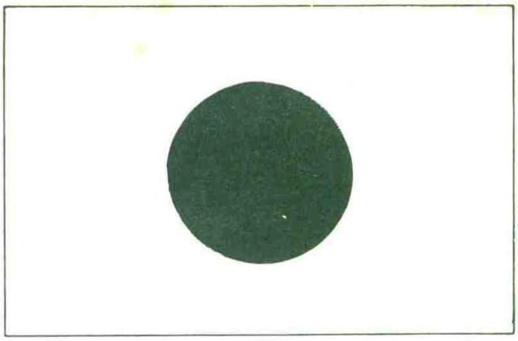


U.S.A.

UJNR

U.S./Japan Cooperative Program in Natural Resources

日本

日米天然資源協力プログラム

13TH MEETING U.S.–JAPAN MARINE FACILITIES PANEL

NOVEMBER 1985
CONFERENCE RECORD

Thirteenth Meeting of the United States-Japan Cooperative Program in Natural Resources (UJNR) Panel on Marine Facilities March 1985

November 1985

IN MEMORIAM

Dr. Peter W. Anderson

Panel Member 1978-1984
Chief, Marine and Wetlands Protection Branch, Environmental Protection Agency
Major contributions dealing with protection of the marine environment

Mr. Phillip Eisenberg

Panel Adviser 1980-1984
Founder and Chairman of the Board HYDRONAUTICS INC.
Major contributions in naval architecture and marine engineering
Past President of the Society of Naval Architects and Marine Engineers, and the Marine Technology Society

Mrs. Richard M. Shamp

Participant 1982 & 1983 Meetings
Office Manager, Engineering Service Associates
Personal contributions in support of UJNR/MFP social activities

This conference record is dedicated in remembrance of their contributions and participation in Marine Facilities Panel activities of the U.S. - Japan Cooperative Program in Natural Resources.

PREFACE

This document contains technical papers and special reports presented at the 13th annual meeting of the Marine Facilities Panel of the United States - Japan Cooperative program in Natural Resources (UJNR), held March 14-15, 1985 in Tokyo, Japan. Following two days of presentations of technical papers and discussion, the Panel toured marine facilities from March 16-28, 1985. A final meeting of the joint panels was held March 26 at the Ship Research Institute in Mitaka, Tokyo, Japan. A complete schedule and summaries of the meetings and tour are provided herein.

The purpose of this document is to provide a permanent record, and to enable a wider dissemination of the technical information presented and exchanged at the meeting.

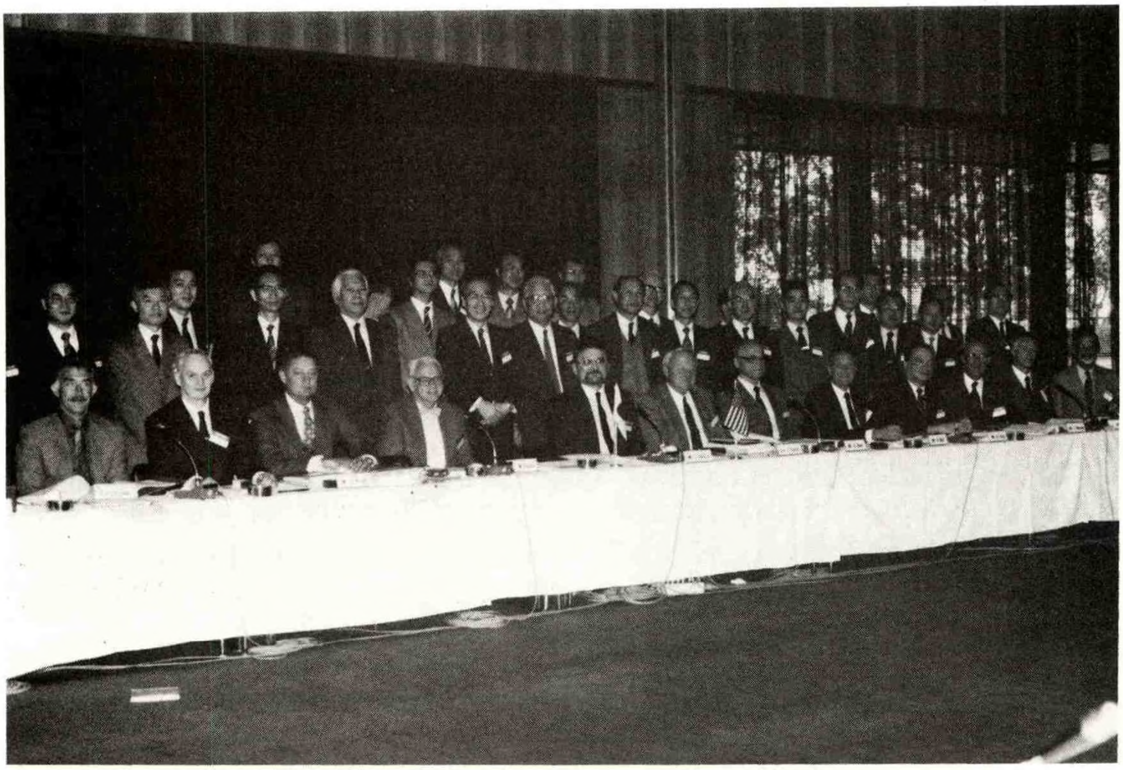
The United States-Japan Cooperative Program in Natural Resources was established in 1964 to facilitate cooperative efforts and technology exchange in the field of natural resources that would provide a better environment for present and future generations. Seven of the seventeen UJNR panels deal with marine science and technology and are a part of the Marine Resources and Engineering Coordination Committee (MRECC) of UJNR.

Participating governmental agencies in Japan are: the Science and Technology Agency; Ministry of Foreign Affairs; Environmental Agency; Ministry of Agriculture, Forestry, and Fisheries; Ministry of International Trade and Industry; Ministry of Transport; Ministry of Construction; and Japan Marine Science and Technology Center.

Participation of governmental agencies in the United States include: the Department of Agriculture, Department of Commerce, Department of Energy, Department of Interior, Department of Transportation, Department of State, Department of Defense, and Environmental Protection Agency. The Marine Facilities Panel meeting enabled valuable exchanges of technical information between key representatives of the ocean community from Japan and the United States.

Special recognition is given to Mr. Gerard F. Helfrich, Counselor for Scientific and Technological Affairs, U.S. Embassy, Tokyo, for his valuable advisory assistance and introductory remarks; Mr. Makoto Utsonomiya, Japan Chairman, UJNR Marine Resources Engineering Coordinating Committee for his introductory remarks; and to Mr. John A. Pritzlaff and Ms. Joyce Flipse Smith, who provided the photographs used in this conference record.

Morton Smutz,
Editor



Participants at Sasakawa Hall

Mr. Joseph R. Vadus, Chairman, U.S. Panel
Dr. Hitoshi Nagasawa, Chairman, Japan Panel

OPENING REMARKS

Dr. Hitoshi Nagasawa
Chairman, Japan Panel

It is a great honor and privilege for me, on behalf of the Japan Panel, to express our heartfelt welcome to Mr. Joseph Vadus, Chairman of the U.S. Panel and to each of the members advisers of the U.S. Panel at the opening of the 13th Japan and U.S. Joint Meeting of the UJNR Marine Facilities Panel.

In opening the meeting, I also would like to express my deep appreciation for the guidance and cooperation from the National Oceanic and Atmospheric Administration of the U.S.A., Science and Technology Agency of Japan, and the other related agencies.

It has been fifteen years since the inauguration of the first Japan and U.S. Joint Meeting in March 1970, and thirteen meetings have been conducted to date. Japan and U.S. panels have cooperated on mutual exchange of information between the two countries and the development of technology in relation to natural resources, and I believe that the Marine Facilities Panel is one of the most active panels under UJNR.

At this 13th Meeting, about 50 papers have been submitted, which I am sure, will contribute greatly toward significant discussions between the two countries on the development of marine facilities. Through this meeting we hope that we will further promote mutual exchange between the two countries and also contribute to the development of natural resources of the two countries.

I am saddened to report to you that Mr. Phillip Eisenberg who has been so active as an adviser on the U.S. Panel passed away last December, and also Dr. Peter Anderson who was a member of the U.S. Panel and presented papers at meetings in Japan and the U.S.A. has passed away since our last meeting. Two years ago, the 12th Japan and U.S. Joint Meeting was conducted in the U.S., and I would like to express our thanks to Chairman Mr. Vadus and all of the members and advisers of the U.S. Panel.

In this meeting, field trips to visit several marine facilities in Kyushu and the Science EXPO '85 have been scheduled following the plenary session. Normally at the end of March there is still much snow piled up in the northern part of Japan and this is the start of Spring in Kyushu and cherry blossoms are expected. I hope that every member of the U.S. Panel will enjoy the field trip to the southern part of Japan.

Joseph R. Vadus
Chairman, United States Panel

Distinguished members and advisers of the UJNR Marine Facilities Panel, on behalf of the U.S. Panel, it is my pleasure to extend our warmest greetings and best wishes to Dr. Hitoshi Nagasawa, Chairman of the Japan Panel, and to each of the members and advisers of the Japan Panel. We are pleased to be participating with you in this 13th joint meeting in Tokyo, one of the truly great cities of the world, and we are delighted for this reunion with our many friends from past meetings and having this opportunity to make some new friends.

I would like to express our appreciation to Chairman Nagasawa and the Japan Panel for planning and organizing an excellent technical program and study tour of marine facilities. We are very impressed with your planning and coordination skills and appreciate your fine hospitality.

I am saddened to report to you that two of our members have passed away since our last meeting. Mr. Phillip Eisenberg and Dr. Peter W. Anderson. Mr. Eisenberg was an adviser to our panel for over 5 years and participated in several meetings. He was founder and chairman of HYDRONAUTICS, Inc., and was internationally known for achievements in naval architecture and marine engineering, especially in the field of hydrodynamics. He was past president of the Society of Naval Architects and Marine Engineers and the Marine Technology Society. Dr. Anderson was a member of our panel for over 7 years and presented papers at meetings in Japan and the U.S. He was Chief of the Marine and Wetlands Protection Branch of the U.S. Environmental Protection Agency and was very effective in exchanging information dealing with disposal and management of wastes in the oceans. We are grateful for their friendship, many contributions, and dedicated service to our panel. In their honor and memory, let us share in a moment of silence.

The U.S. Panel has appreciated the cooperation, technical ability, and cordiality of the Japan Panel. We find the meetings and facilities tours to be very informative and valuable in providing an equitable technology exchange with mutual benefits and advantages in development of the oceans and their resources. The need for marine facilities in Japan and the U.S. continues to expand in scope and intensity, and the Panels have responded to this challenge, with excellent support from the marine technical community.

