992. Based on the policy statement, Japan continues to build on its S&T for the future, including the future UJNR activities we deal with. The basic principles stated are: "For humans to construct a stable and more prosperous 21st century, it is absolutely necessary to further promote science and technology in harmony with human society and the environment. Especially, in Japan, where humans are its largest resource, future prosperity is heavily dependent on science and technology. Realizing this and recognizing that Japan should contribute to the international society and humans as a whole, the government strives to develop a positive and comprehensive policy on science and technology with the following three goals:

1. Coexistence of humans in harmony with the Earth: Japan will aim at solving various issues such as global environmental energy and food issues, constructing a stable international order and solving the north-south problems.

2. Expansion of intellectual stock: Japan will accumulate well-balanced high-quality scientific knowledge including results of basic research so that all humans will be benefitted.

3. Construction of a charming society where people can live with peace of mind: Japan will make the quality of national life more affluent, while coping with and solving social issues such as the sharp increase in the number of old people."

Priority measures to be promoted include:

1. Harmonization between S&T and human society
2. Securing S&T personnel
3. Increase of R&D investment
4. Modernization of R&D infrastructure
5. Activation of research and improvement of creativity
6. Intensification of international S&T activities
7. Promotion of regional (within Japan) S&T

As UJNR strives toward bilateral cooperation between Japan and the U.S. it is gratifying to see the long-term view of the Item 6 above on the international collaboration. The Japanese government position on this is as follows:

In order to intensify international activities, considering Japan's position in international society, the government will:

1. Promote international collaborative R&D; propose and lead international collaborative R&D adopting

original idea of Japan; to improve the environment required for promoting the international collaborative R&D;

2. Examine how Japan should cope with each project of "mega-science" (which refers to projects absolutely requiring international cooperation because participation of researchers and engineers from a wide range of areas and very large or complex facilities are necessary) with subjectivity in reference to the discussion among scientists and engineers and Japan's research potential, paying attention not to cause pressure to other R&D activities while it is being promoted; to make efforts to form internationally common recognition of "mega-science".

3. Take following action to expand science and technology cooperation for developing countries based on the concept that cooperation suitable for the situation of each country should be extended mainly for creating human resources as an aid to their own efforts:

a) Enhancement of the chances of dialogues to identify developing countries' need for cooperation. Intensification of the function of clearing houses which provide information concerning S&T in developing countries and Japan.

b) Expansion of the technical assistance in the official development aid such as the reception of trainees and dispatch of experts and improvement of effectiveness of the cooperation by intensifying liaison with fund assistance.

c) Continuous and systematic expansion of the research cooperation and intensification of cooperation in cultivating human resources with the countries in regions including Asia-Pacific region, which are aimed at the improving their own R&D ability and have to cope with a variety of S&T.

d) Securing of the close liaison between research cooperation and technical and fund assistance to improve cooperation effectively.

4. Extend research cooperation and, as required, technical assistance for the former Soviet Union etc. to help develop a market economy;

5. Establish an internationally open research scheme by promoting the employment and acceptance of foreign researchers and by smoothing their activities in Japan, while implementing training on the Japanese language and expanding fellowship; to expand the dispatch of Japanese researchers and administrators to foreign countries;

6. Expand the international distribution of S&T information: and

7. Promote the international transfer of S&T by making efforts to standardize the protection level of intellectual property and other areas concerned with S&T.

Personally I applaud Japan's position on international cooperation. Although some cultural barrier still exists between Japan and the U.S., the U.S. policy too is very open-minded in international cooperation, especially in such areas as mega-science and assisting the developing countries. In the field of natural disaster reduction, I have been assisting the U.S. government-wide Subcommittee on Natural Disaster Reduction since 1990 to carry out the Japan-U.S. accord of 9 January 1992 that specifically spells out to assist jointly developing countries. For instance, on 9 January 1992, Prime Minister Miyazawa and President Bush jointly announced the Global Partnership Plan of Action, in which the two heads of the state agreed to "cooperate to reduce natural hazards, in accordance with the International Decade for Natural Disaster Reduction and the Japan-U.S. Science and Technology Agreement, by assisting developing countries to prepare disaster reduction plans, including hazard mapping, risk assessment and the establishment of databases:..." In the same spirit, Japan and the U.S. have been working together to promote GOOS already.

JAPAN-U.S. COOPERATION ON GOOS

In February 1992 Mr. Yoshiro Miki, then Director of Ocean Development Division at Science and Technology Agency invited Professor Dana R. Kester to Japan for one week to mutually develop bilateral cooperation for GOOS. Their collective recommendations they drafted are an important milestone for our quest to implement the GOOS activities in the future. Their recommendations to both Japan and the U.S. are shown below; I hope that our two countries agree to carry on the priority recommendations being developed by them timely and effectively. Ocean technologists should be <u>bona fide</u> part of this important endeavor from the beginning.

Recommendations for Japan-U.S. Cooperation in The Development of a Global Ocean Observing System

by Yoshiro Miki, Japan, and Dana R. Kester, USA

In 1991 the 117 member states of the Intergovernmental Oceanographic Commission launched an effort to establish a Global Ocean Observing System (GOOS) to address issues of global change, to implement El Nino-Southern Oscillation forecasts, to provide data required for the applications of global ocean circulation models, and to extract the maximum value from the investment by the world's space agencies in ocean remote sensing (more than one billion U.S. dollars over ten years). The objectives of the GOOS will focus on new levels of oceanic and climatic predictability, on assessing coastal pollution, and on determining the sustainability of living marine resources. The GOOS will be a complete system, including satellite observations, <u>in situ</u> observations, numerical modeling of oceanic processes, and the exchange, processing, and management of diverse oceanic data sets. A series of practical and economic benefits will be derived from the information generated by the GOOS.

Japan and the U.S. share a common interest in developing an ocean observing system that draws upon the strengths of both countries and that will provide the most effective use on the resources that each can contribute to GOOS. This mutual interest naturally focuses on the Pacific Basin, though it also recognizes the importance of such regions as the Arctic Basin, the Southern Ocean, and the Indian Ocean. Following a series of initial discussions, we recommend that the following steps be taken to foster cooperation between the U.S. and Japan in the development of a Global Ocean Observing System:

1. A Japan-U.S. GOOS Development Working Group should be established to address the following topics:
   a) Oceanic and climatic predictions
      i. ENSO observations and predictions
      ii. Ocean time-series measurements
   b) Large Marine Ecosystems
      i. The East China Sea
      ii. The equatorial Pacific upwelling
   c) Development of new ocean observing technology
   d) Data processing, exchange, and management
      i. Data quality control
      ii. Database structures
      iii. Data product generation

2. The Charge to this Working Group would be:
   a) Examine the status of each counry's GOOS development plans on a periodic basis.
   b) Review and modify, as appropriate, the basic GOOS concept.
   c) Coordinate the development of national GOOS plans to strive for consistency where possible.
   d) Identify and foster the implementation of joint Japan-U.S. GOOS project.

3. The Working Group should consist of about six people from each country who have expertise in the areas outlined above.

4. The initial meeting of the Working Group should be convened at a location in the U.S. during the summer of 1992. Subsequent meetings should alternate between the two countries at the rate of about two meetings a year for the next two years.

The development of the Pacific Basin portion of GOOS will require contributions and participation by as many Pacific nations as possible. As the Japan-U.S. Working Group achieves initial progress with its charge, consideration should be given to convening a Pacific Ocean Measurements Analyses, and Predictions (PacMAP) workshop with broad participation by countries interested in the development of GOOS.

On 9 January 1992 the President of the United States and the Prime Minister of Japan agreed to promote cooperation in the areas of Global Change Research and of Ocean Research. This joint effort to develop GOOS is one step toward that goal. The cooperation of Japan and the U.S. in the development of the ocean observing system will complement other ongoing areas of cooperation in marine science. The UJNR includes seven panels in the area of marine science and technology and the other marine Panels address specific topics such as Sea Bottom Surveys, Marine Mining, and Aquaculture. These Panels are not structured to address the development of GOOS. In November 1991, the Japan-U.S. workshop on Global Change Research identified a number of topics for coopertive projects pertaining to an Asian monsoon observing and monitoring system, the Global Climate Observing System, the coupled physical and biological interactons in the Pacific-Indian Ocean sector, and the long-term monitoring of upper ocean biogeochemical properties in the Pacific Ocean by a fixed buoy complement the effort to establish a GOOS.

In addition to pursuing joint efforts in the area of long-term ocean measurements, analyses, and predictions, we recommend that both countries continue, and where possible expand their support for the major international oceanic research programs that are advacning our basic knowledge of the oceans. These programs include TOGA, WOCE, JGOFS, and others being considered by the WCRP and IGBP.

We also recommend that both countries encourage the broad interntional participation in GOOS development which will be required to achieve a truly global system. This goal can be achieved by working through the IOC and by providing assistance and leadership to the IOC in its development of GOOS.

FUTURE CHALLENGE

Continuous technology development and improvement are mandatory to plan and execute the GOOS activities for humanity in the 21st century. As shown in Figure 1, a schematic GOOS for late 1990s shows much utilization of volunteer observing ships (VOS) that routinely transact the oceans. Presently sea surface temperature (SST) is measured by VOS but its data quality has been poor, resulting in 70% substandard data that are not useful. Precise and robust system is yet to emerge. Furthermore, power supply and data transmission system for drifting buoys and moored arrays need to be improved. When real-time data are needed, inexpensive data transmission system must be available, for the present system is very expensive.

Inexpensive sensors for <u>in situ</u> oceanic measurements too must be developed and improved. Professor Dana R. Kester suggests we work on the following items for routine, operational purposes, in addition to other important measurements.

a) Marine UV sensors for use on buoys and VOS
b) Salinity sensors based on conductivity, index of refraction, or sound speed
c) Barometric pressure sensors with good stability
d) Chlorophyll sensors for VOS and buoys
e) pH or pCO2 sensors
f) Rainfall sensors
g) Evaporation rate sensors
h) Oxygen sensors
i) Nutrient sensors or automated analyzers
j) Adaptation of XCTD sensors for re-use in wire-guided profilers

There are other challenges. Japan has made her S&T policy commitment on 24 January 1992. When the U.S. too makes a similar commitment, the forum of UJNR can greatly enhance the development and execution of important S&T programs, one of which is Global Ocean Observing System (GOOS), especially for the 21st century. I solicit the vigorous participation of the Japan-U.S. Ocean Engineering community in this endeavor from the planning stage.

ACKNOWLEDGMENT

I thank Professor Dana R. Kester of the University of Rhode Island who unselfishly shared with me both published and unpublished information on GOOS. As Goethe said: "Whatever you do, or dream you can, begin it. Boldness has genius, power and magic in it. Begin it now."

REFERENCE SOURCES

The best reference sources are to enquire directly to Drs. Kester, Sherman and Briscoe, for the GOOS planning is continually updated. I offer their addresses:

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Nation Wide Network of Coastal Wave Observation and its application to wave prediction

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ABSTRACT

The Bureau of Ports and Harbours of Ministry of Transport and its associated agencies including the Port and Harbours Research Institute(P.H.R.I.), have been taking a great effort since 1950s, to obtain the field data of the coastal waves around Japan and to utilize the obtained data for planning, design, and construction of the maritime structures. Since 1970, the P.H.R.I.has been processing and analyzing the wave records obtained at the network stations and the Nationwide Ocean Wave information network for Ports and HArbourS (NOWPHAS) has been functioning.

This paper explains the NOWPHAS system and several recent topics on the NOWPHAS, including a new real time data gathering system, characteristics of the observed waves in 1990, wave directional spectrum observation and analysis, and wave predictions using the NOWPHAS real time data. In the description of the wave predictions, newly developed method named 'a Multiple Regression wave forecast model described in PHysical parameters (MRPH)' is explained and the accuracies are checked by comparison with the observed waves.

1. Introduction

Ocean waves are the most important phenomenon to be considered among the various environmental conditions affecting maritime structures, because they exercise the greatest influence. The presence of waves makes the design procedure for maritime structures quite different from the procedure for structures on land. However, waves in the sea are one of the most complex and changeable phenomena in nature. To achieve a full understanding of the fundamental character and behavior of sea waves is not an easy task.

For this reason, the Bureau of Ports and Harbours of Ministry of Transport and its associated agencies including the Port and Harbours Research Institute (P.H.R.I.), have been taking a great effort since 1950s, to obtain the field data of the coastal waves around Japan, and to utilize the obtained data for planning, design, and construction of the maritime structures. As the result of the effort, several types of wave gauges were developed, modified and put into practical use. Among them the most notable type was the ultrasonic type wave gauge(USW).

The Bureau of Ports and Harbours has been gradually constructing wave observation stations all around Japan with its associated agencies, for the port facilities' planning, design and construction. Since 1970, the P.H.R.I. has been processing and analyzing the wave records obtained at those stations and the Nationwide Ocean Wave information network for Ports and HArbourS (NOWPHAS) has been functioning[1),2),3)].