I was pleased to note that the proceedings of our 12th meeting in the U.S. were printed in Japanese and English. In order to improve our technical exchange, we have distributed pre-prints of the U.S. and Japan papers before this meeting to enable more effective discussion of the topics presented.

We are seeking opportunities for more cooperative efforts between the two panels, especially in development of joint projects and ventures in government and industry. This meeting and facilities tour will provide an opportunity to engage in discussions leading to closer cooperation. We sincerely hope that both panels will find this 13th meeting and marine facilities tour mutually beneficial and successful.

PARTICIPANTS

Japan

Members	Organizations
Dr. Hitoshi Nagasawa, Chrmn	Ship Research Institute
Mr. Tadanori Asada	Ministry of Transport
Mr. Yoshihito Chikunuki	Maritime Safety Agency
Dr. Susumi Fujimatsu	Ministry of Construction
Dr. Yoshimi Goda	Ministry of Transport
Mr. Takao Hirota	Ministry of Transport
Dr. Hayato Iida	Meteorological Agency
Mr. Hajime Inoue	Ministry of Transport
Mr. Kiyoshi Katagiri	Meteorological Agency
Mr. Eifu Kataoka	Ministry of Transport
Mr. Hirotaka Kawamoto	Ministry of Intl Trade and Ind
Dr. Tomohiko Ohno	Ministry of Intl Trade and Ind
Dr. Kazuo Sugai	Ministry of Transport
Dr. Hajime Takahashi	Ministry of Transport
Dr. Yoshifumi Takaishi	Ministry of Transport
Mr. Norio Tanaka	Ministry of Transport
Mr. Tadashi Tanimoto	Ministry of Construction
Mr. Shigeo Toyoda	Ministry of Transport
Dr. Hajime Tsuchida	Ministry of Transport
Mr. Yasuo Ueta	Ministry of Transport
Mr. Yasuyuki Yamakoshi	Ministry of Agriculture
Mr. Akira Yamazaki	Maritime Safety Agency
Mr. Kouichi Yokoyama	Ministry of Construction
Mr. Kousei Watanabe	Ministry of Transport
Mr. Takashi Yamamoto	Ministry of Transport

Advisers

Mr. Hisashi Ando	JAMSTEC
Dr. Noritaka Ando	Shipbuilding Research Centre of Japan
Mr. Hiroyasu Haga	Shipbuilding Research Association of Japan
Dr. Noboru Hamada	JAMDA
Mr. Kenichi Hirabayashi	Kawasaki Heavy Industries, Ltd.
Mr. Shouzou Hirano	Ishikawajima-Harima Heavy Ind., Ltd.
Mr. Yasuo Hisada	Nippon Steel Corporation
Mr. Harumi Matsuda	Hitachi Zosen Corporation
Prof. Seizo Motora	Nagasaki Inst of Applied Science
Mr. Ikuo Mutoh	Mitsui Ocean Dev & Eng Co.Ltd.
Mr. Yukihiro Narita	JAMDA
Dr. Kenji Okamura	Ryowa Ocean Development Co.Ltd.
Mr. Masao Ono	Mitsubishi Heavy Industries, Ltd.
Mr. Masanao Oshima	Mitsui Eng and Shipbuilding Co. Ltd.
Mr. Muneharu Saeki	JAMSTEC

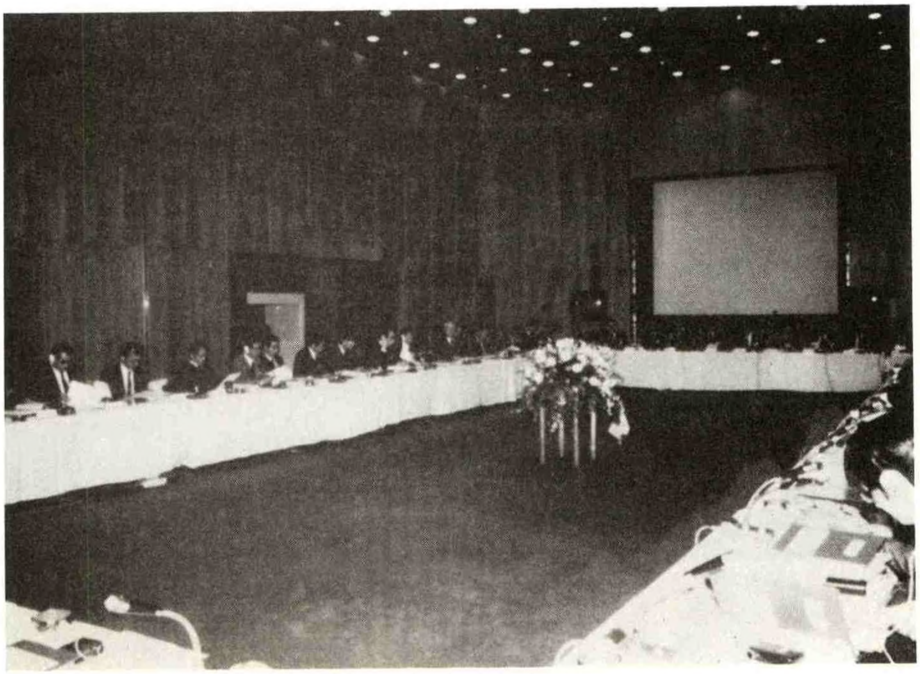
Dr. Naonosuke Takarada	Sumitomo Heavy Industries Co. Ltd.
Mr. Masatoshi Takeuchi	JAMSTEC
Dr. Sinkichi Tashiro	Nippon Kaiji Kyoukai
Mr. Hiroshi Watanabe	Nippon Kokan K. K.

Observers

Mr. Hirofumi Satake	Science and Technology Agency
Mr. Nobukazu Takahashi	Ministry of Transport
Mr. Hiroshi Tani	Ministry of Transport
Mr. Makoto Utsunomiya	Science and Technology Agency

Japanese Speakers Other than Members

Dr. Hiroyuki Adachi	Ministry of Transport
Mr. Shinji Hashiguchi	Hitachi Zosen Corporation
Dr. Mutsuo Hattori	JAMSTEC
Dr. Masayoshi Hirano	Mitsui Eng and Shipbuilding Co. Ltd.
Mr. Natsuo Inagaki	JAMSTEC
Dr. Reisaku Inoue	Ministry of Transport
Mr. Shinichi Ishii	JAMSTEC
Mr. Nobuo Ito	JAMSTEC
Mr. Masaki Kitazume	Ministry of Transport
Mr. Nobuo Nagatomi	Ishikawajima-Harima Heavy Ind. Co. Ltd.
Mr. Shinichi Takagawa	JAMSTEC
Mr. Shigeo Takahashi	Ministry of Transport
Dr. Masaaki Terashi	Ministry of Transport
Mr. Shinichi Tomita	Kawasaki Heavy Industries Ltd.
Mr. Toshihiro Watanabe	Nippon Kokan K. K.



Meeting at Sasakawa Hall

United States

Members

Mr. Joseph R. Vadus, Chrmn	National Oceanic & Atmos Admin
Mr. John Freund	US Navy
Mr. J. D. Hightower	US Navy
Mr. Richard B. Krahl	Department of Interior
Dr. Kilho Park	National Oceanic & Atmos Admin
Dr. Alan Powell	US Navy
Dr. Reuben Schlegelmilch	US Coast Guard
Dr. Morton Smutz	National Oceanic & Atmos Admin

Advisers

Prof. John E. Flipse	Texas A&M University
Mr. Ronald Geer	Shell Oil Co.
Mr. Clifford E. McLain	Systems Planning Corporation
Mr. Kurt Merl	Sperry Corporation
Mr. John A. Pritzlaff	Westinghouse Electric Corporation
Dr. Richard J. Seymour	Scripps Inst. of Oceanography
Mr. James G. Wenzel	Marine Development Associates

Speaker

Mr. Robert Rupp	Sperry Corporation

Group on Study Tour

ITINERARY

Date	Local Time	Event
Mar 12		U.S. Panel arrives in Tokyo
Mar 13	0900-1200	Meeting of U.S. Panel, New Sanno Hotel
Mar 14	0900	Opening of 13th Meeting of U.S. - Japan Panels, Sasakawa Hall, Tokyo
	1000-1030	Presentation of UJNR awards to Dr. N. Hamada and Dr. H. Nagasawa and Marine Technology Society Award to JAMSTEC (received by Mr. M. Saeki)
	1700	Conclusion of first day's session
	1800-2000	Japan Reception, Sasakawa Hall
Mar 15	0900	Meeting continued, second day
	1400-1430	Meeting with Mr. R. Sasakawa. Presentation of UJNR award to Mr. Sasakawa.
	1700	Conclusion of meeting.
	1800-2000	U.S. Reception at the residence of U.S. Counselor for Scientific and Technological Affairs, Mr. Gerard Helfrich
Mar 16	0800	Depart Tokyo
	1055	Arrive Fukuoka, Kyushu
	1300-1500	Visit OTEC Heat Exchanger Facility, Imari, Kyushu
	1800	Arrive Nisshokan Hotel, Nagasaki, Kyushu
Mar 17		Free Day
Mar 18	0830-1300	Depart Nagasaki. Visit Nagasaki Technical Institute and Mitsubishi Heavy Industries Co.

	1400-1700	Visit Hitachi Zosen - Ariake Works, Tahira, Kyushu
	1800	Arrive Hotel Castle, Kumamoto, Kyushu
Mar 19	0830	Leave Kumamoto
	1400-1500	Visit Hatchobaru Geothermal Power Station
	1600	Arrive Shiragiku Ryokan Hotel, Beppu, Kyushu
Mar 20	0900	Leave Beppu
	1400-1500	Visit MAGLEV Experiment Center, Hyuga, Kyushu
	1700	Arrive Sun-Hotel Phoenix, Miyazaki, Kyushu
Mar 21	0830	Leave Miyazaki
	1100-1200	Visit Saboten Park
	1500	Arrive Tokyu Hotel, Kagoshima, Kyushu
Mar 22	0900	Leave Kagoshima
	1030-1200	Visit Kiire Oil Storage Terminal, Kiire, Kyushu
	1400	Arrive Ibuski Kanko Hotel, Ibusuki, Kyushu
Mar 23	1000	Leave Ibusuki
	1645	Arrive Tokyo
Mar 24		Free Day
Mar 25	0900-1500	Visit Mitsui Engineering and Shipbuilding Co. Ltd., Chiba, Honshu
Mar 26	0900-1300	Final Meeting, Ship Research Institute, Mitaka, Tokyo
Mar 27-28	0800-1800	Visit EXPO '85, Tsukuba, Honshu
Mar 29		U.S. Panel departs for U.S.