This paper explains the NOWPHAS system and several recent topics on the NOWPHAS, including a new real time data gathering system[4)], characteristics of the observed waves in 1990[5)], wave directional spectrum observation and analysis[6)],and wave predictions using the NOWPHAS real time data. In the description of the wave predictions, newly developed method named 'a Multiple Re-

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Table 1 Historical Maximum Observed Waves at Each Station

Station	Wave Gauge	Depth (m)	Wave Height and Period				Year, Month Day, Hour	Atmospheric Phenomena	Observation Term
			$H_{1/3}$(m)	$T_{1/3}$(s)	H_{max}(m)	T_{max}(s)			
1	USW	-50.0	7.33	10.5	11.20	9.0	'82. 11. 25. 10:	W	70.01 ~
2	USW	-52.9	6.95	10.9	9.67	11.6	'81. 10. 24. 10:	W	80.01 ~
3	USW	-30.0	8.10	11.1	11.52	12.2	'86. 11. 11. 18:	W	79.12 ~
4	USW	-29.5	8.53	13.0	11.46	12.8	'90. 12. 2. 16:	T9028, W	88.09 ~
5	SRW-V	-45.0	8.63	12.6	9.94	11.5	'70. 2. 2. 2:	W	69.11 ~
6	USW	-35.0	5.63	11.8	8.37	11.5	'90. 11. 11. 6:	L, W	89.10 ~
7	USW	-22.7	6.34	11.8	9.02	12.3	'83. 12. 1. 16:	L	82.09 ~
8	USW	-27.0	7.19	10.5	10.30	11.0	'80. 1. 7. 8:	W	79.01 ~
9	USW	-20.2	7.82	14.1	12.01	16.2	'90. 12. 27. 10:	L, W	70.01 ~
10	USW	-21.3	7.79	13.2	10.10	11.8	'81. 12. 2. 6:	W	80.09 ~
11	USW	-30.0	7.51	11.2	12.57	10.3	'81. 12. 2. 4:	W	79.09 ~
12	USW	-51.0	7.93	11.2	12.31	12.5	'90. 12. 11. 18:	L, W	74.03 ~
13	USW	-20.7	5.61	12.1	9.39	14.4	'87. 2. 3. 18:	W	75.04 ~
14	USW	-28.0	7.72	12.3	11.52	13.5	'87. 2. 3. 18:	W	80.08 ~
15	USW	-50.0	6.81	12.1	8.92	11.6	'87. 7. 15. 20:	T8705	74.12 ~
16	USW	-50.0	7.49	11.1	10.97	10.2	'87. 1. 13. 14:	W	77.03 ~
17	USW	-51.0	9.24	14.1	13.77	14.9	'90. 10. 6. 20:	T9021	73.07 ~
18	USW	-52.0	7.73	12.8	11.21	13.1	'88. 10. 30. 18:	L, W	75.11 ~
19	USW	-50.7	6.10	15.5	8.10	15.0	'72. 2. 28. 10:	L, W	70.01 ~
20	USW	-49.0	7.91	11.0	11.44	10.9	'90. 12. 1. 8:	T9028, L	74.04 ~
21	USW	-28.0	6.09	13.1	8.70	12.0	'83. 12. 27. 2:	L, W	71.03 ~
22	USW	-23.3	4.62	11.0	6.76	6.6	'87. 2. 3. 22:	L	81.07 ~
23	USW	-49.0	5.30	11.0	8.63	11.5	'86. 3. 24. 8:	L	78.03 ~
24	USW	-20.0	5.36	9.9	8.70	11.0	'82. 10. 20. 10:	L	79.01 ~
25	USW	-16.0	5.99	11.9	8.55	11.5	'90. 12. 1. 0:	T9028	82.08 ~
26	USW	-19.0	6.80	12.0	11.38	12.6	'90. 12. 1. 2:	T9028	80.01 ~
27	USW	-30.0	6.99	11.3	9.09	10.9	'89. 8. 6. 16:	T8913	79.12 ~
28	USW	-23.4	7.09	13.2	9.60	10.5	'75. 11. 12. 2:	T7519	72.04 ~
29	USW	-22.0	7.30	11.7	10.06	12.2	'85. 7. 1. 6:	T8506	72.09 ~
30	USW	-48.0	8.36	10.7	11.02	9.0	'81. 8. 23. 2:	T8115	73.04 ~
31	USW	-50.0	6.08	11.1	11.49	11.3	'90. 9. 20. 2:	T9019	88.04 ~
32	USW	-17.0	5.49	15.0	8.56	13.2	'90. 11. 30. 18:	T9028	88.04 ~
33	USW	-50.5	8.77	11.3	12.33	12.6	'89. 8. 27. 8:	T8917	70.08 ~
34	DS.B	-170.0	11.37	13.8	16.72	19.6	'87. 10. 17. 0:	T8719	83.12 ~
35	USW	-17.0	2.66	5.9	5.40	7.0	'83. 5. 16. 18:	L	71.05 ~
36	USW	-30.0	5.63	12.8	10.29	12.9	'90. 9. 19. 10:	T9019	80.09 ~
37	USW	-40.0	6.26	12.6	11.23	15.7	'90. 8. 22. 6:	T9012, T9014	90.04 ~
38	USW	-48.5	10.34	13.0	13.42	15.3	'80. 9. 10. 22:	T8013	75.03 ~
39	USW	-35.0	7.88	12.3	11.03	14.3	'82. 8. 26. 22:	T8213	80.04 ~
40	USW	-50.0	8.46	14.9	12.11	10.4	'79. 8. 22. 16:	T7911	73.01 ~

Wave Gauge

USW: Ultrasonic Type

SRW-V: Step Type

Ds.B: Buoy Type

Atmospheric Phenomena

T: Typhoon

W: Winter Seasonable Wind

L: Low Pressure

gression wave forecast model described in PHysical parameters (MRPH)' is explained and the accuracies are checked by comparison with the observed waves.

2. General Description of the NOWPHAS

The Fig.1 shows the location of the NOWPHAS wave observation stations in the year of 1990. The Table 1 shows the historical maximum observed waves at each station. The number of the stations from 1 to 40 corresponds to the Fig.1. The water depth of these stations varies from 17m (No.35: Kobe) to 170m (No.34: Gobo Oki). $H_{1/3}$ and $T_{1/3}$ means the observed maximum significant wave height and period respectively,and H_{max} and T_{max} means the corresponding maximum wave height and period at the same observation time.

Wave measurement at each station is being carried out every 2 hours. In each measurement water surface elevation is recorded for 20 minutes (1200 seconds) with the data sampling interval of 0.5 seconds. Wave Heights and periods are defined by the zero-up-cross method[7].

Figure 1 Nationwide Ocean Wave Information Network for Ports and Harbours

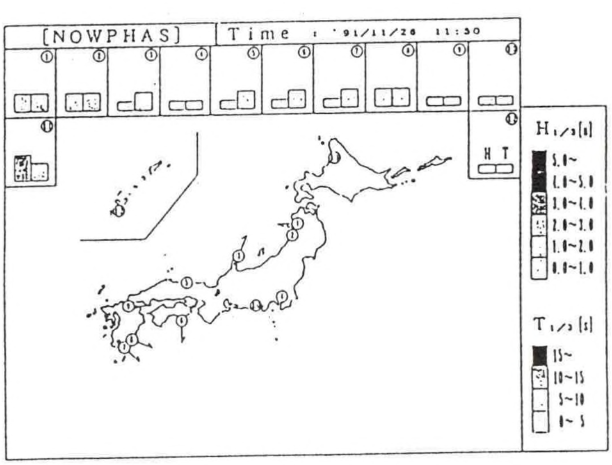

Figure 2 Example of the Real Time Wave Monitoring System

The year, month, day and hour of the maximum $H_{1/3}$ and $T_{1/3}$ are also shown in the Table 1, with their atmospheric causes. The dotted mark shows the stations where extreme significant wave height records were renewed during 1990. At the stations faced to the pacific Ocean, typhoons are the most important cause of the extreme high waves, where at those faced to the Japan Sea, winter seasonable winds are the most important.

At the right of the Table 1 observation terms are also shown. It must be noted that although the NOWPHAS started in 1970, not all observation stations have 20 years wave records history.

3. Data Gathering System of the NOWPHAS

As the amount of the NOWPHAS data is enormous one, the development of the data gathering system itself has been a very important theme of research.

At the first stage (in 1970s) wave observation data were recorded in the P.T.(Paper Tape) and the P.T.s were sent by mail to the P.H.R.I. from Local Port Construction Offices which administer those stations. As the number of the observation stations increased, the amount of the data also increased and the P.T. had to be changed to the C.M.T.(Cartridge Magnetic Tape) which can store much more data than P.T. per volume. During 1980s C.M.T. mailing system was dominant data gathering system in the NOWPHAS.

Recently real time data gathering system was realized using NTT telecommunication line, with the development of the personal computer communication technique. Among the 40 stations shown in the Fig.1 and the Table 1,12 stations were connected to the P.H.R.I. with the NTT telecommunication line, by January 1992. The Fig.2 shows an example of the real time wave monitoring system all around Japan.

4. Coastal Wave Characteristics around Japan in 1990

The Fig.3 shows the monthly and yearly average value of $H_{1/3}$ and $T_{1/3}$ of the 4 representative observation stations. The station numbers correspond to the Fig.1. The Fig.3 compares the wave climate in 1990 with the long term statistics. The Table 2 shows the eminent high waves terms during 1990 with their atmospheric cases. From the Fig.3 and the Table 2 the characteristics of the waves in

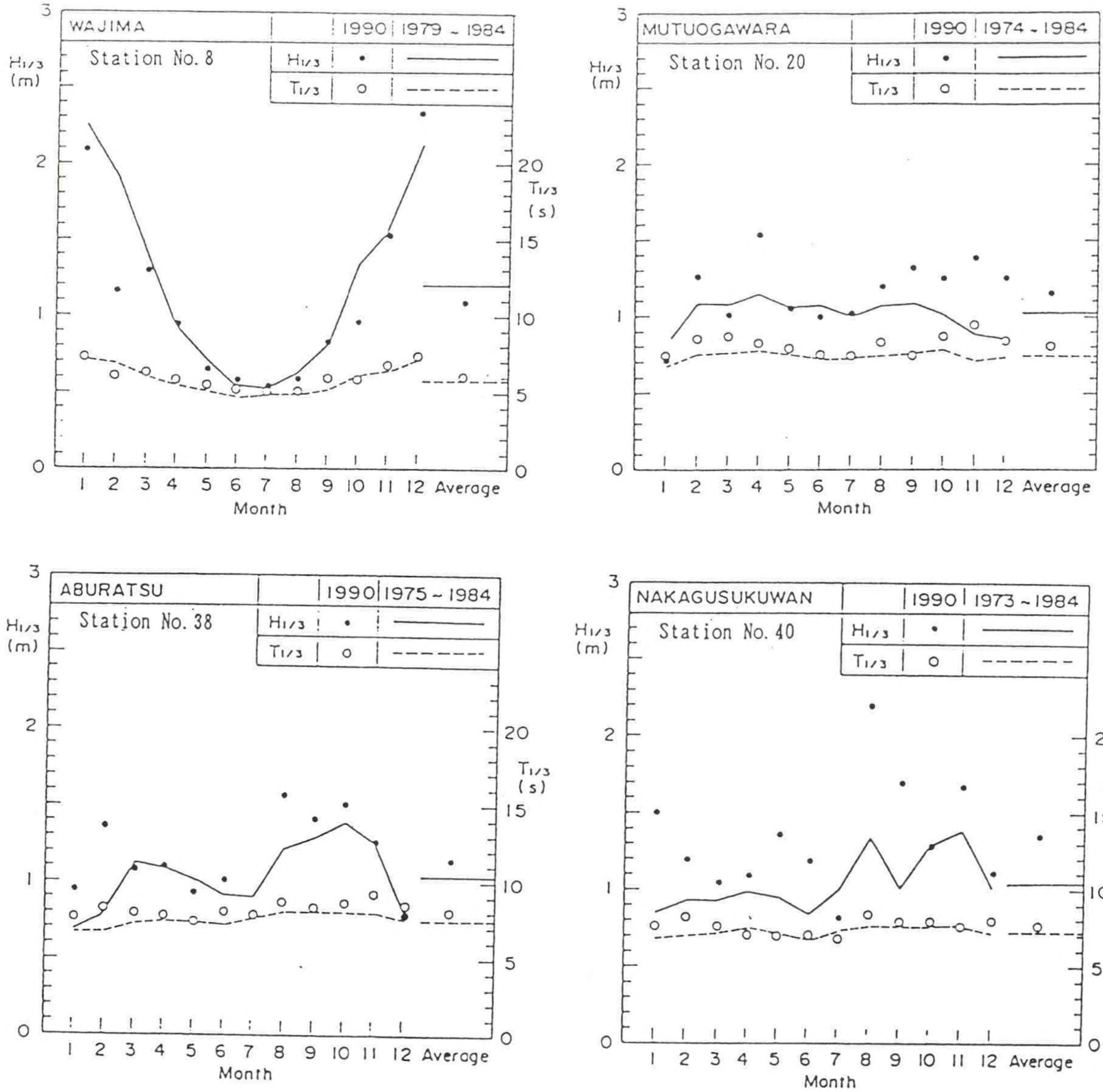

Figure 3 Comparison of the Wave Climate in 1990 with the Long Term Statistics

Table 2 High Wave Terms in 1990 around Japan

Term	High Wave Area	Atmospheric Phenomena
3/11 ~ 3/14	All around Japan	L.W
9/16 ~ 9/21	All around Japan	T9019
11/ 9 ~ 11/13	All around Japan	L.W
11/28 ~ 12/ 5	All around Japan	T9028.W
12/16 ~ 12/30	Japan Sea Coast and Northern Pacific Ocean Coast	L.W

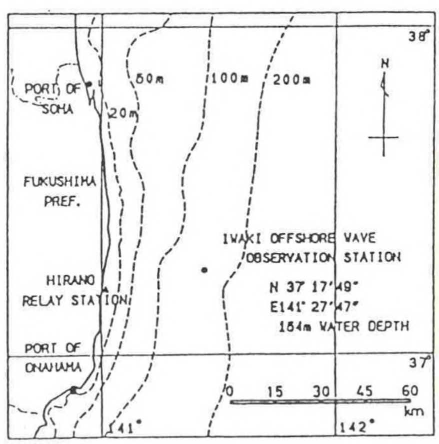

Figure 4 Location of the Iwaki Oki Wave Directional Spectrum Observation Station

1990 can be mentioned as follows.

a. Yearly average $H_{1/3}$ in 1990 along the Pacific Ocean side was a little higher than the long term statistics, while along the Japan Sea side was a little lower.

b. In January and February, as the winter seasonable winds were not so strong as the usual years, monthly average $H_{1/3}$ along the Japan Sea side (8:Wajima) was lower than the long term statistics. On the other hand, along the southern Pacific Ocean side monthly average $H_{1/3}$ was higher than the long term statistics due to the effects of the low pressures.

c. In August and September, due to the frequent attack of the typhoons in the southern area of Japan, monthly average $H_{1/3}$ was higher than the long term statistics at the stations 38 and 40. Especially at the station 40 (Nakagusukuwan) the $H_{1/3}$ in August (2.20m) was extremely higher than the long term statistics (1.34m).

d. In December, due to the abnormal attack of the typhoon (T9028) and the strong winter seasonable winds, the average $H_{1/3}$ was higher in all around Japan.

5. Research on Directional Ocean Waves

The Second District Port Construction Bureau installed wave gauge array at the Iwaki Oki natural gas excavation platform located at the water depth of 154m as shown in the Fig.4. At the 4 legs of the platform, step type wave gauges were set respectively. In addition to the 4 step type wave gauges, two components horizontal current meter and one pressure gauge were also set at the platform with the water depth of 15m. Using those 7 components simultaneous wave data, directional wave spectrum can be calculated with fairly good precision by Bayesian directional spectrum analysis method[8].

The Fig.5 shows one example of the calculated directional spectrum at 22:00 of September 29th in 1986, when a typhoon passed near the station. From the Fig.5, we can understand that swells from the direction of SSE and wind waves from ESE simultaneously existed at this moment and the directional spectrum had eminent 2 peaks.

The Fig.6 shows wind speed, wind direction, significant wave height, directional energy distribution history from September 16th to 18th in 1987[9]. Wave energy distributions calculated from the wind (result of wave hindcast with MRI spectrum method) are also shown in the Fig.6, so that the observation and the calculation can be compared. Both the observation and the calculation show that the dominant wave energy direction changed from S-E to E-N at 16:00 of 17th as the typhoon moved

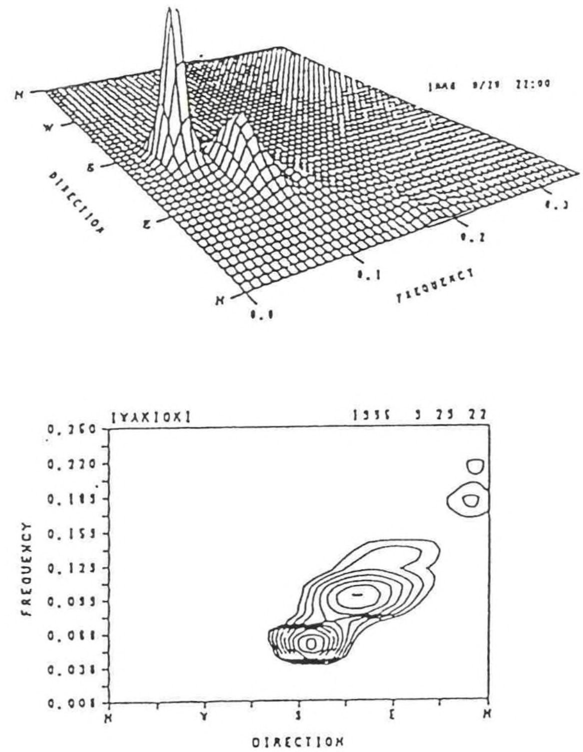

Figure 5 Example of the Observed Wave Directional Spectrum at the Iwaki Oki Station

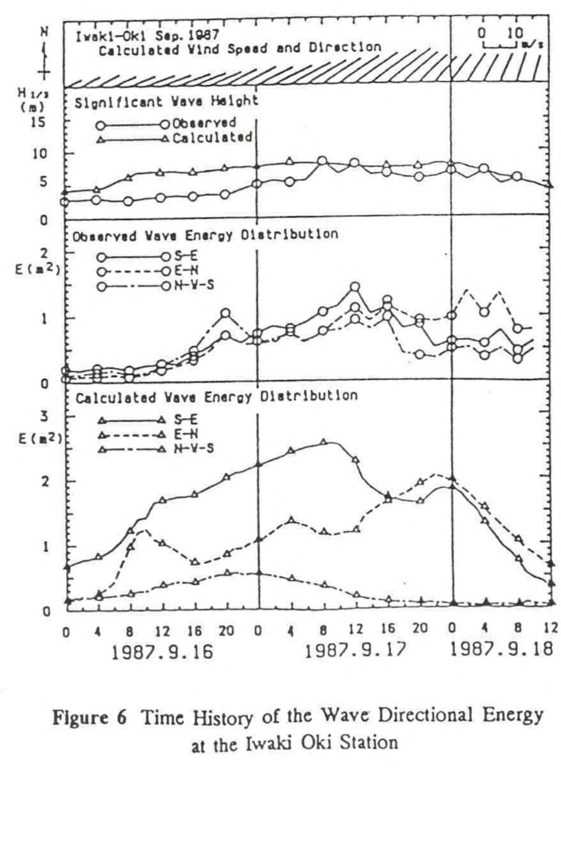

Figure 6 Time History of the Wave Directional Energy at the Iwaki Oki Station

from the south to the north.

6. General Description of the Wave Forecast model (MRPH model)

Accurate wave forecasting information are indispensable for keeping safety on broad ocean activities such as construction of maritime structures, navigation of ships and ocean recreations. For this purpose, wave hindcast model and multiple regression wave forecasting model had been used. However, there are some indeterminable difficulties in these forecasting models for practical use.

As a new model supersedes the conventional methods, the Multiple Regression wave forecasting model described in PHysical parameters (MRPH) was developed. The MRPH model describes each processes of wave growth, wave propagation and decay of wave energy as physically. And as the governing equations of the model are expressed in a set of algebraic equations, the model coefficients are able to identify from the comparison between calculated and observed values explicitly. Furthermore, the model coefficients of every forecasting hours are also able to improved momently by observed data.

7. Application of MRPH model

Fig.7 shows the comparison of significant wave forecasted results (forecasting time is after 12 hours) by using model B with observed wave data at the port of Hitachinaka. Duration is February in 1983. In this figure, forecasted results of wave height and periods and observed shows good agreements for fluctuations of both stormy waves and low wave height conditions. From the compared results, MRPH model shows more accurate forecasting than other forecasting methods.

Fig.8 shows the case of more long forecasting time (after 168 hours) at same location and same duration in fig.7. Although the forecasting accura-

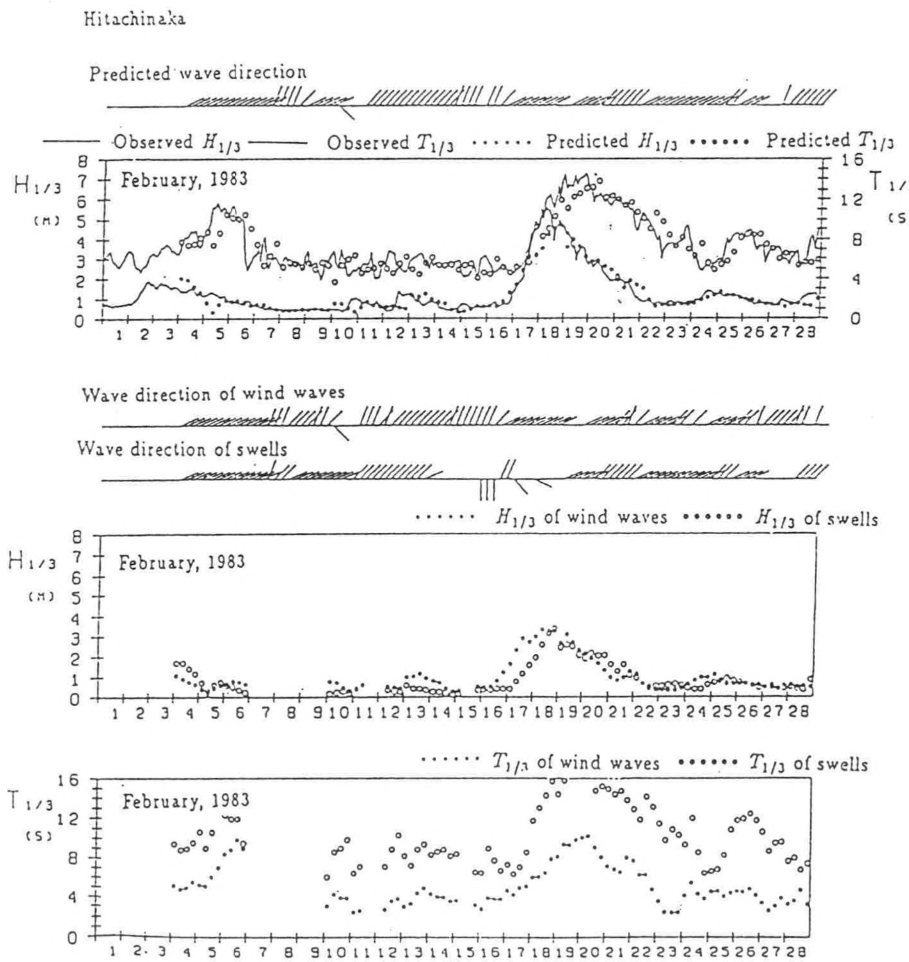

Figure 7 After 12 Hours Wave Forecasting Results at Port of Hitachinaka (Model B)

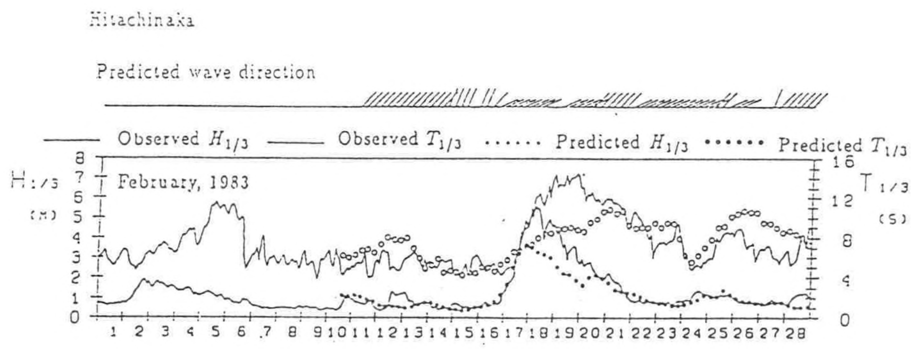

Figure 8 After 168 Hours Wave Forecasting Results at Port of Hitachinaka(Model B)

cies are worth than the case of after 12 hours in fig.7, it is observed that acceptable engineering accuracy for long term forecasting.