AWARDS

On March 15, 1985 representatives of the Marine Facilities Panel met with Mr. Ryoichi Sasakawa in his reception room in Sasakwa Hall. Members of the Japan Panel included Dr. Hitoshi Nagasawa, Dr. Noburu Hamada, and Professor Seizo Motora. Members of the U.S. Panel included Mr. Joseph R. Vadus, Professor John E. Flipse, Dr. Alan Powell, and Mr. John A. Pritzlaff.

Mr. Sasakawa is known throughout the world for his leadership and philanthropic endeavors to improve the welfare of mankind. He is chairman of more than 50 organizations concerned with public health, social welfare, international understanding, culture, and sports. He is chairman of the Japan Shipbuilding Industry Foundation, the organization which formed the basis of his many accomplishments. He is very interested in marine activities and supportive of the objectives and progress of the Marine Facilities Panel. During the meeting Mr. Vadus presented a plaque on behalf of the U.S. Marine Facilities Panel, to Mr. Sasakawa in recognition and appreciation of his interest and support of the activities of the U.S. - Japan Marine Facilities Panel.

Dr. N. Hamada, Dr. H. Nagasawa
in Meeting with Mr. R. Sasakawa

Professor J. Flipse, Mr. J. Vadus
in Meeting with Mr. R. Sasakawa

During the Plenary Session at Sasakawa Hall, Mr. Vadus presented plaques on behalf of the U.S. Marine Facilities Panel to: Dr. Noboru Hamada, Past Chairman and advisor of the Japan Panel in recognition and appreciation of his distinguished service over the past decade; and to Dr. Hitoshi Nagasawa, Chairman of the Japan Panel, in appreciation of his distinguished service as Chairman of the 13th meeting.

As President of the Marine Technology Society, Professor John E. Flipse used the occasion to present the MTS - Compass International Award to the Japan Marine Science and Technology Center (JAMSTEC). Receiving the award for JAMSTEC was Mr. Muneharu Saeki, Executive Director.

FINAL MEETING

The final meeting was held at the Ship Research Institute, Ministry of Transport, 38-1, 6-Chome, Shinkawa, Mitaka, Tokyo, on March 26, 1985, with Dr. Hitoshi Nagasawa presiding.

Dr. Nagasawa summarized activities of the 13th meeting and study tour and asked if all of the objectives were accomplished. Mr. Vadus thanked Dr. Nagasawa and other members of the Japan Panel for their efforts in making the meeting and study tour both successful and enjoyable.

A number of questions raised by U.S. Panel members during the study tour were answered by the Japan Panel members at this final meeting. The questions and answers (summarized) are noted below.

1. What research is being conducted on offshore mobile drilling unit structures for non-arctic use?

    References to five Ship Research Institute Reports were provided dealing with dynamic positioning systems, tension-leg platforms, and collision with platforms.

2. What research is being conducted on mooring large floating vessels or platforms in deep water (500 to 3,000 m)?

    Reference was made to "Research on Deep Sea Mooring of Offshore Structures" performed by SR 187 Research Panel of the Shipbuilding Research Association of Japan (1974). The research addressed: environmental conditions, mooring line characteristics, slowdrift motion of moored body, mooring devices, and strength of mooring lines.

3. Does Japan have an equivalent program to that of the U.S. in coastal zone management? Is there a general report or description of such a program?

    There is no equivalent or similar program in Japan. No Ministry was given the responsibility to develop and coordinate a plan or program for use of the coastal sea area. Any plan or program would be coordinated on a case-by-case basis by all interested parties.

4. Report on the program of a new foundation "Technical Research Center for Coastal Development," particularly future research projects.

   The Coastal Development Institute was established September 17, 1983, in Tokyo under the Ministry of Transport. Personnel includes three administrative staff and 13 researchers. Examples of research are (1) demand for coastal development technology, (2) concepts for offshore artificial islands, (3) durability and maintenance of large marine facilities, and (4) motion of large floating moorings and the development of mooring facilities.

5. Information on research pertaining to ice forces, ice structures, and ice mechanics.

   A pamphlet was provided that outlines a project on the study on ice-transiting commercial ships. Research items for 1984 were (1) Resistance and Propulsion Tests in Level Ice, and (2) Fundamental Performance of Propellers in Ice.

6. Budget at the Ship Research Institute? Budget for ice research and testing at the Ship Research Institute? Budget for ice research in Japan?

   A detailed budget for 1984 was provided showing a total budget of 2.6 billion yen ($10,410,000) with salaries of 1.5 billion yen ($6,170,000). Budget data on ice research is included. The total Japanese budget for ice research including private sectors was not available.

7. Latest information on bottom-crawling vehicles.

   a. JH-160 Bulldozer

   b. D-155W Bulldozer

   c. Underwater Trencher

   d. Rubble Leveling Robot

   e. Mud Eater

   f. RECUS-Bottom Survey and Inspection Vehicle

The JH-160 (Hitachi) and D-155W (Komatsu) are underwater bulldozers designed for operations in relatively shallow depths and are believed to be inoperative.

According to Dr. N. Takarada, Sumitomo Heavy Industries, Ltd., they have suspended further development of their Underwater Trencher because there was insufficient demand from the construction industry.

The Rubble Leveling Robot was developed by Penta Ocean Construction and Komatsu, Ltd. for leveling rubble on the sea floor for construction of breakwaters. The system is designed for operation to 30 meters depth and is remotely controlled by one man from a surface control station. The system can clear about $200m^2$ per day.

Mr. I. Mutoh, Mitsui Ocean Development and Engineering Co., provided a brief description of the Mud Eater which is capable of suction dredging at 50 meters depth. The Mud Eater is remotely operated from a crane barge and is propelled by Archimedean screws for bottom crawling.

Regarding the RECUS, a bottom survey and inspection vehicle, there was no information available at the meeting.

8. How do you obtain technical and research information from other countries and how do you translate and distribute such information in Japan?

    Dr. Nagasawa described the usual institutional methods of keeping abreast of international progress in science and engineering. The individual scientist and engineer is expected to keep abreast of the latest developments in his field.

9. How does the Nagasaki Technical Institute use radio-controlled models in the maneuvering basin?

    Mr. M. Ono, Mitsubishi Heavy Industries, Ltd., provided a brief description indicating that they use a 14 channel radio (140 MHZ) control system to control a free-running ship model. The system controls the propulsion motor, auto pilot and steering system, and on-board measuring instruments. Radio telemetry is used for data acquisition.

10. How do you correct for Reynold's Number on models of offshore structures or bridges in a wind tunnel?

    Mr. Takarada indicated that wind-tunnel tests are conducted using Reynold's Numbers for actual offshore structures and bridges by changing wind velocity. In the case where we cannot simulate the Reynold's Number for an actual large-scale offshore structure, we evaluate the effect by using a partial model and then correct the results for a full-scale model test.

11. In addition to vessel traffic control of Tokyo Bay area, do you provide real-time information on water level, currents, wave, wind, and fog (visibility)?

    The traffic control of Tokyo Bay gets real-time information on direction and velocity of wind, atmospheric pressure, and fog from various fixed points such as Izuoshima, Jusangochi, as well as from the center itself. As to current, we provide it in the tide table, and we know any water depth from charts; hence we do not measure any real-time data at present. Wave height is measured only by eye.

12. What ocean/meteorological measurements are made to assist vessel traffic and to avoid delays?

    See answer to question 11.

13. Data on Nippon Tetrapod Co., Ltd.

    A pamphlet was provided showing data on Nippon Tetrapod products.

14. Offshore artificial island concepts.

    Summaries of two study reports were provided: one by the Ministry of Transport on concepts for offshore artificial islands; and another by the Research Institute for Ocean Economics on various concepts for utilization of sea space. These studies were completed in 1984.

<u>Final Meeting (continued)</u>

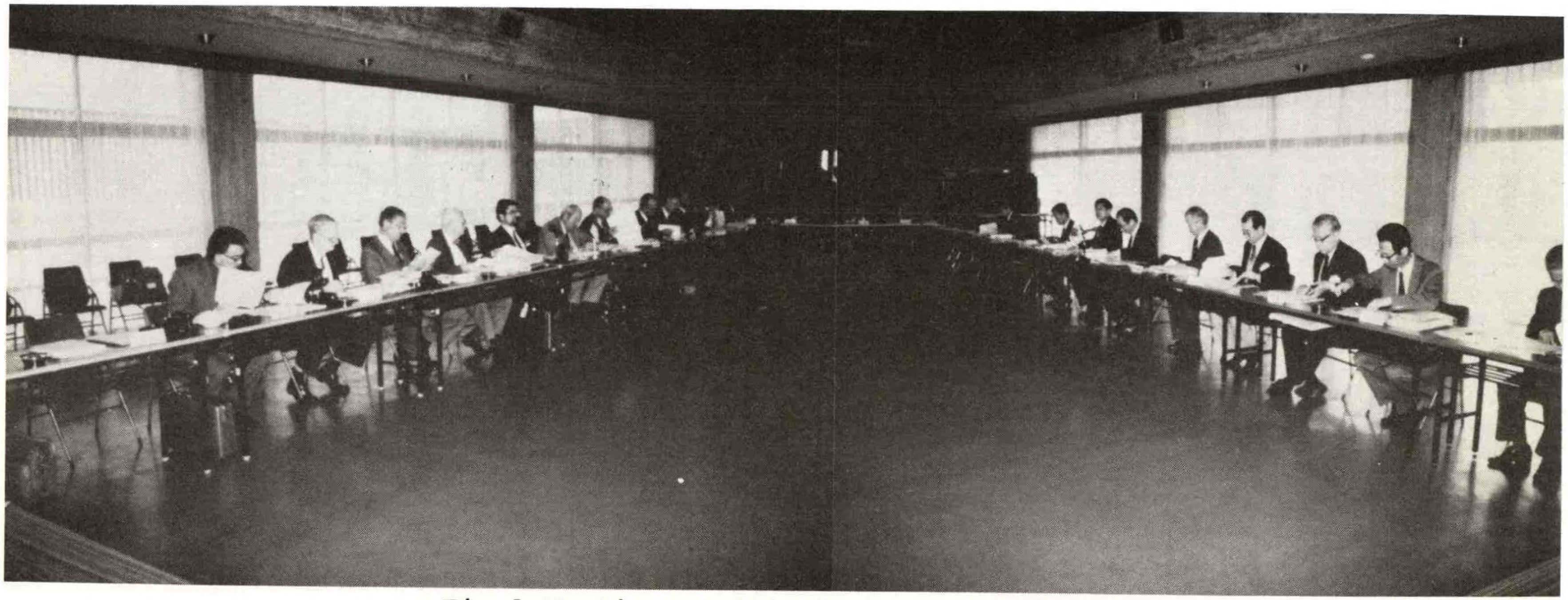
Mr. Vadus proposed conducting the 14th Meeting in the United States in September 1986, to coincide with the OCEANS '86 Conference to be held in Washington, D.C. Previous meetings in the United States traditionally included the OCEANS Conference. Since the OCEANS '86 Conference will be held September 22-24, 1986, Mr. Vadus proposed that the 14th Meeting be held on

September 18-19, 1986, and the study tour conducted September 24 to October 5. He further suggested that the study tour include visits to marine facilities in the New Orleans and San Diego area. Another possibility is to conclude the study tour with a visit to the Transportation Exposition to be held in Vancouver, British Columbia, Canada, in 1986.