Fig.7 also shows the evaluated significant wave height and period of wind waves and swells respectively, with wave direction of each components. The location and the duration at fig.9 are same as in fig.7. There are no methods to separate the wind waves and swells from observed wave data, so comparison is not able to treat qualitatively. However, by considering topology around the port and characteristics of wind waves and swells, it is imagined that each time processes of wave height, period and direction indicates adequate tendencies.

8.Conclusion

In this papers, the NOWPHAS system and some topics on NOWPHAS and the MRPH model are explained. The NOWPHAS system (the Nationwide Ocean Wave information networks for Port and HArbourS) includes real time wave gathering systems, and the MRPH model (the Multiple Regression wave forecast model described in PHysical parameter) is the new wave forecasting model. The results of this study may be summarized as follows.

The NOWPHAS systems have 40 wave observation stations, and 1 offshore directional spectrum observation station. Wave measurements at each station is being carried out every 2 hours. Significant wave height and period, maximum wave height and period are evaluated from observation data. The real time data gathering system is realized using NTT telecommunication line, 40 stations are connected to the P.H.R.I..

Coastal wave characteristics around Japan in 1990 is considered from NOWPHAS observation data. From the consideration, wave seasonal characteristics and wave characteristics difference between Pacific Ocean side and Japan Sea side is evident. Wave directional spectrum at station of Iwaki Oki shows offshore directional characteristics.

In the MRPH model, ocean waves are separated into wind waves and swells, and assumed that the propagation velocity of each wave components is constant respectively. From this assumption, governing equations of the MRPH model are expressed as algebraic equation, though growth, propagation and decay of the waves are essentially described as partial differential equation. An explanation variables in the MRPH model are energies of wind waves and swells for each direction. And production factors are not only significant wave height and period but wave direction, equivalent wave height, period and direction for wind waves and swells. The MRPH model shows more excellent accuracy of forecasting, and solves the difficult problem that the presence of lag time when appears at the initial states of the waves growth which is defects of multiple regression model. Also, accuracies of the MRPH model does not decreases remarkably in the case of long term wave forecasting. Furthermore, the MRPH model is able to predict wave period, direction, and the component value of wind waves and swells which have not predicted by usual statistical model. The things which the MRPH model holds the dominant positions in wave forecasting methods seems to be the most probable in the near future.

Acknowledgements

The Nationwide Ocean Waves information network for Ports and HArbourS (NOWPHAS) was developed and operated by many engineers and their assistants. Wave observations are being carried on by the District Port Construction Bureaus of the same Ministry. Wave gauges and data gathering and processing system adopted in the NOWPHAS were

born from more than 30 years' research in the P.H.R.I. and its cooperative organizations. The Coastal Development Institute of Technology and its associating private companies help the P.H.R.I. in the routine NOWPHAS data processing and analysis.

Authors must express sincere gratitude to all of the concerned persons.

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Porosity, Permeability and Shear Strength (P*2S) Cross-Well Tomography Experiments of a Noisy Foundation

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Summary

Experiment and analysis of cross-well tomography of a sedimentary foundation with very high background noise at an iron foundry are performed. High resolution velocity images between wells separated by long distances (up to 250 m) have been obtained using long sequences (up to 4095 cycles) of pseudo-random binary codes at high carrier frequencies (1 to 10 kHz) to excite a piezoelectric source in a water-filled well. Transmitted signals are received by a 24-channel hydrophone array in another well. Beamforming performed on common source gather data identifies the directions and arrival times of multiple ray paths and tube waves, and further enhances the signal to noise ratio. Using the first arrival data travel time inversion is performed to obtain the compressional wave velocity image using the dumped least square method and ray tracing algorithm. Assuming the normal consolidation condition, the porosity and shear strength images are transformed from the compressional wave velocity image. The slight differences in the compressional wave velocity images obtained using different carrier frequencies can be used to determine the permeability image of sediments based on the Biot theory.

Introduction

Earlier theoretical studies by the senior author and co-workers (Yamamoto, 1983; Turgut and Yamamoto, 1988; Yamamoto and Turgut, 1988) showed that the porosity, permeability, pore size and grain shape of sediments can be measured acoustically based on the Biot theory. An experiment conducted at a beach to measure the velocity dispersion and attenuations supported the theoretical predictions (Turgut and Yamamoto, 1990). Using the empirical relation found between the porosity and the shear modulus of sediments (Ohsaki and Iwasaki, 1973), it has been shown that the shear wave velocity can be determined from the measured compressional wave velocity and vice versa (Yamamoto, et al., 1989). Therefore the images of porosity, permeability and shear strength distributions within sediments can be determined from the cross-well compressional wave travel time measurements. The method is referred to as P*2S-tomography. In order to apply this geoacoustics cross-well method to the foundation engineering practice the cross-well distance must be increased to over 100 m without losing high imaging resolutions and the experiment must be conducted under a very noisy environment generated by heavy equipments.

In this paper, the pulse compression technique and beamforming technique are applied to solve these problems and the results from the field experiments conducted at a reclamation in Tokyo Bay are reported.

Cross-Well Experiments

First, two cross-well measurements were made using eight 60 m deep PVC cased 4 inch I. D. boreholes at the KSC Chiba plant in July and November, 1991. The cross-well distances ranged from 66 to 247 m. This site was recently reclaimed and is located in the northeastern section of Tokyo Bay about 5 km offshore. The geological formations deeper than 10 m below ground surface are part of the original seabed of Tokyo Bay. During the experiments construction works of pile driving, bull- dozers and train operations continued and generated an extremely noisy background.

The instrumentation systems diagram of P*2S-tomography system is shown in Figure 1. It utilizes a piezoelectric source driven to send pseudo random binary sequence (PRBS) codes from a borehole to be received by an array of hydrophones in a second borehole. The hydrophone array is a 24-element oil filled array. Each individual element has two Teledyne T-2 phones and a preamplifier. Since PRBS codes increase the signal to noise ratio (S/N) and greatly increases the effective source output level, it allows for the use of very high frequencies (typically 1 to 10 kHz), thus enabling one to attain very high resolution tomographic images. The data acquisition system consists of a multichannel A/D board installed on an 386/33 mHz IBM computer with mass storage facilities. A detailed description of instrumentation and data acquisition is given in Yamamoto et al. (1992).

Beamforming Applied to Common Source Gather Data

The digital data from each hydrophone is averaged and cross-correlated with the source signal to compute the wave form. Figure 2 presents a typical common source gather data taken during the 20-15 cross-section test. The source is located 22 m below ground surface in well-20. The hydrophone array is in well-15. Hydrophone number 1 is located deep, 49 m below surface and number 24 is near the surface, 3 m below surface. For the same source location, there is another common source gather with the hydrophone array offset by 1 m to the other common source gather. Beamforming results, using the five hydrophone traces located between 14 to 18 m below surface, are shown in Figure 3. The large hydrophone spacing of 1 m as compared to the wave length of 1.5 m or so causes the spacial aliasing and marginal directional resolution. None the less, the first and direct (D) arrival, the surface reflected (SR) arrival, the bottom reflected surface reflected (BRSR) arrival, other multipath arrivals as well as tube waves (T) are identifiable. The system noise in the traces is greatly reduced in the process. As demonstrated here, the beamforming procedure may be used to remove the system noise and tube waves and to identify the multipath arrivals in cross-well data.

P*2S-Tomography Results

After the wave form time series are found, the travel time of the first arrival is found automatically using the program GRA1.EXE. Finally, the travel time data is used as input to the TOPOVEL.EXE inversion program which was produced using Bergman et al. (1989). By far the longest of the cross-sections is 15-12; it measures 247 m across. This section utilized a 4095 cycle PRBS stacked 4 times and averaged. This is about the limit of the system. The data quality is given as 'poor' due to a low S/N. Figure 4 produces the inversion result for this cross-section using a 55x48 data matrix and a 20x40 matrix of unknowns. The tick marks at both sides of the picture indicate the source-receiver locations. The Chiba site is characterized by a highly attenuating slag layer near the surface. The surface slag layer is modelled by a faster layer and the bottom sand layer is extended to the 60 m depth. This figure shows the low velocity zone giving way to a faster layer at 40 m depth. The transition is very sharp near the center of the section.

Using the aforementioned transformation procedure (Yamamoto et al., 1989) the porosity image Figure-5 and the shear strength image Figure-6 of section 15-12 are developed from the compressional wave velocity image Figure-4. Although not shown here, imaging the permeability distribution of the sediment is possible using a shorter interwell spacing and broad band source frequencies (Yamamoto, et al., 1991).

Well-11 is located approximately in the middle of the line connecting well-12 and 15. Comparisons among sections 12-15, 12-11 and 11-15 provide an opportunity to check the tomographic results. For section 15-11, the source is in 15 and the receiver in 11 providing a cross-section 136 m wide. The result of this section is considered 'good', but has only 28 source positions and 24 receivers. Figure-7 shows the compressional wave velocity result using a 20x20 matrix of unknowns. Cross-section 12-11 is 116 m wide, has the source in 12 and the receiver in 11. This section is considered 'good' for a 27x24 data matrix. The compressional wave velocity presented in Figure-8 resulting from 20x20 matrix of unknowns can be looked at as an extension to 15-11 when the two are placed side by side. Together, they also agree fairly well with 15-12.

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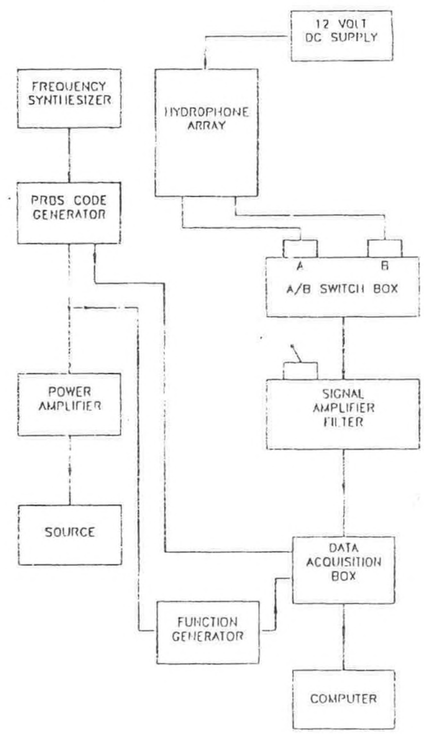

FIG. 1. P*2S-tomography instrumentation system diagram.

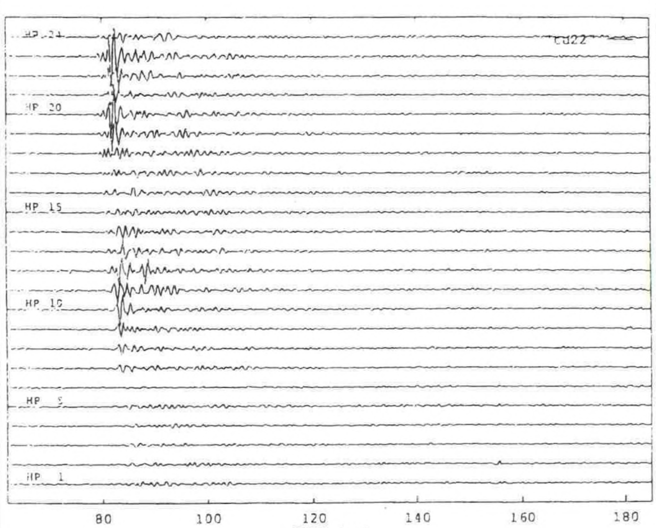

FIG. 2. Common source gather: source 22 m below surface in well-20, phone-1 at 49 m below surface, 24 at 3m in well-15, cross-well distance 122 m.

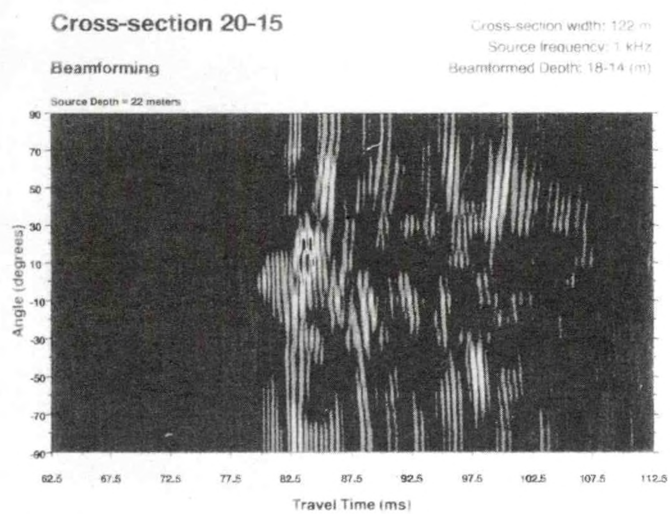

FIG. 3. Beamforming of common source gather in Fig. 2., beamformed depth, 14-18 m.