Dr. Nagasawa stated that the members of the Japan Panel will study and discuss the proposed plan and options, and will reply within several months.

Prior to the conclusion of the final meeting, Mrs. Alan Powell made a special presentation of a painting which she personally created. It is an excellent work of art and was appreciated by all. It was received by Chairman Nagasawa on behalf of the Japan Panel and will be hung in a prominent location at the Ship Reserach Institute. Dr. Nagasawa and Mr. Vadus acknowledged the valuable technical contributions made by the members of both panels and declared the 13th Meeting was most successful. Dr. Nagasawa adjourned the meeting.

Group at Ship Research Institute



Final Meeting at Ship Research Institute

SPECIAL PRESENTATION

Artist June Powell with her painting enscribed "Moonlight" by Chung Pao-hua, presented as a token of friendship to the Ship Research Institute.

The subject of the painting - The Lotus - is in Japan a symbol of purity which well represents the spirit of friendship and cooperation existing between the members of UJNR from Japan and the United States. The Ship Research Institute has been a gracious host to our meetings in Japan.

JAPAN PANEL

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Mr. Akira Yamazaki
Chief Hydrographer
Hydrographic Department
Maritime Safety Agency
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Mr. Kousei Watanabe
Deputy Director-General
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Ministry of Transport
6-38-1 Shinkawa, Mitaka city
Tokyo 181

Secretary

Mr. Takashi Yamamoto, Director
Research Plan and Program
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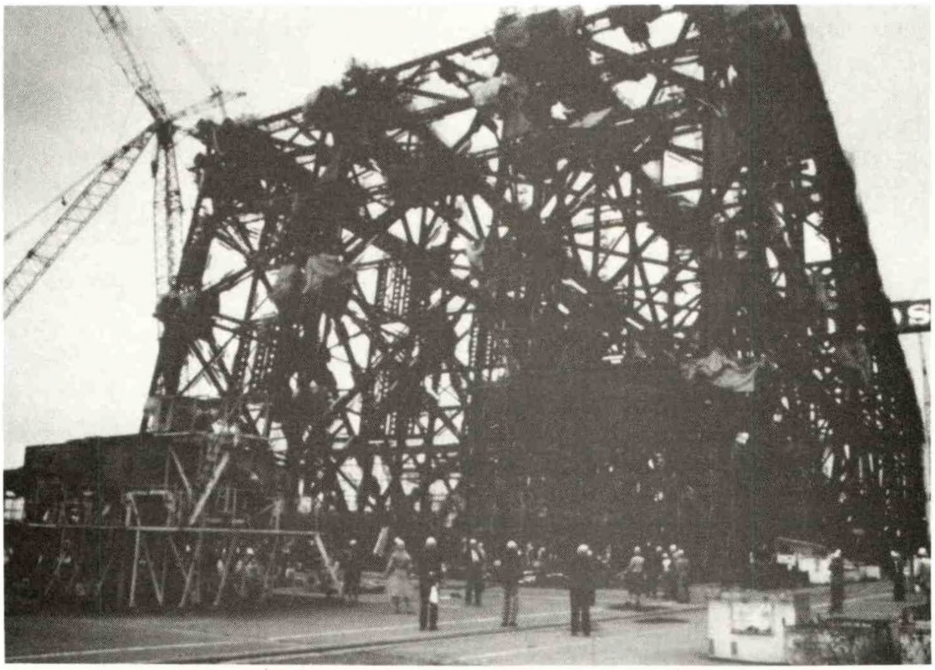


HERMOSA PLATFORM, Ariake Shipyard
Hitachi Zosen Corporation

STUDY TOUR

Saga University - OTEC Heat Exchanger Research Facility, March 16, 1985

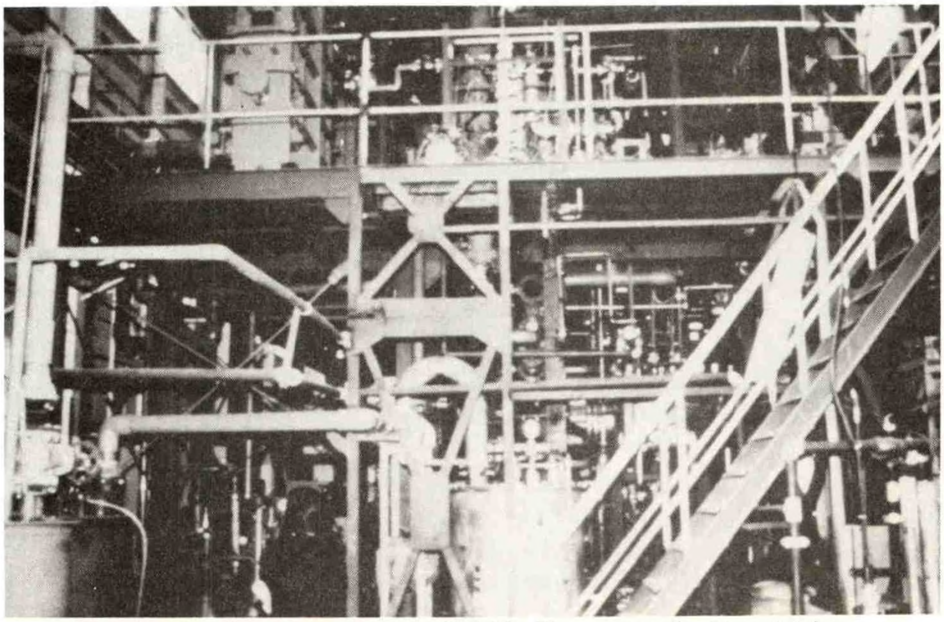
Saga University was founded by the Japanese Government in 1949, and enrollment is now more than 4500. Saga University's OTEC Facility in Imari, Kyushu is involved in research activities concerned with the advancement of heat exchangers for Ocean Thermal Energy Conversion (OTEC) systems. Assistance for much of their research is funded through the Japanese Ministry of Education Science and Culture.

In 1979, Saga University served as team leader in the test of Japan's Mini OTEC system developed by a consortium of Japanese companies. This was the first test for OTEC in Japan.

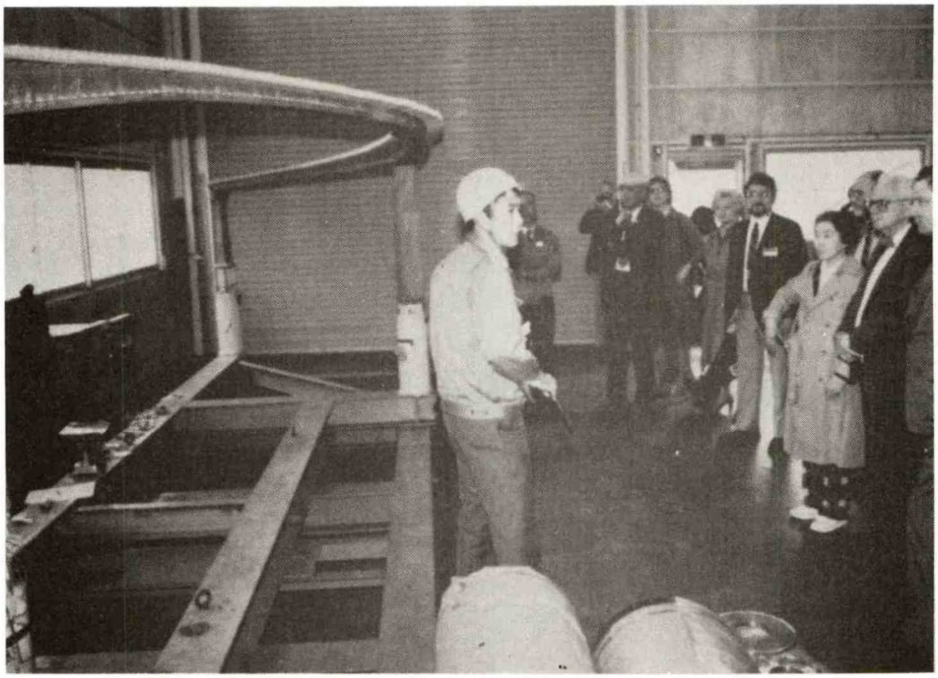
Research activities at Saga University include enhancing the performance of evaporators and condensers which are major cost items for an OTEC plant. Several new designs of titanium shell- and plate-type heat exchangers have been developed for evaporators and condensers. Performance tests with fresh water have shown that very high heat transfer coefficients have been achieved.

A 50kw experimental plant located at Shin-Tokunoshima (an island near Kagoshima, Kyushu) developed for the Kyushu Electric Power Company utilizes shell- and plate-type heat exchangers. The polyethylene pipe is 60 cm in diameter and about 2500 m long on a slope to a depth of 300 m. This plant has been undergoing test since late 1982.

Other OTEC activity in Japan includes a design for a 500KW shelf-mounted plant for the Republic of Nauru. Another design for future development will be for a 3MW plant using titanium plate heat exchangers and a slope-mounted buoyant sandwich-type cold water pipe design that is anchored along the slope.