FIG. 4. Compressional wave velocity image from travel time inversion, cross-section 15-12, cross-well distance 247 m.

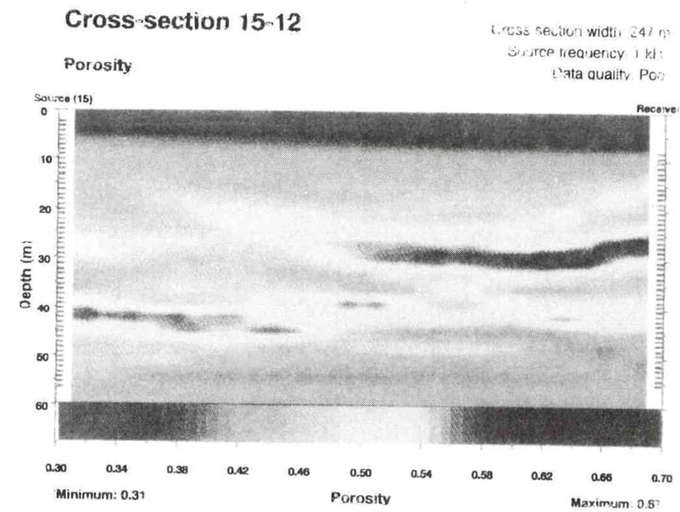

FIG. 5. Porosity image of cross-section 15-12, 247 m.

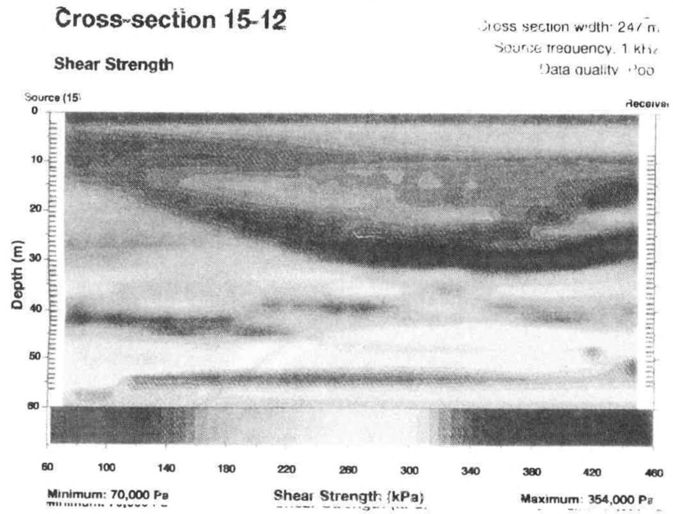

FIG. 6. Shear strength image of cross-section 15-12, 247 m.

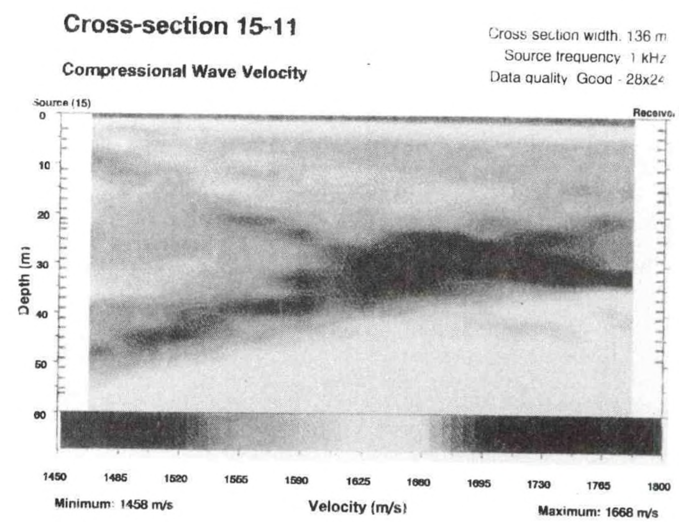

FIG. 7. Compressional wave velocity image of cross-section 15-11, 136 m.

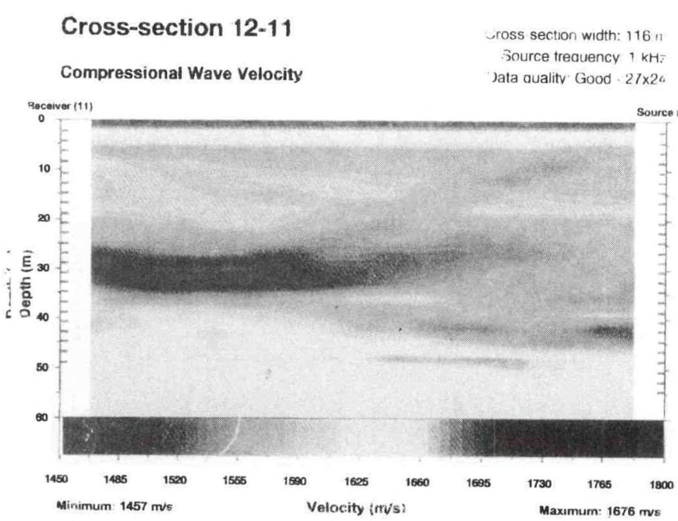

FIG. 8. Compressional wave velocity image of cross-section 12-11, 116 m.

Review of Research Works of Corrosion and Its Prevention by Paint Coating at Ship Research Institute

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1. Introduction

Ocean is very corrosive environment for steel which is one of main material for marine going ships and offshore structures. Because of the fact mentioned above, researches into corrosion and its prevention have been conducted at Ship Research Institute (SRI).

Purposes of these researches at SRI can be classified into four groups. The first group is a quantitative research into corrosion and its effects on strength of structures. The second is an experimental and theoretical research into paint coating film such as coating film life expectancy, mechanism and measurement of coating film degradation, effects of coating film on corrosion fatigue life of steel plates and so on. The third is a research to develope a offshore maintenance system using paint coating. And the fourth is a research directing to evaluate mechanical properties of steel materials in corrosive environment.

In this report, major papers in these groups are briefly reviewed.

2. Researches on Corrosion and Its Effects on Strength of Steel and Structures [1]

Investigations on amount of corrosion, surface pattern due to corrosion degradations of mechanical and fracture properties of steel material, effects of these factors on strength of materials were continuously conducted.

Based on these basic researches, 56 years old ship, K-maru, was investigated for items concerning her strength, and her overall strength. And her seaworthiness was discussed from view point that she should be replaced or not. Items investigated were the thickness of shell and deck plates, local and overall deformations of the hull, the wear of rivet head and mechanical properties of steel plates of decks and hull. The characteristics of old plates investigated were chemical compositions, static and dynamic tensile strength, fracture toughness and fatigue strength. Thickness distribution of old plate with worn out holes due to corrosion were also measured.

Fig. 1 shows a relation between whole area corrosion ratio Δ (mean corrosion ratio calculated by thickness data measured at strength members ship hull) and corrosion hole ratio V (total area of holes divided by total area of strength members). This figure shows that numbers and area of corrosion holes rapidly increase as whole area corrosion ratio increases beyond 5%.

Fig. 2 shows a fatigue life diagram for plates from K-maru (rough surface due to corrosion) and SM41A. In the figure, stress amplitude is calculated for a test specimen so as load amplitude is divided by minimum sectional area of the specimen. As shown in the figure, fatigue strength of plates from K-maru is very low (even lower than the strength of SM41 specimens with weld defects). It is concluded that there are two reasons of reduction in fatigue strength of corroded specimens. One is the increase of applied stress amplitude due to decrease of minimum sectional area. The other is stress concentration due to very rough surface or even due to corrosion holes. These factors accelerate fatigue crack initiation and propagation.

Based on the results of investigations, strength and seaworthiness of K-maru was dicussed. Results obtained were summarized as following.

The plate thickness reduction by corrosion of decks and shell plates at midship was about 5% in spite of her old age, though there existed some deep corroded parts in them.

The 5% of the whole hull deterioration rate corresponded to about 0.6% corrosion hole area ratio of the whole hill.

A small amount of deformation of the ship hull as a whole was responsible for the long term service and repeated repairs by welding (originally K-maru was built by rivets).

The original old plates of 56 years showed good tensile strength, but poor weldability and fracture toughness.

Very rough surface due to corrosion largely diminished their fatigue lives, because of decrease in thickness and stress concentration by surface roughness.

The seaworthiness level of the ship was very low. This level may reveal itself at the time of emergency. So K-maru should be replaced as soon as possible.

3. Researches on Deterioration of Paint Coating Film

Based on enormous numbers of weather test of heavy duty coating films at ship Research Institute (Mitaka Tokyo), at real sea environment (Offshore Structure for Synthetic Ocean Research, Suruga Bay Shizuoka Prefecture) and other data publish on obtained, experimental and theoretical investigations were conducted.

3.1 Early stage deterioration of anti-corrosive epoxy coating [2]

The early stage determination of anti-corrosive epoxy coating for offshore use was discussed theoretically and experimentally. The degree of determination was deterioration by the critical strain measured at the three-point bending of coated test specimen exposed to the marine environment. The relation between this critical strain ε_c and the detached area S and the deflection at cracking δ_c of the coating at three-point bending was theoretically calculated and it showed fairly good agreement with experimental data.

Based on the assumption about ε_c mentioned above and also on the assumption that the deterioration velocity of coating obeyed to the usual thermochemical reaction velocity law, the accelerating effect of several kinds of accelerated deterioration test methods were evaluated quantitatively.

Finally, the deterioration phenomena of epoxy coating in an early stage was schematically shown for the changes of critical strain, volume resistively and alternating current resistance against the exposed period as shown in Fig. 3.

3.2 Quantitative approach to durability of anti-corrosive coating system [3]

The factors, which affect a durability of anti-corrosive coating system for steel structure, are analyzed and quantified. Seven factors are extracted as follows; zone of exposure, surface preparation, tool for painting, number of coats, secondary surface preparation, number of coating materials, and lamination structure. Twenty nine kinds of materials, which compose coating systems are chosen (see Table 1). An effective thickness T of a coating system, normalized with equivalent thickness ratio of the coating materials, is supposed.

Based on the assumptions that an effective thickness T and durability period of a coating system Y^{d} can be expressed as following, effects of the factors and equivalent thickness ratios are determined, based on the data at real environments, using the first kind of quantification theory and the method of least squares.

$$T = \sum_{i=1}^{29} d_i T_i \qquad \ln Y^j = A_1 + \ln T^j + X_E^j + X_S^j + X_T^j + X_N^j + X_M^j + X_P^j + X_L^j$$

where

A_1 = constant, $T^j = \sum_{i=1}^{29} d_i T_i^j$ = for coating thickness,

$X_E^j = \sum_{i=1}^{8} \delta_i^j e_i$ = for environment, $X_S^j = \sum_{i=1}^{4} \delta_i^j s_i$ = for surface preparation,

$X_T^j = \sum_{i=1}^{3} \delta_i^j t_i$ = for tool, $X_N^j = \sum_{i=1}^{5} \delta_i^j n_i$ = for number of coats,

$X_M^j = \sum_{i=1}^{5} \delta_i^j m_i$ = for number of materials, $X_P^j = \sum_{i=1}^{3} \delta_i^j p_i$ = for secondary preparation,

$X_L^j = \sum_{i=1}^{5} \delta_i^j l_i$ = for lamination structure.

The analytical results are compared with data at real environment as shown in Fig. 4. The estimated durability by the analyses and those at real environments correspond fairly good.

3.3 New evaluation method of anti-corrosive properties of heavy duty coating systems for offshore structure using thermal shock technique [4]

Two important factors in the flow, determining necessary conditions of heavy duty anti-corrosive coating systems for offshore structure use, were investigated. One was a distribution of coating thickness, which was closely related to defects in coating system. A relation between the characteristics of coating thickness distributions and a shapes of objects, on which a coating system was applied , was measured and discussed. Fig. 5 shows a relation between diameter D and coefficient of variation σ/t_m for hemisphere. The other factor discussed was an accelerated deterioration method of coating systems which was called a thermal shock test using a hot and a cold water bathes. Table 2 shows description of coating system used. Fig. 6 shows results of thermal shock test. It is shown that the test has a possibility to evaluate anti-corrosive properties of coating system within a relatively short period of time.

3.4 Corrosion preventing system of offshore structure by paint coating [5]

A corrosion preventing system of offshore structure is proposed as shown in Fig. 7. The system is composed of four parts. The first is the selection of the optimum coating conditions based on a data base of coating film service life. The second is the determination of the minimum allowable radius of curvature of corners of structure's detail. The third id the estimation of residual service life of coating film deterioration. And the last part is the feedback procedure of field and experimental data to the data base. We have made every effort to construct data bases necessary to proceed the four parts mentioned above. And we have completed tentative three data bases. The first is a data base of coating film service life. The second is a data base of coating film thickness distribution. The third is a data base of coating film deterioration. Table 3 shows the structure of data base of the last. And Fig. 7 shows a example of output of this data base.

By adopting the proposed system, the corrosion preventing method by paint coating may be guaranteed to become reliable from the view point of service life estimation.

4. Maintenance of Offshore Structure [6]

Experimental investigation into maintenance of offshore structure were carried out, using a floating offshore structure POSEIDON. Surfaces of eleven columns out of twelve and side wall of deck house of POSEIDON were carefully coated by experimentally specified heavy duty paints as shown in Table 4.

During four-year operation of POSEIDON, changes of plate thickness and coating film characteristics were observed. Amount and species of marine fouling animals on coating surfaces around submerged parts of columns were also measured and observed.

After the end of four years experimental operation, POSEIDON was broken, in order to make thorough investigations of weld joint parts and paint coated parts of columns and deck house wall. Table 5 shows evaluation grade (5 points evaluation method) of coating films of POSEIDON after four years operation. Fig. 9 shows the relation between defect area by outer observation A_i and whole defect area A which includes corrosion area under coating for a brace with corrosion pittings and hollows on the coating surface after four years operation.

From the experimental research we obtained two conclusions. One is that, in order to maintain safety operation of offshore structure, proper maintenance and repair should be performed and that choice of maintenance system should be made at initial stage of structural design. The other is that, for proper maintenance of offshore structure, initial conditions and values of structural details such as penetration of weld joint metal, properties of paint coatings and local deformation of structural parts are to be measured before operation.

5. Evaluation of Steel Properties in Corrosive Environment

5.1 Corrosion characteristics of prestressing steel wire [7, 8]

In order to make prestressed concrete offshore structures more reliable, corrosion characteristics of reinforcing steel wire for prestressed concrete structure was widely investigated.

One was the stress corrosion cracking (SCC) investigation. SCC tests of seven-wire prestressing strand (one central wire and six side wires) with and without mortar were conducted in 3% NaCl aqueous solution under a constant load and an anodic polarization. Fig. 10 shows a sketch of experimental apparatus used (in this figure, the test specimen is a strand with mortar).

In the experiment, effects of electrode potential, applied load and mortar crack width (for strands with mortar) on the time to failure were measured. Corrosion rate of wires and strands in NaCl solution, relation between mortar crack width and the corrosion rate, and observation of stress corrosion cracks on wire surface were conducted.

Some conclusions were obtained. For a strand without mortar, time to failure t_f decreased linearly as an electrode potential became nobler as shown in Fig. 11. For $P_{sc}/P_u \geq 0.7$ (P_{sc}=applied load, P_u=ultimate tensile load), time to failure was observed to be short for all values of electrode potential. But the applied load did not affect to tf value for $P_{sc}/P_u \leq 0.6$. Corrosion rate was independent of applied load. On other hand, for a strand with mortar, lifetime became longer and consequently corrosion rate decreased remarkably compared to. When a localized corrosion occurred at -450 to -400 mV vs. SCE, SCC of active type corrosion path was observed on side wire surface.

The other investigation was corrosion fatigue strength of strands. For also seven-wire prestressing strand, fatigue tests in air and corrosion fatigue tests in a 3% NaCl aqueous solution were conducted. Numbers of cycles to first wire failure was chosen as a criterion of fatigue life of a strand. S-N curves for number of load cycles less than 2×10^6 were constructed by experiments. And they were extrapolated using experimental data and theoretical considerations. Reduction of corrosion fatigue strength compared to that of in-air were discussed.

It was observed on a logarithmic-logarithmic scale graph (see Fig. 12) that the corrosion fatigue life decreased nonlinearly with decrease of stress range, but this trend was not observed for a graph on a semilogarithmic scale. The fatigue strength at $5x10^6$ and $1x\ 10^7$ loading cycles was estimated from the experimental data of those for loading cycles of $5x10^5$ to $2x10^6$. The estimated corrosion fatigue stress range at loading cycles of 5x106 and 1x10 were 3.3% and 2.3% of the ultimate tensile strength respectively. The corrosion fatigue stress ranges at loading cycles of $1x10^6$ and $2x10^6$ were 49% and 34% of those of fatigue limit in air respectively. The reduction in stress range mentioned above was independent of mean stress level.

5.2 Effect of coating film on corrosion fatigue strength of steel [9]

In order to evaluate the effects of coating film and its thickness distribution on fatigue, corrosion fatigue tests were conducted using paint coated fillet weld test specimens. Three configurations fillet weld were used. They were "as weld ", "straight" and "Φ12 dressed" as shown in Fig. 13. Coating film thickness distribution around fillet weld depends on configuration of weld. Corrosion fatigue tests were conducted in artificial ocean water (temperature 25±1°C), at loading rate of 10rpm, under constant amplitude of R=-1. And obtained following results.

Fatigue strength of weld specimens without coating film depends largely on their configuration at higher stress level, but not depends on it at lower stress level.

Corrosion fatigue strength of specimens with coating film is almost the same as that of joint specimens in air, if the coating thickness distribution level is good enough.

Bad coating distribution results in the reduction of corrosion fatigue strength at higher stress level, because of the fact that the coating breaks at early stage of fatigue loading. The conceptional illustration of corrosion fatigue strength of coated specimen is well shown in Fig. 13 which also includes experimental data.

Coating thickness distribution can be evaluated by the fatigue strength diagram proposed in this paper.

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Table 1 Coating material under consideration [3]

No.	ABBREVIATION	MATERIAL
PRIME COAT		
1	WP	WASH PRIMER
2	EZP	EPOXY ZINC RICH PRIMER
3	IZP	INORGANIC ZINC RICH PRIMER
4	PE.A/C	EPOXY ANTICORROSIVE PAINT
5	CR.A/C	CHLORINATED RUBBER ANTICORROSIVE PAINT
6	AR.A/C	ALKYD RESIN ANTICORROSIVE PAINT
7	OL.A/C	OIL BASE ANTICORROSIVE PAINT
8	MIO	MICACEOUS IRON OXIDE PAINT
9	EZ	EPOXY ZINC RICH PAINT
10	IZ	INORGANIC ZINC RICH PAINT
INTERMEDIATE		
11	AR	ALKYD RESIN PAINT
12	CR	CHLORINATED RUBBER PAINT
13	PE	PURE EPOXY PAINT
14	TE	TAR EPOXY PAINT
15	U	POLYURETHANE PAINT
16	V	VINYL PAINT
(SILVER)		
17	ALS	ALUMINUM PAINT
18	CRS	CHLORINATED RUBBER PAINT
19	PUS	POLYURETHANE PAINT
LINING		
20	ESF	POLYESTER GLASS FLAKE LINING
21	PEF	EPOXY GLASS FLAKE LINING
22	TEF	TAR EPOXY GLASS FLAKE LINING
23	VEF	VINYL ESTER GLASS FLAKE LINING
24	PEM	EPOXY MORTAR LINING
TOP COAT		
25	AR.T/S	ALKYD RESIN TOPSIDE PAINT
26	CR.T/S	CHLORINATED RUBBER TOPSIDE PAINT
27	PE.T/S	PURE EPOXY TOPSIDE PAINT
28	PU.T/S	POLYURETHANE TOPSIDE PAINT
29	V.T/S	VINYL TOPSIDE PAINT

Table 2 Specification of coating system [4]

SPEC NO.	DESCRIPTION OF COATING (THICKNESS IN μm)						TOTAL THICK-NESS (μm)
	1ST COAT	2ND COAT	3RD COAT	4TH COAT	5TH COAT	6TH COAT	
1	IZ (75)	PE·A/C MIST COAT	PE·A/C (100)	PE·A/C (100)	PE·IM (40)	PU·T/S (35)	350
2	IZ (75)	TE MIST COAT	TE (250)	–	–	–	325
3	PE·A/C (100)	PE·A/C (100)	PE·A/C (100)	PE·T/S (40)	PE·T/S (40)	–	380
4	TE (200)	TE (200)	–	–	–	–	400
5	IZ (75)	PE·A/C MIST COAT	PE·A/C (100)	V·IM (60)	V·T/S (40)	–	275

SURFACE PREPARATION • SHOT BLAST + IZP

IZP • INORGANIC ZINC RICH PRIMER

IZ • HIGH-BUILT INORGANIC ZINC RICH PAINT

PE·A/C • PURE EPOXY ANTI-CORROSIVE PRIMER

PE·IM • PURE EPOXY INTERMEDIATE PAINT

PU·T/S • POLYURETHANE TOPSIDE PAINT

TE • TAR EPOXY PAINT

V·IM • VINYL INTERMEDIATE PAINT

V·T/S • VINYL TOPSIDE PAINT

Table 3 Structure of data base for paint coating deterioration [5]