Heat Exchangers at OTEC Research Facility



Research Facility at Nagasaki Technical Institute

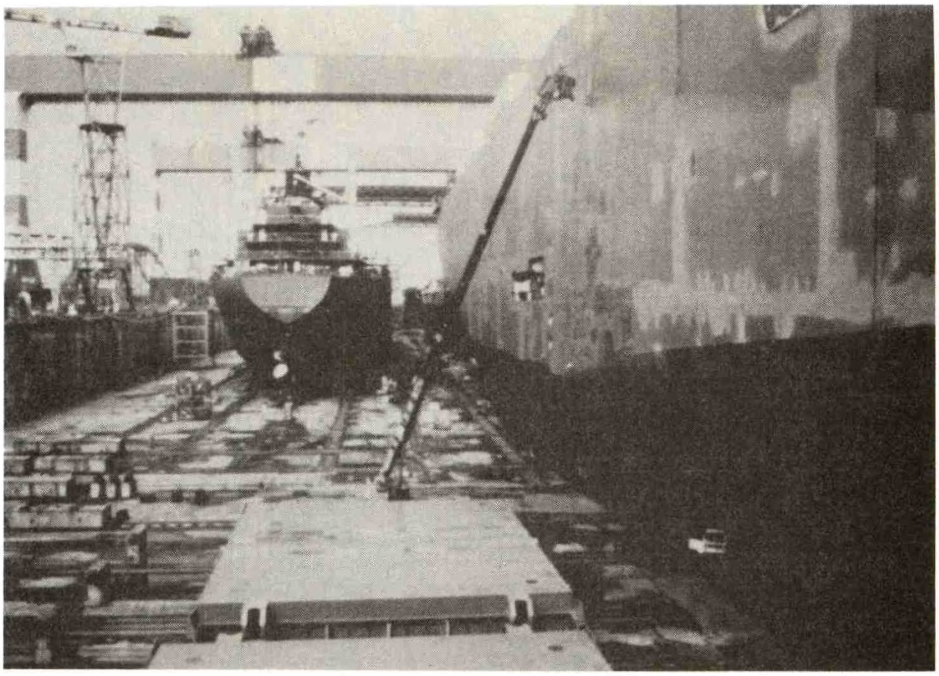
Nagasaki Technical Institute, Mitsubishi Heavy Industries, March 18, 1985

For the past 80 years Nagasaki Technical Institute (NTI) has conducted research related to ships and prime movers in the fields of strength of materials, chemistry, vibration, hydrodynamics, aerodynamics, and tribology. The Fugahori-Koyagi Branch was inaugurated in 1970. It houses the world's largest private enterprise owned experimental tank consisting of towing tanks, a cavitation tunnel, and a seakeeping and maneuvering basin.

Research on materials include evaluating materials needed for marine propellers, cylinder liners, and heat exchangers. Various automatic welding processes for ship hulls and piping have been developed and are in use.

Research has been conducted on blade vibration, rotor dynamics, noise control, and lubrication.

NTI has developed techniques for improving diesel engine performance with low NO_x exhaust emission. Research is under way on minimizing air pollution in stack gases.



Large Dry Dock

Nagasaki Shipyard and Engine Works, Mitsubishi Heavy Industries, March 18, 1985

With the advent of "steel ships" in the Western World, the feudal government of the Tokugawa Shogunate decided to construct a foundry in Nagasaki in 1855 and establish a Naval Training Institute. In 1857 a group of Dutch engineers arrived with the necessary materials and machine tools. The YUGAO MARU was launched in 1887. Ships constructed at the Koyagi site include the very large bulk carrier SHINO MARU, the LNG carrier BANSHU MARU, escortship SAWAKAZE, oil transport JAPAN STORK, and the bulk carrier RIVER BOYNE.

Among the main products produced by the Machinery Division are a 200 megawatt power plant for Iraq; a geothermal power plant at Hatchobaru, Japan; and large marine steam turbines.

The Koyagi Plant features two 600-ton lifting capacity Goliath cranes, a kilometer-long building dock, extensively automated shops and production equipment, and a million ton dry dock.

The POLAR PIONEER

Ariake Works, Hitachi Zosen Corporation, March 18, 1985

The Ariake Works, Hitachi Zosen's largest and most modern plant, was completed in October 1974 and now has about 2,500 employees. It occupies an area of 1.5 million square meters. It has two docks, each served by its own 700-ton gantry crane, supplemented by revolving cranes. One hundred thousand evergreen trees and flowering shrubs have been planted at the site and greatly improve the appearance of the shipyard environment.

Ships constructed at Ariake include the 17,743 dead-weight-ton car carrier GLORIOUS ACE, the 260,000 dead-weight-ton ore carrier HITACHI VENTURE, the refrigerator cargo ship FUJI REEFER, and the 509,000 dead-weight-ton tanker ESSO ATLANTIC.

Other large marine structure constructed at Ariake include a floating desalination plant, jack-up oil-drilling rigs, and a semi-submersible oil-drilling rig.

Land-use equipment constructed on site include very large circulation pipes for nuclear reactors, heat exchangers, crude-oil distillation columns, and high-pressure chemical reaction vessels.

The offshore structures POLAR PIONEER and HERMOSA were constructed at this site.

Hatchobaru Geothermal Power Station, March 19, 1985

Development and studies of geothermal power production around Hatchobaru began in 1949. On June 24, 1977 its commercial production had commenced with an operating capacity of 55,000 KW; it is the largest among the Japanese geothermal power stations (in 1983 Japan produced 160,000 KW of electricity via geothermal steam).

The principle used here is that natural steam is extracted from hotwater reservoir underground, 759-1971 meters deep; the steam then drives generator turbines directly. Separated water is returned underground through reinjection wells, 550-1250 meters deep.

Hatchobaru Power Station uses a double flashing system. Hot water that has been separated from the steam is sent into a flash system where secondary steam is produced for additional 20% power production.

In Japan, the total geothermal power production can be as much as 145 million KW. Economically 20 million KW can be generated by the presently available technology. By the year 2000 Japan hopes to produce 4.8 million KW geogthermally.

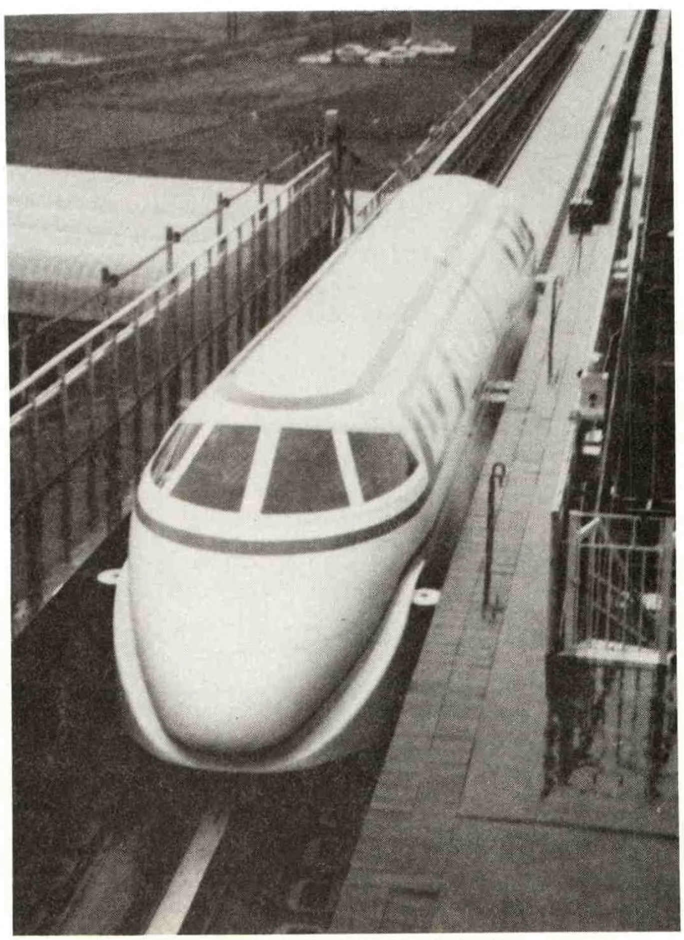
Explanation of Geothermal Plant Operation

MAGLEV Experiment Center, Hyuga, Kyushu, March 20, 1985

The Japanese National Railways (JNR) are now developing a superconducting Magnetically Levitated (MAGLEV) electric motor propelled railway system. Experiments began in 1977 on a full-scale track at Miyazaki Prefecture, Kyushu. In December 1979, the test vehicle reached its target speed of 500 km/hour. Further research is now underway on a new vehicle designed for a U-shaped guideway. The advantages claimed for MAGLEV include greater safety, faster travel, less noise and vibration, better riding quality, and less maintenance.

From an observation deck above the monorail we witnessed a trial run of the newly designed vehicle. After a short run the vehicle "took off" and "flew" several kilometers down the track and returned. At the observation deck we were able to monitor the speed, location, and "altitude" (clearance above the track).

The principle of operation is that when the magnet aboard the vehicle passes over a coil laid on the ground, an electric current is induced in the coil and it becomes an electromagnet whose polarity is the same as that of the magnet aboard the vehicle. The repulsion force between the two magnets levitates the vehicle.



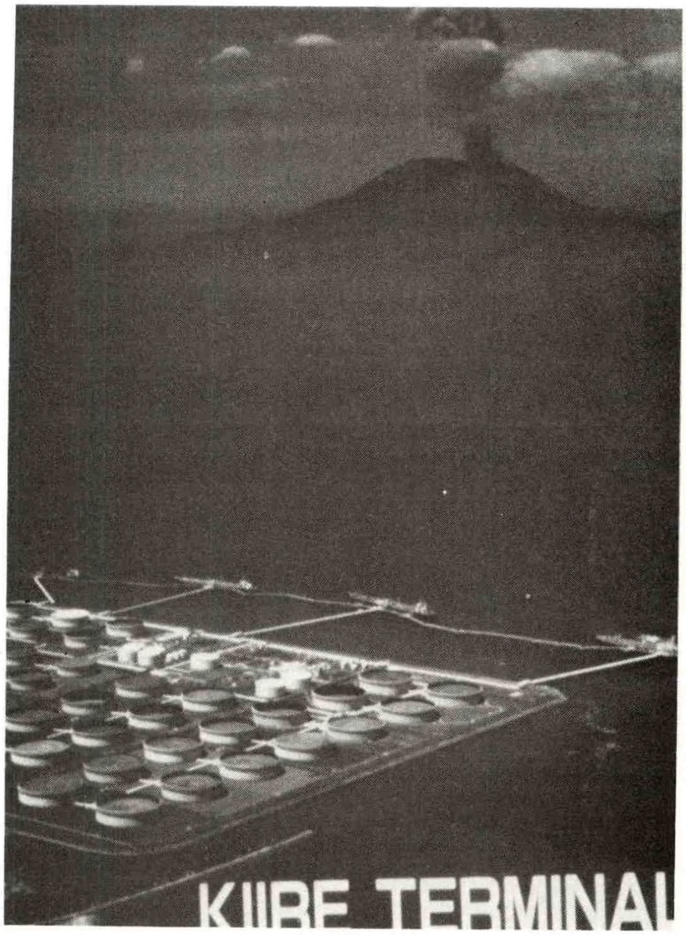
MAGLEV Test Vehicle

Kiire Terminal, March 22, 1985

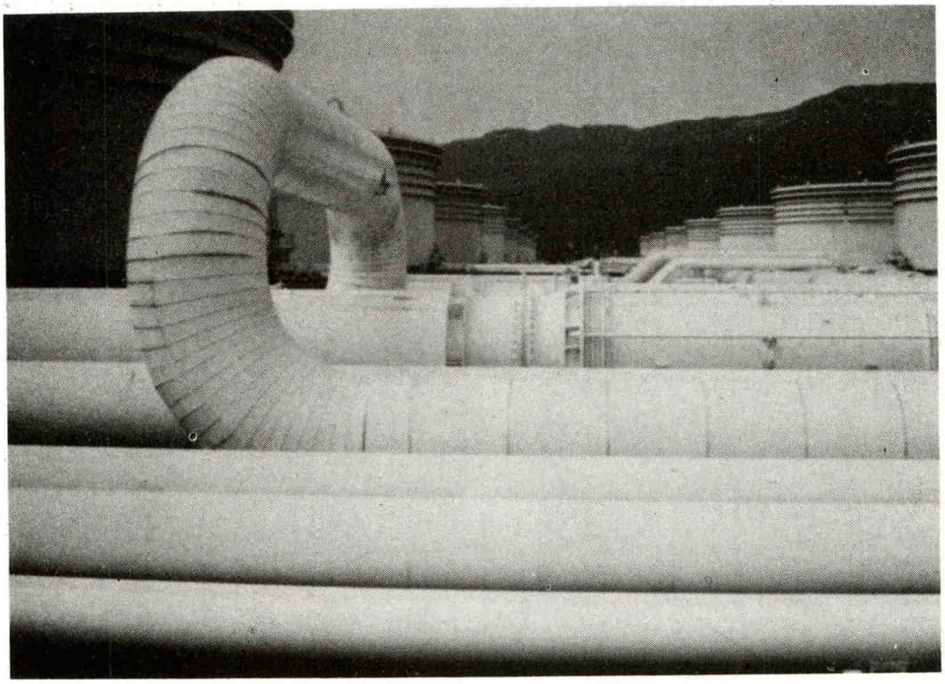
Japan must rely on imported crude oil to meet her energy requirements. It is, therefore, imperative to reduce the costs of the oil through the use of large carriers to Japan, large storage facilities on land, and efficient transport to refineries. All such operations need be carried out under high standards of safety and environmental protection in a region that has experienced typhoons and earthquakes.

The sea berth of the Kiire Terminal (established in 1967) is designed to handle 500,000 dead-weight-ton tankers. When berthed, the tanker is connected to the 7.5 miles of 60-inch diameter on-shore pipe lines through the remote-controlled loading arm to any of the thirty 629,000 barrel or twenty-four 944,000 barrel storage tanks. Water ballast is preseparated from the recovered oil and processed through a sand filter, activated carbon bed, and a guard basin before being released to Kinko Bay.

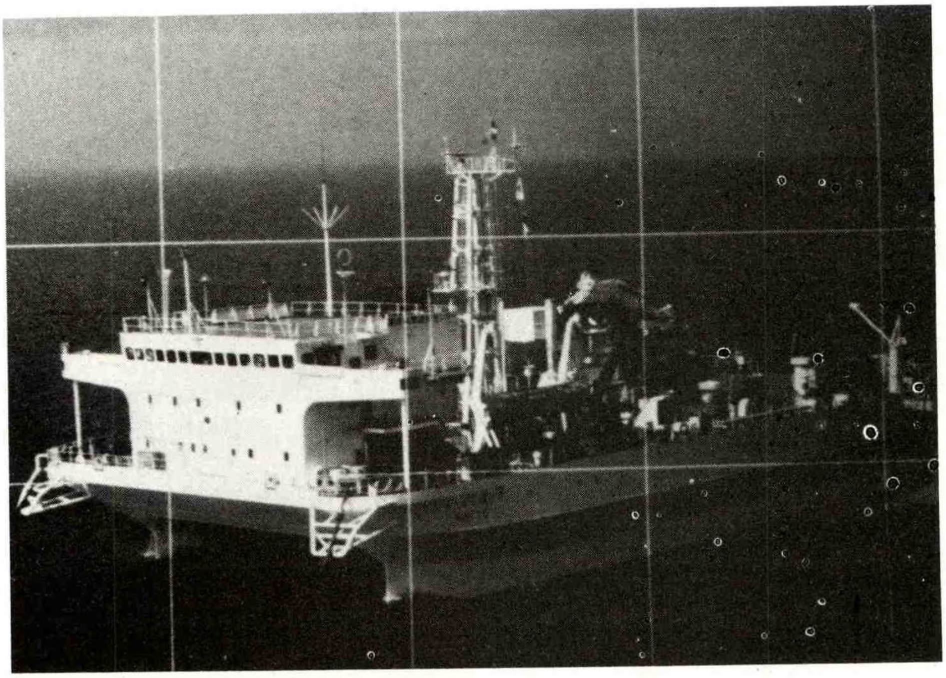
Emergency equipment on hand includes eight fire engines, 271 fire hydrants, and five tug boats that also serve as fire boats. An oil fence is laid around the tankers and oil-recovery ships are always on stand-by alert.



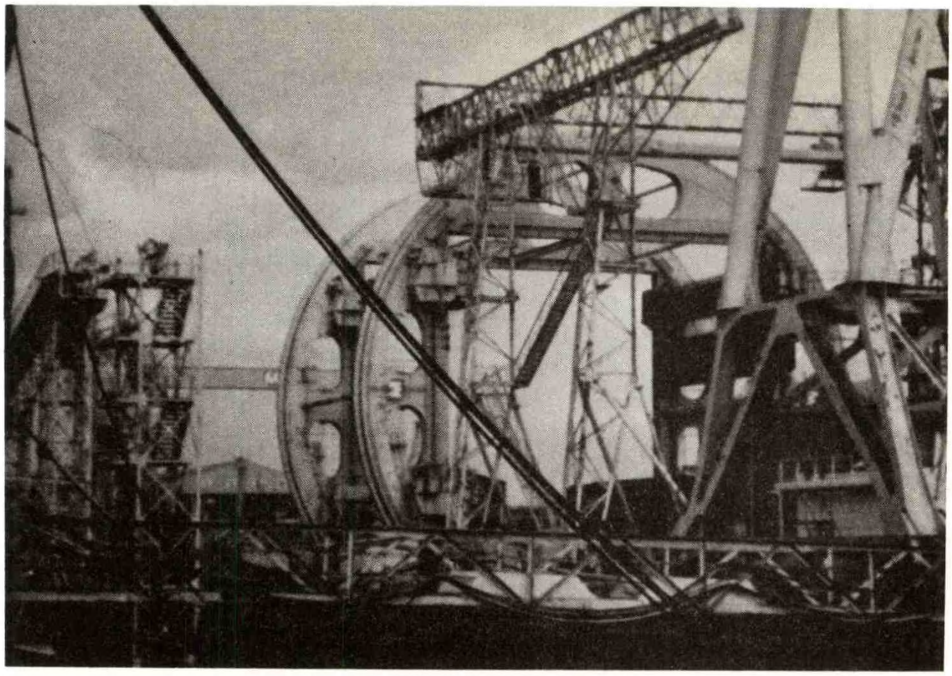
Kiire Terminal



Kiire Terminal Storage Tanks & Piping System



Mitsui's KAIYO-Semi Submersible Catamaran



ROTAS at Chiba Works

Mitsui Engineering and Shipbuilding, Chiba, Honshu, March 25, 1985

The Chiba Works began operations in May 1962 as the first modern shipyard in Japan. Ships constructed at this site includes the first very large crude carrier (VLCC) 215,000 dead-weight-ton tanker for the United Kingdom, the super-automated tanker MITSUMINESAN MARU, Mitsui's largest vessel the BERGE EMPEROR 417,000 dead-weight-ton tanker, the semi-submersible offshore oil drilling rig JOHN SHAW, the LNG carrier SENSHU MARU, and the 600 ton semi-submerged catamaran passenger craft MESA 80.

A semi-submerged catamaran (SSC) support vessel (about 2,800 tons) called KAIYO (OCEAN) is undergoing final tests for JAMSETC (Japan Marine Science and Technology Center). It is a diver support craft equipped with a submersible decompression chamber. It is capable of launching and controlling remotely operated vehicles. It will be Japan's first exclusive vessel that can function as an offshore testing base stable enough to maintain its position offshore for a long period of time.

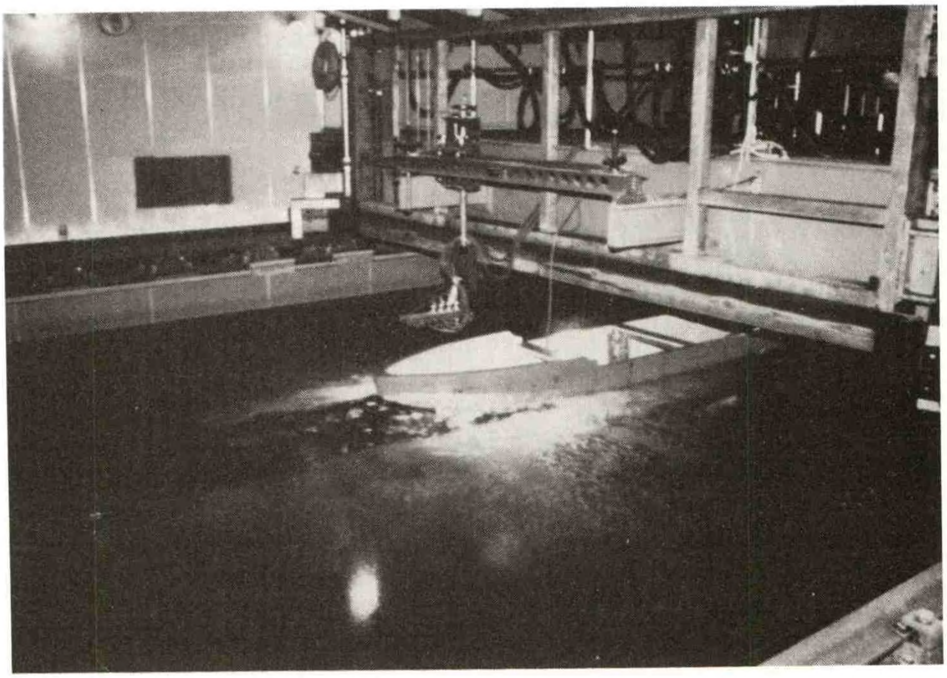
The Chiba Works has developed two highly innovated ship construction methods, ROTAS (Rotating and Sliding) permits huge ship module to be rotated and slid for simpler and safer construction. MAPS (Mitsui Automated Pipe Shop System) automates the complicated task of pipe fabrication by means of computer control.