Organization of Experiment	Test Place	Test Condition	Specimen Number	Paint Specification	Surface Preparation	Specimen Size	Test Period	0.11kHz A.C. Resistance	0.11kHz A.C. Impedance	0.11kHz A.C. tan (delta)	0.33kHz A.C. Resistance	0.33kHz A.C. Impedance	0.33kHz A.C. tan (delta)	1.0kHz A.C. Resistance	1.0kHz A.C. Impedance	1.0kHz A.C. tan (delta)	3.0kHz A.C. Resistance
Ship Research Institute	Tokyo/Mitaka	Weather Test	SRI101	#1	JASd2	300*100*4	0.00	2.93E+08	4.92E-11	0.100	1.38E+08	4.67E-11	0.075	5.97E+07	4.48E-11	0.080	2.50E+07
Ship Research Institute	Tokyo/Mitaka	Weather Test	SRI101	#1	JASd2	300*100*4	1.00	1.53E+08	6.51E-11	0.145	6.87E+07	6.00E-11	0.117	2.89E+07	5.59E-11	0.099	1.19E+07
Ship Research Institute	Tokyo/Mitaka	Weather Test	SRI102	#1	JASd2	300*100*4	0.00	2.90E+08	4.83E-11	0.103	1.40E+08	4.58E-11	0.075	6.05E+07	4.40E-11	0.080	2.48E+07
Ship Research Institute	Tokyo/Mitaka	Weather Test	SRI102	#1	JASd2	300*100*4	1.00	1.35E+08	6.63E-11	0.162	6.48E+07	6.09E-11	0.122	2.90E+07	5.68E-11	0.097	1.26E+07
Ship Research Institute	Tokyo/Mitaka	Weather Test	SRI103	#1	JASd2	300*100*4	0.00	3.04E+08	4.61E-11	0.103	1.45E+08	4.38E-11	0.076	6.29E+07	4.20E-11	0.080	2.58E+07
Ship Research Institute	Tokyo/Mitaka	Weather Test	SRI103	#1	JASd2	300*100*4	1.00	1.47E+08	5.91E-11	0.167	7.20E+07	5.35E-11	0.125	3.42E+07	4.99E-11	0.093	1.44E+07
Ship Research Institute	Tokyo/Mitaka	Weather Test	SRI104	#1	JASd2	300*100*4	0.00	3.13E+08	4.20E-11	0.110	1.56E+08	3.97E-11	0.078	7.08E+07	3.81E-11	0.059	3.05E+07
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Organization of Experiment	Test Place	Test Condition	Specimen Number	Paint Specification	Surface Preparation	Specimen Size	Test Period	D.C. Resistance	0.2kHz A.C. Resistance	0.2kHz A.C. Impedance	0.2kHz A.C. tan (delta)	0.5kHz A.C. Resistance	0.5kHz A.C. Impedance	0.5kHz A.C. tan (delta)	1.0kHz A.C. Resistance
Mitsui Zosen	Okayama/Tamano	Splash Zone at Sea	MSB100	#1	JASd2	150*150*4.5	0.00	3.50E+11				1.21E+08	2.00E-11	0.132	8.44E+07
Mitsui Zosen	Okayama/Tamano	Splash Zone at Sea	MSB100	#1	JASd2	150*150*4.5	0.50	3.80E+10	2.35E+08	2.00E-11	0.169	1.22E+08	2.00E-11	0.130	9.06E+07
Mitsui Zosen	Okayama/Tamano	Splash Zone at Sea	MSB100	#1	JASd2	150*150*4.5	1.00	4.20E+10	1.50E+08	2.80E-11	0.189	9.53E+07	2.50E-11	0.134	6.46E+07
Mitsui Zosen	Okayama/Tamano	Splash Zone at Sea	MSB100	#1	JASd2	150*150*4.5	1.50	6.00E+10	1.77E+08	2.00E-11	0.225	9.08E+07	1.60E-11	0.219	6.00E+07
Mitsui Zosen	Okayama/Tamano	Splash Zone at Sea	MSB100	#1	JASd2	150*150*4.5	2.00	9.80E+10	1.35E+08	2.00E-11	0.295	9.85E+07	2.00E-11	0.162	9.25E+07
Mitsui Zosen	Okayama/Tamano	Splash Zone at Sea	MSB100	#1	JASd2	150*150*4.5	2.50	1.30E+10	6.05E+08	1.30E-11	0.101	3.10E+08	1.20E-11	0.086	1.90E+08
Mitsui Zosen	Okayama/Tamano	Splash Zone at Sea	MSB100	#1	JASd2	150*150*4.5	3.00	3.10E+11	2.25E+08	2.00E-11	0.177	1.45E+08	2.00E-11	0.110	9.15E+07
Mitsui Zosen	Okayama/Tamano	Splash Zone at Sea	MSB100	#1	JASd2	150*150*4.5	3.50	2.00E+10	2.15E+08	2.20E-11	0.168	1.07E+08	2.00E-11	0.149	6.18E+07
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Organization of Experiment	Test Place	Test Condition	Specimen Number	Paint Specification	Surface Preparation	Specimen Size	Test Period	1.0kHz A.C. Resistance	1.0kHz A.C. Impedance	1.0kHz A.C. tan (delta)	Adhesion Test (kg/cm2)	Adhe Test
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI100	#1	JSRA,Sd2-3	150*200*3.2	0.00	1.40E+08	1.70E-11	0.067		
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI100	#1	JSRA,Sd2-3	150*200*3.2	0.25	5.20E+07	1.90E-11	0.161		
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI100	#1	JSRA,Sd2-3	150*200*3.2	0.50	4.40E+07	2.40E-11	0.151		
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI100	#1	JSRA,Sd2-3	150*200*3.2	1.00	5.30E+07	2.30E-11	0.131		
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI100	#1	JSRA,Sd2-3	150*200*3.2	1.50	2.30E+07	2.80E-11	0.247		
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI100	#1	JSRA,Sd2-3	150*200*3.2	2.00	2.70E+07	2.80E-11	0.211		
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI100	#1	JSRA,Sd2-3	150*200*3.2	3.00	1.50E+07	3.20E-11	0.332		
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI101	#1	JSRA,Sd2-3	150*200*3.2	0.00	1.30E+08	1.80E-11	0.068		
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI101	#1	JSRA,Sd2-3	150*200*3.2	0.25	8.00E+07	2.10E-11	0.095		
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI101	#1	JSRA,Sd2-3	150*200*3.2	0.50	3.70E+07	2.70E-11	0.159		
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI101	#1	JSRA,Sd2-3	150*200*3.2	1.00	4.50E+07	2.50E-11	0.141		
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI101	#1	JSRA,Sd2-3	150*200*3.2	1.50	2.10E+07	3.00E-11	0.253		
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI101	#1	JSRA,Sd2-3	150*200*3.2	2.00	3.50E+07	2.70E-11	0.168		
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI101	#1	JSRA,Sd2-3	150*200*3.2	3.00	9.20E+06	3.40E-11	0.509		
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI102	#1	JSRA,Sd2-3	150*200*3.2	0.00	1.40E+08	1.70E-11	0.087		
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI102	#1	JSRA,Sd2-3	150*200*3.2	0.25	8.60E+07	2.00E-11	0.093		
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI102	#1	JSRA,Sd2-3	150*200*3.2	0.50	3.70E+07	2.50E-11	0.172		
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI102	#1	JSRA,Sd2-3	150*200*3.2	1.00	5.20E+07	2.20E-11	0.139		
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI102	#1	JSRA,Sd2-3	150*200*3.2	1.50	2.30E+07	2.80E-11	0.247		
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI102	#1	JSRA,Sd2-3	150*200*3.2	2.00	5.80E+07	2.30E-11	0.119		
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI102	#1	JSRA,Sd2-3	150*200*3.2	3.00	2.10E+07	2.80E-11	0.271		
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI103	#1	JSRA,Sd2-3	150*200*3.2	0.00				32.67	
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI104	#1	JSRA,Sd2-3	150*200*3.2	0.50	4.70E+07	2.40E-11	0.141	29.00	
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI105	#1	JSRA,Sd2-3	150*200*3.2	1.00	5.60E+07	2.20E-11	0.129	27.00	
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI106	#1	JSRA,Sd2-3	150*200*3.2	1.50	2.40E+07	2.80E-11	0.237	32.00	
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI107	#1	JSRA,Sd2-3	150*200*3.2	2.00	5.60E+07	2.20E-11	0.129	31.50	
Mitsubishi H.I.	Nagasaki/Nagasaki	In Sea Water	MHI108	#1	JSRA,Sd2-3	150*200*3.2	3.00	3.80E+07	2.10E-11	0.199	40.00	

Table 4 Specification of coating for POSEIDON [6]

Paint Specification	Column (In Air zone)	Column (Splash Zone)	Column (Submerged Zone)	Side Wall of Deck House
A	methacrylate primer (40μm) methacrylate paint (300μm)	methacrylate primer (40μm) methacrylate paint (300μm)	methacrylate primer (40μm) methacrylate resin mortar (2000μm)	
B	inorganic zinc rich primer (75μm) pure epoxy paint/ mist coat (100μm) polyurethane paint (30μm)	epoxy mortar lining (5000μm)	tar epoxy paint (125μm) x 2	
C	inorganic zinc rich primer (75μm) pure epoxy paint (80μm) x 2 polyurethane paint (30μm)	epoxy mortar lining (400μm) x 2	inorganic zinc rich paint (50μm) tar epoxy paint (150μm) x 2	
D	inorganic zinc rich primer (75μm) pure epoxy primer (100μm) x 2 pure epoxy topside paint (75μm)	inorganic zinc rich paint (75μm) pure epoxy primer (250μm) x 2	inorganic zinc rich paint (75μm) tar epoxy paint (200μm) x 2	inorganic zinc rich primer (75μm) pure epoxy anti-corrosive primer (60μm) x 2 polyurethano intermediate paint (30μm) fluorine-contained resin topsido paint (25μm)
E	epoxy zinc primer (25μm) epoxy glass flake lining (450μm) x 2 epoxy glass flake topside lining (100μm)		epoxy zinc primer (touch up) modified epoxy paint (200μm) x 2	inorganic zinc rich primer (etheysilicate)(75μm) fluorine-contained resin primer/ mist coat (100μm) fluorine-contained resin intermediate paint (50μm) fluorine-contained resin topside paint (30μm)
F	inorganic zinc rich primer (75μm) pure epoxy primer/ mist coat (40μm) pure epoxy primer (180μm) vinyl intermediate paint (60μm) vinyltopside paint (30μm) x 2	inorganic zinc rich primer (75μm) tar epoxy paint/ mist coat (40μm) tar epoxy paint (100μm) x 3	tar epoxy paint (150μm) x 2	
G	epoxy zinc primer (touch up) pure epoxy paint (100μm) x 2 pure epoxy topside paint (35μm)	pure epoxy paint (2000-3000μm)	epoxy zinc primer (touch up) pure epoxy anti-corrosive primer (100μm) x 2	
H	inorganic zinc rich primer (15μm) pure epoxy paint (100μm) x 2 polyurethane topside paint (40μm)		inorganic zinc rich primer (15μm) tar epoxy paint (100μm) x 2 vinyl tar paint (50μm) antifouling paint (SPN-2) (100μm) x 2 antifouling paint (SPN-3) (100μm)	
K	modified epoxy glass flake lining (250μm)	pure epoxy primer (30μm) epoxy glass flake lining (250μm)	tar epoxy glass flake lining (250μm)	
L	epoxy glass flake primer (40μm) epoxy glass flake lining (300-500μm) polyurethane anti-corrosive primer (40μm) polyurethane topside paint (40μm)	epoxy glass flake primer (40μm) epoxy glass flake lining (500-750μm)	epoxy glass flake primer (40μm) tar epoxy glass flake lining (500-750μm)	
M	epoxy glass flake lining (750μm)			

Table 5 Evaluation grade of coating films of POSEIDON after 4 years operation [6]

Paint Specification	Position: Column – In Air Zone	Column – Splash Zone	Column – Submerged Zone	Side Wall of Deck House
A	TEG 3, Chalking 4, Pinhole 3, Rust 4	TEG 3, Chalking 3, Pinhole 3, Flaking 4	TEG 5, Chalking 5	
B	TEG 2, Chalking 4, Pinhole 2, Rust 2	TEG 2, Chalking 3, Rust 2	TEG 2, Flaking 2 Rust 2	
C	TEG 3, Chalking 4, Wrinkling 3	TEG 3, Chalking 4, Rust 3	TEG 2, Rust 2	
D	TEG 3, Chalking 4, Rust 3	TEG 5, Chalking 4, Coming up of Fillers	TEG 5, Chalking 4	TEG 5, Chalking 5
E	TEG 5, Rough Surface	TEG 4, Coming up of Fillers	TEG 3, Flaking 2	TEG 5, Chalking 5
F	TEG 5, Rust 5, Gloss Remaining	TEG 4, Chalking 4	TEG 1, Rust 1, Flaking 4	
G	TEG 5, Pinhole 5, Rust 5	TEG 5	TEG 5, Chalking 4	
H	TEG 4,Chalking 4, Rust 5	TEG 4,Chalking 4, Flaking 4	TEG 2, Flaking 2	
K	TEG 3, Chalking 3 Local Corrosion 2	TEG 3, Chalking 5, Pinhole 4,Coming up of Fillers	TEG 3, Rust 4, Locally Damaged 3	
L	TEG 5, Chalking 4 Flaking 5, Rust 5	TEG 3, Rust 3	TEG 1, Rust 1, Flaking 4	
M	TEG 4, Chalking 5 Cracking 4, Rust 5	TEG 4, Chalking 5, Cracking 4	TEG 4, Chalking 5, Rust 4,	

TEG = Total Evaluation Grade. All Grades are based on 5 point system.

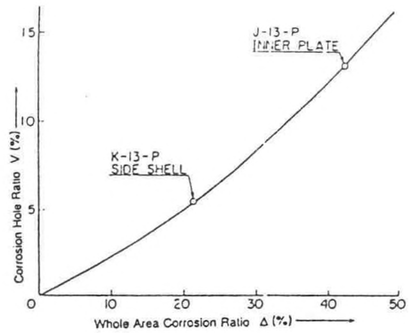

Fig. 1 Relation between whole area corrosion ratio Δ and corrosion hole ratio [1]

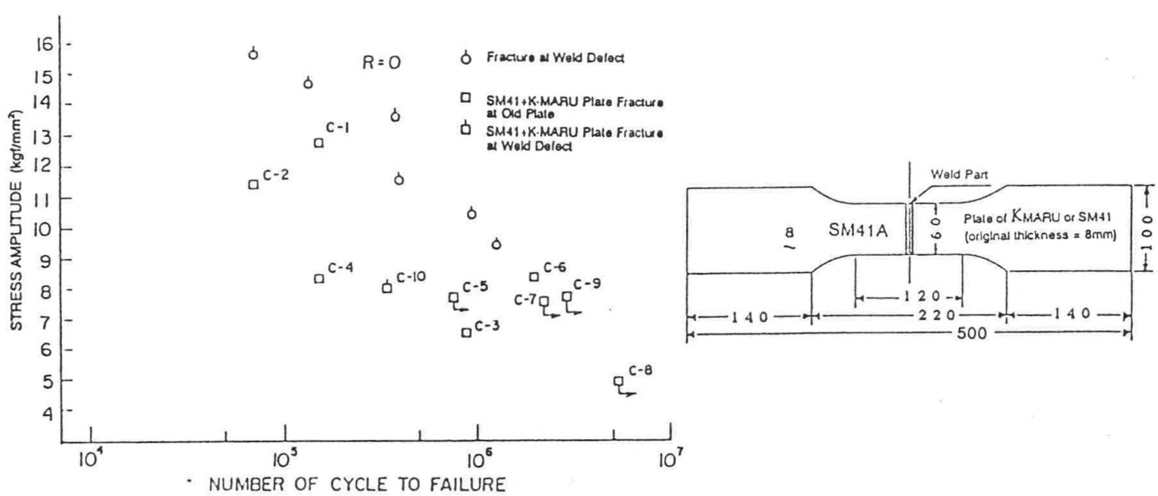

Fig. 2 Fatigue life diagram expressed by stress at section with minimum sectional area [1]

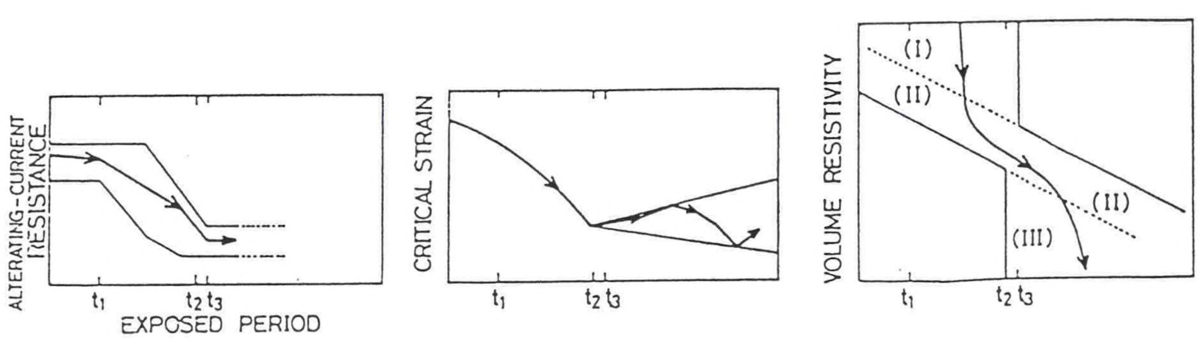

Fig. 3 Schematic view of deterioration phenomena of epoxy coating in an early stage [2]