Ship Research Institute, Mitaka, Tokyo, March 26, 1985

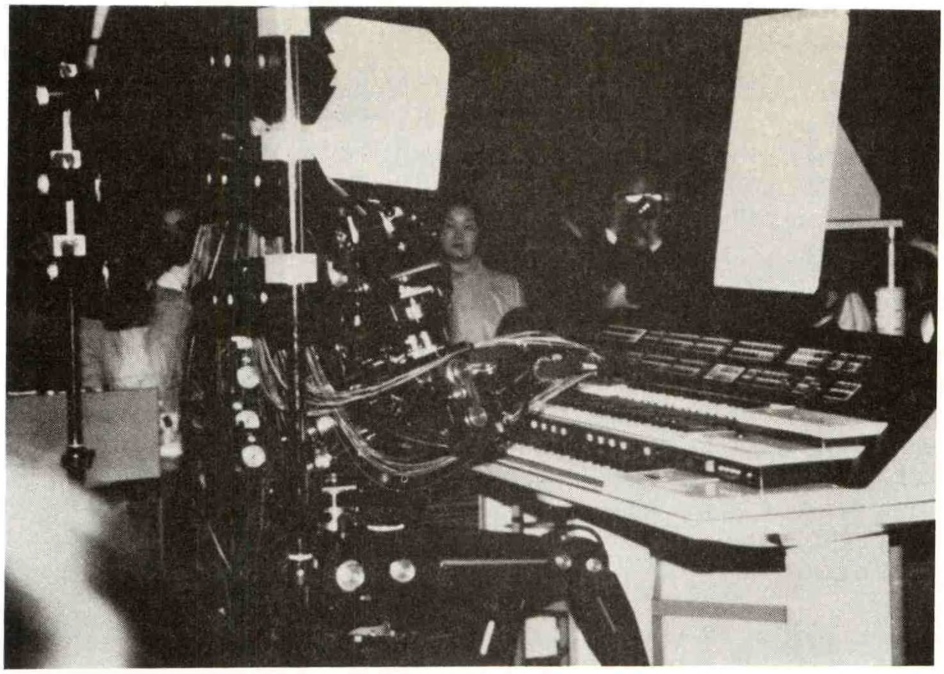
Ship Research Institute was founded in 1963 as a research organization of the Ministry of Transport, and its research work covers the whole fields of shipbuilding technology including ocean engineering and marine environmental preservation. The present staff numbers 277, including 204 research members.

The Offshore Structure Experimental Basin, 40 m in length and 33 m in width, has a sloping bottom with water depth from 0 to 2 m. The Ocean Engineering Division is engaged in both theoretical and experimental studies of dynamics, seaworthiness, mooring techniques, anchoring equipment of special ships, floating marine structures, self-elevating platforms, and other facilities employed in ocean exploration.

The Ice Model Basin is contained in a prefabricated building 54 m by 25 m. The basin itself is 6 m wide, 1.8 m deep, and 35 m long. At the northern end is a trim tank 1.6 m wide, 0.9 m deep, and 8 m long that is connected through a lock gate to the test basin. An access tunnel (observation corridor) is provided to allow underwater viewing of ice phenomena during model tests. The ice breaking and the motions of the ice pieces around the ship model can be observed and photographed.



Ship Research Institute's Ice Model Basin



Robotic Piano Player at EXPO 85

Tsukuba EXPO 85, March 27 and 28, 1985

The EXPO 85 site is located in Tsukuba Science City about 60 km northwest of Tokyo. The city is the result of a government program to create a national center for scientific and technological research and education in many fields. Tsukuba University and 47 national research institutes are located here. Tsukuba Science City was first conceived in 1963 as a way of meeting Japan's technological needs of the future through coordinated high-level research and educational facilities.

One objective of EXPO 85 is the consideration of ways to integrate major scientific and technological advances to improve the quality of life throughout the world with emphasis on living in the 21st century. EXPO 85 featured 28 pavillions sponsored by major Japanese corporations and 35 international pavillions including the U.S.

Special arrangements were made for members of the Marine Facilities Panel to visit selected pavillions which included exhibits and demonstrations of future integrated telecommunications and computer systems, applications of robotics, high speed transportation and other applications of high technology.

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CONSTRUCTION OF MOLIKPAQ

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PREFACE

Mobile Arctic Caisson named "MOLIKPAQ" - an Inuit language meaning great wave -, the first of its kind in the world was delivered to BeauDril Limited Partnership, a subsidiary of Gulf Canada Resources Inc. at IHI Aichi Works on April 16, 1984. After preparation for towing, MOLIKPAQ left IHI Aichi Works, Nagoya on June 11, 1984 and arrived at Canadian Beaufort Sea after 45 days voyage.

MOLIKPAQ consists of a continuous steel annulus, deck structure and drilling modules and has the capability of year round operation in the iced Arctic Ocean in water depth from 15 to 40 m. The sand filled in the core of annulus and the ballast water are designed to resist the horizontal ice loading. IHI undertook the engineering for fabrication in cooperation with Designer, SWAN WOOSTER ENGINEERING CO., LTD., and developed detail drawings and performed construction.

TYPICAL CHARACTERISTICS

As compared with conventional type of artificial gravel island, MOLIKPAQ has the following advantages.

- Easy Relocation

  After completion of the drilling of an exploratory well, the center core sand is removed partially by dredging, and then the caisson is floated to a new location.

- No installation works of drilling equipment at site

  All the drilling equipments were already installed and prepared for drilling on the deck at fabrication yard.

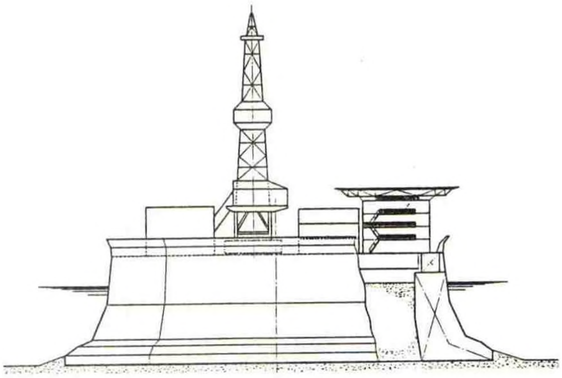
- Decrease of the dredge volume of sand and/or gravel

  The merit will glow up in proportion as the water depth increases.

Type: Bottom-founded steel structural caisson

Dimension:	Upper section	86.6 m x 86.6 m
	Lower section	111 m x 111 m
	Core	73 m x 73 m
	Height to deck	29 m
	Height to top deflector	33.7 m

Design water depth: 21 m



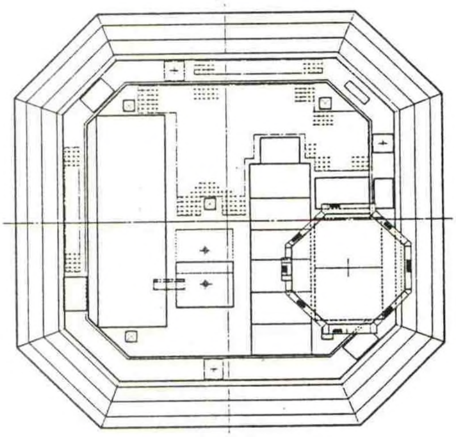


Fig. 1 General arrangement

Operating range	:	15 m - 40 m (set in dredged hole or on deposited sand berm)	
Displaced weight	:	Lightship	32,000 ton
		Fully laden	46,100 ton
Draft	:	Lightship	5.35 m
		Fully laden	8.90 m
Core quantity	:	106,250 m^3	

Water ballast quantity: 80,140 m^3

Classification: ABS + A1 Caisson Drilling Unit

CASISSON STRUCTURE

Structural parts of MOLIKPAQ consist of doughnut shaped caisson structure and box shaped deck structure. Both caisson and deck are completely made of steel. Refer to Table 1 and Fig. 2.

The steel materials used in exposed surface of the caisson structure are required to possess high toughness under ambient temperatures descending down to -50°C. The steel material EH36-060 for this purpose was developed by Japanese steelmakers with "Thermo-Mechanical Control Process".

On the other hand, the application of large heat input welding processes such as one-side submerged arc welding, currently practiced in shipyards, would utilize efficiently the existing shipyard facilities and practices in the construction of these offshore structures, and this should contribute significantly to shortening construction time and reducing work volume in construction.

Prior to the start of construction, investigation of welding properties of EH36-060 steel and its application were carried out at our welding laboratory and Aichi Works. Up to the present, the heat input is held at lower level in case of welding the low temperature service steels, for example, 35 - 40 KJ/cm for LPG and LNG storage tanks. However, the welding procedure in large heat inputs was successfully established; 124.9 KJ/cm to one-side submerged arc welding process with flux-copper backing, 78.7 KJ/cm to flux-asbestos backing process and 110.9 KJ/cm to tandem submerged arc welding.

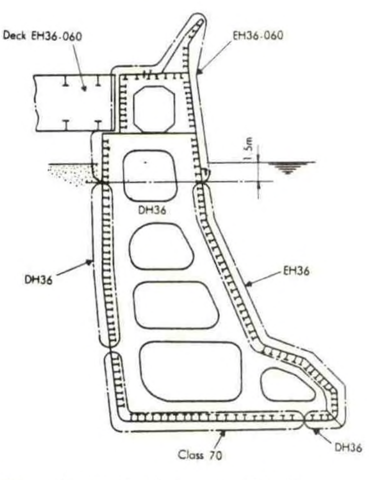


Fig. 2 Material constitution

MECHANICAL AND ELECTRICAL SYSTEMS

The following mechanical and electrical systems for caisson operation are provided:

(1) Ballast system consists of the sea chests and pumps located at the lowest level. The pump capacity selections were made on the time basis of removing the water from the point of neutral buoyancy to empty. The system also supplies service water for the drilling equipment and make-up water for the fire water tank.

(2) Core dewatering system dewaters from core sand through filters on the inner periphery of the caisson.

(3) Heating system is used for heating the machinery space, fuel oil storage tank and ballast water tank. Heated air circulation system and closed glycol/water system is selected according to the requirement of the space and location to be heated.

(4) Drainage system picks up the drainage from the deck area, from all manned areas, and the bilge from the pump rooms and other machinery rooms. The oil contaminated water are processed through the oil-water separator. Sewage from the accommodation module is processed through the sewage treatment plant.

(5) Fire protection system consists of the salt water fire fighting system and halon gas extinguishing system. The fire detection and alarm system are also provided.

(6) Fuel oil system transfers the fuel oil from structural tank to day tank.

(7) Dredge piping system in the deck structure is used to discharge sand evenly into the core of the caisson.

(8) Electrical power of caisson is supplied from the top-side generator.