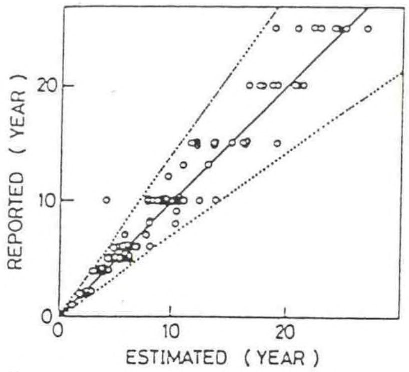

Fig. 4 Correlation between estimated and reported period of durability [3]

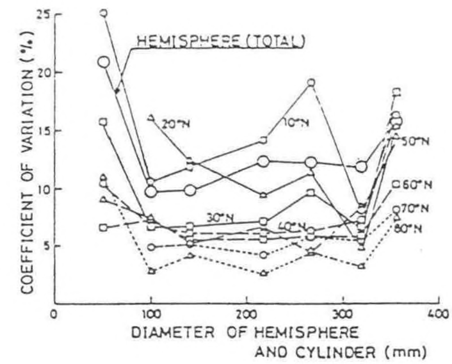

Fig. 5 Relation between diameter D and coefficient of variation σ/t_m for hemisphere [4]

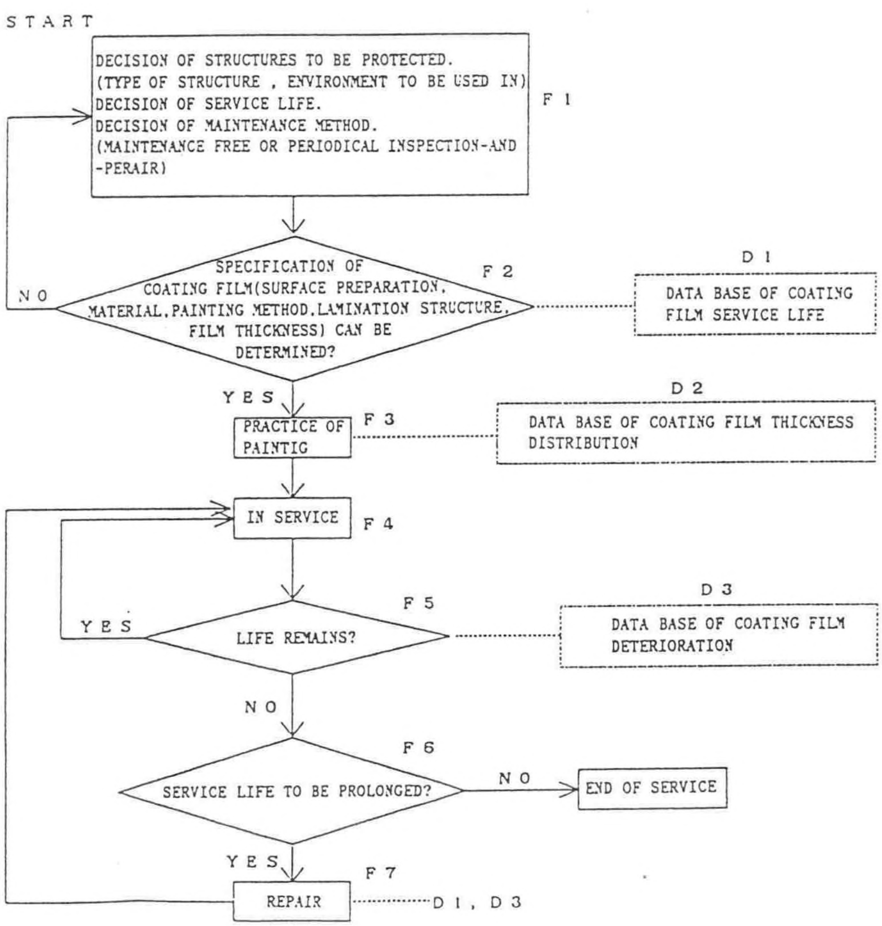

Fig. 7 Composition of corrosion preventing system of paint coating [5]

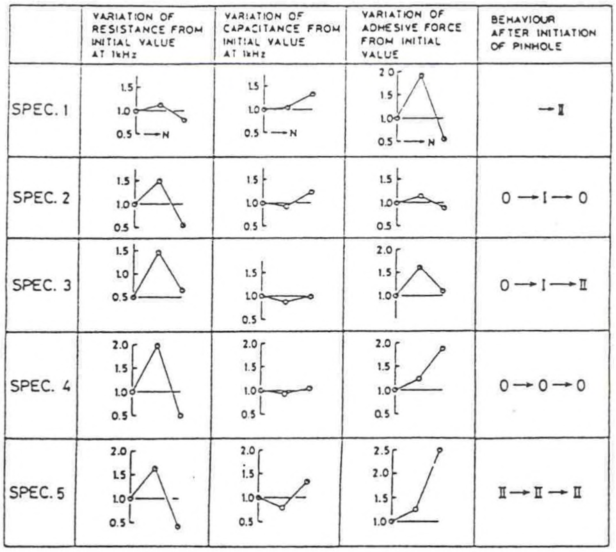

Fig. 6 Summary of thermal shock test [4]

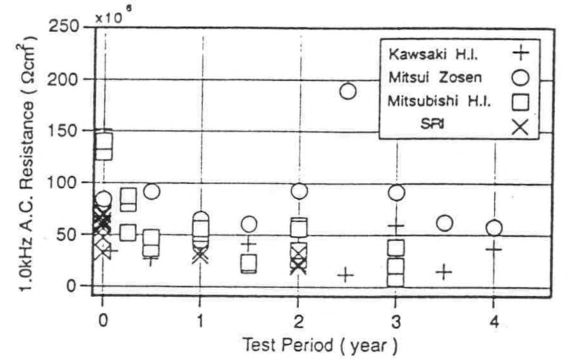

Fig. 8 Output example of deterioration data base [5] (Relation between alternating current resistance and test period for epoxy coating of 220μm in thickness)

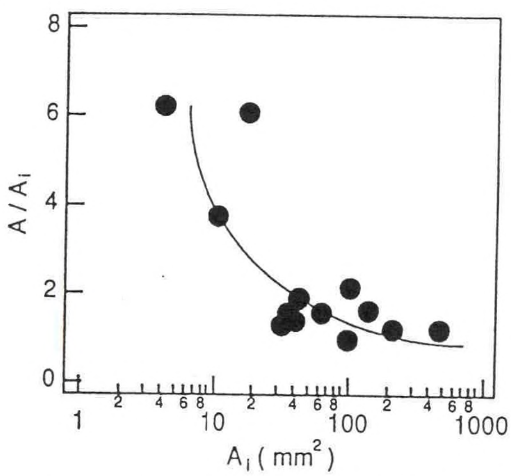

Fig. 9 Relation between visual defect area Ai of coating and real defect area A [6]

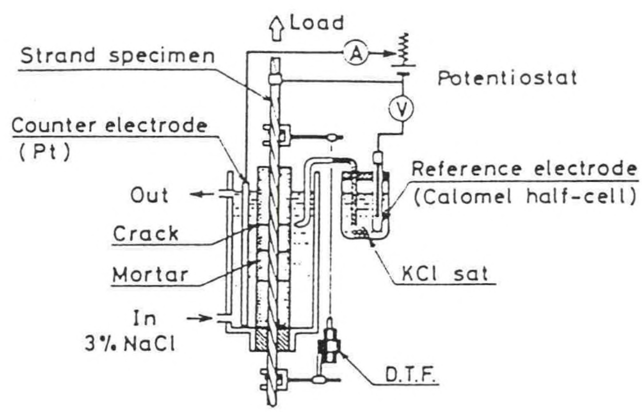

Fig. 10 Sketch of testing paratus of strand [7]

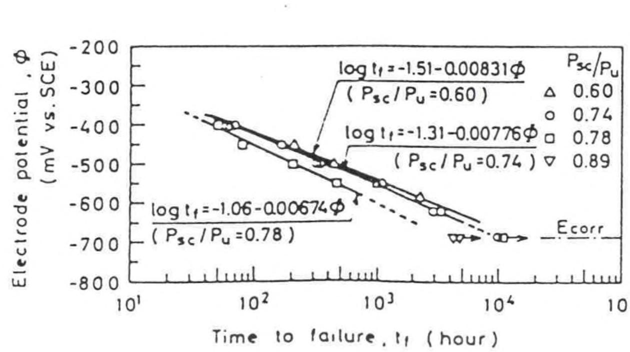

Fig. 11 Effect of electrode potential on time to failure [7]

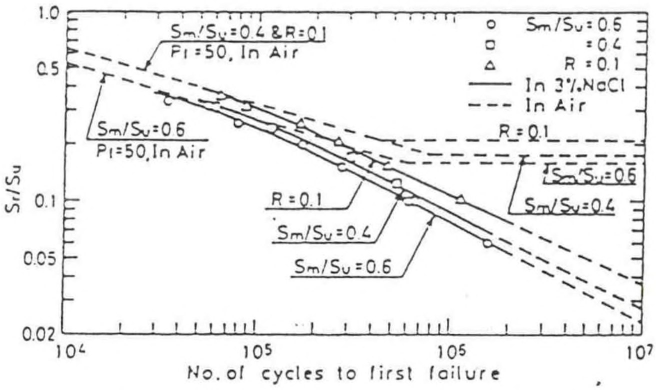

Fig. 13 Test specimen for corrosion fatigue [9]

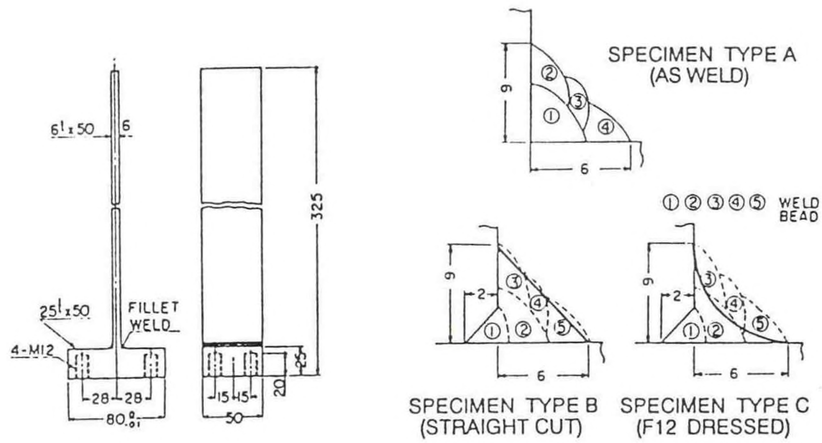

Fig. 12 S-N curves of corrosion fatigue of strand [8]

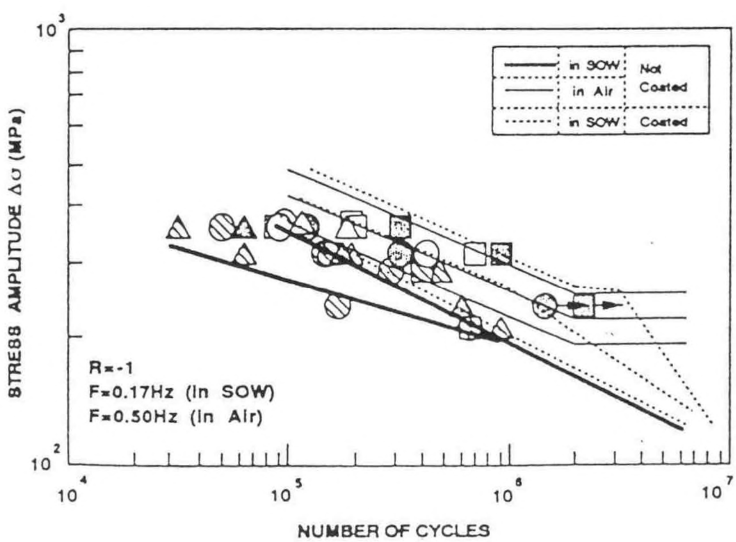

Fig. 14 Conceptional illustration of corrosion fatigue strength of coated specimen [9]

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