Table 1 Specification of materials

Item / Steel	Base metal									Welded joint					
	Yield stress (σ_y)		Reduction of area	Charpy absorbed energy						Charpy absorbed energy					
				Temp.	L-direct.		C-direct.			Temp.	Location	Manual arc welding		Automatic arc welding	
	(kgf/mm²)	{MPa}	(%)	(°C)	(kgf·m)	{J}	(kgf·m)	{J}		(°C)		(kgf·m)	{J}	(kgf·m)	{J}
EH36-060	≧36	≧353	≧20	−60	≧3.5	≧34	≧2.4	≧24		−60	t/4	≧3.5	≧34	≧2.4	≧24
EH36	≧36	≧353	≧20	−40	≧3.5	≧34	≧2.4	≧24		−20	t/4	≧5.5	≧54	≧4.1	≧40
DH36	≧36	≧353	≧20	−20	≧3.5	≧34	≧2.4	≧24		0	t/4	≧5.5	≧54	≧4.1	≧40
Class 70	≧70	≧686	≧18	−30	≧3.5	≧34	≧2.4	≧24		−30	t/4	≧3.5	≧34	≧2.4	≧24

DRILLING RIG EQUIPMENT

The rig possesses the capability to drill wells up to 6,000 meters efficiently and safely year round in the Beaufort Sea. The drilling rig equipment are assembled on the skid in Canada and brought to Japan for installation in the following fourteen (14) modules.

(1) Piperack enclosure is a structural cover for the pipe storage area.

(2) Subbase structure consists of plate girders spanning the platform skid rails crosslinked for rigidity.

(3) Substructure is located on the subbase girders and supports the derrick and encloses the drilling equipment.

(4) Three bulk modules contain bulk cement and mud storage tanks, and handling equipment for bulk material.

(5) Two mud modules contain mud tanks and processing equipment.

(6) Two utility and power modules contain rig and caisson related power generator and distribution equipment.

(7) Accommodation utility module contains power and utility equipment packages related to the accommodation.

(8) Two accommodation modules contain living quarter and related facilities for 100 persons.

(9) Helideck module is designed for Sikorsky S61N.

FABRICATION AND ASSEMBLY

IHI Aichi Works is one of the largest in the world in the terms of site area, shops and handling equipment. There are also 1,000,000 ton dry dock of 810 meter length by 92 meter width. However, as the base dimension of MOLIKPAQ exceeds the width of the dock, a new sophisticated method using submersible pontoon was applied for the most reliable and accurate fabrication.

That is to fabricate the blocks as heavy and large as possible within the limit of lifting capacity of two 400-ton goliath cranes and erect these blocks completely on the submersible pontoon, the caisson is launched and unloaded from the pontoon.

The details of fabrication, assembly and erection are as follows:

(1) Material:

All the steel materials are manufactured at Japanese steel mills and delivered to IHI Aichi Works. The sizes and weights of these steel materials are as follows:

Plates:	maximum length	22.0 m
	maximum width	4.5 m
	maximum weight	20.0 tons
Shapes:	length	25.0 m

(2) Fabrication and block assembly of steel structure:

Steel plates and shapes of framing members are cut by flame cutting equipment and preassembled in shop.

Plates for skin or deck are cut and its edges are prepared by flame planer and jointed to wider plate by welding. Then the framing members and the skin or deck plates are assembled to block, having maximum weight of about 200 MT.

After structure inspection, the completed blocks are painted in the sheltered and air-conditioned paint shop.

(3) Pre-fabrication of piping:

Pipes and fittings for ballasting system, etc. are pre-fabricated in shop according to the spool drawings.

(4) Pre-outfittings

Pipes, valves, cable ways and equipment are incorporated into the blocks in shop before pre-erection at erection yard.

(5) Pre-erection at erection yard:

The blocks are picked up by 400 ton goliath crane and pre-erected to larger blocks having weight of about 700 ton at erection yard.

(6) Erection in dock:

The large blocks are transported individually by two goliath cranes in synchronized operation, and erected on the submergible pontoon placed in the dock. Fig. 3 shows erection sequence.

(7) Final painting:

After completion of erection, touch-up painting on the damaged parts and final painting are carried out on the welded parts at erection stage.

(8) Launching:

The pontoon is floated in the dock and pulled out from the dock by tug boat. Then the pontoon is submerged by filling the ballast tanks with water.

When the caisson floats by its own buoyancy, the pontoon is pulled out from under the caisson and then the caisson is moored to the quay.

(9) Loading of deck structure and drilling modules

The deck structures fabricated in two pieces are installed on the caisson by a floating crane. The drilling modules are installed on the deck by the floating crane.

(10) Test and commissioning

While caisson is moored to quay, all required tests and commissioning are performed and all functions have been verified prior to the delivery.

TOWING

MOLIKPAQ left IHI Aichi Works on June 11, 1984 and started her towage to the Canadian Beaufort Sea. The towing of huge structure such as MOLIKPAQ from Japan to the Arctic Ocean is the world's first event and is a big milestone in new technical range of towing. Towing specification is as follows:

Draft	:	8.9 m
Corresponding displacement	:	46,100 tons
Towing distance (from Nagoya to Cape Lisburne)	:	3,180 N. Miles
Tug Boat	:	16,000 IHP x 3 sets
Average towing speed	:	3.5 kt

Fig. 4 shows towing route and date.

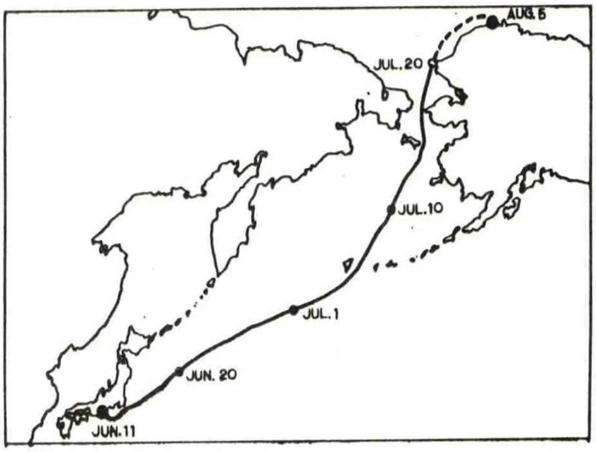


Fig. 4 Towing route and date

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2. M. Fukagawa, Y. Ogawa, S. Mazaki, T. Kohno, Y. Kumakura, H. Nakamuta, T. Murayama, S. Ohga, T. Hirose, S. Kaihara "Large Heat Input Welding Process Applied to Artificial Island in the Arctic Ocean" (Welding Construction of Mobile Arctic Caisson Rig), IHI Engineering Review Vol. 17, No. 4 Oct. 1984

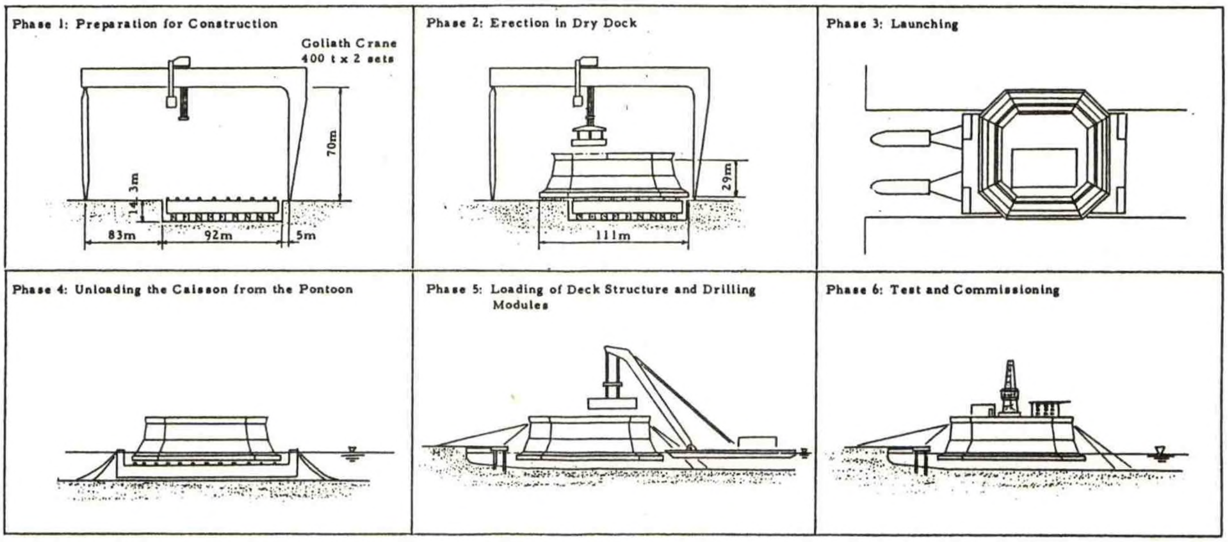

Fig. 3 Construction sequence

CONSTRUCTION OF ARCTIC STRUCTURE "SUPER CIDS"

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ABSTRACT

A unique mobile Arctic drilling structure called "Super CIDS" was delivered by NKK Tsu Works in May 1984. The Super CIDS, completed in only 9 months after the construction contract, is a steel/concrete composite type unit, weighing 56,000 tons. This paper describes the outline of the structure and the applied construction method.

INTRODUCTION

Exploratory drilling in Alaskan Beaufort sea has been conventionally carried out mainly from natural islands and man-made gravel islands. Where natural islands were not available, a gravel island was appropriate and economical for drilling at one specified location with a shallow water depth. However, as the water depth increases, the gravel island becomes proportionately uneconomical.
A solution to this problem of coping with increased water depths was to develop mobile drilling structures which would enable more economical and suitable long-range exploration programs.
Faced with this challenge, Global Marine Development Inc., USA (GMDI) successfully developed a unique design of modularized steel/concrete composite type mobile Arctic drilling structure.
This new design was named Super Concrete Island Drilling System (Super CIDS). GMDI entrusted Nippon Kokan K.K. (NKK) with the difficult task of completing the detailed design and construction work within a very short time: the CIDS had to be built within 9 months after the construction contract was signed. This paper describes the outline of the construction method of Super CIDS in NKK.

PARTICULARS

1. Contract : September 1983
   Delivery : May 1984
   Buyer : Global Marine Development Inc. (USA)
   Builder : Nippon Kokan K.K. (Japan)
   Fabrication Yard : NKK Tsu Works
   Subcontractor for Concrete Part:
   Joint Venture of Shimizu Construction Co. and Penta Ocean Construction Co.

2. Principal Dimensions

Steel Mud Base (SMB)

Length	312'-6"
Breadth	295'-0"
Depth	25'-0"
Light Weight	abt. 13,000 tons
Material	ASTM A-537 class II Modified

Concrete Brick (BB-44)

Length	234'-0"
Breadth	234'-0"
Depth	44'-0"
Light Weight	abt. 35,000 tons
Material	Pre-stressed high strength light weight concrete

Deck Storage Barge (DSB) .... 2 barges

Length	290'-6"
Breadth	136'-0"
Depth	26'-0"
Light Weight	abt. 8,000 tons (for two barges)
Material	ABS EH36-060

3. Class and Flag
   Class ABS *A1 MODU
   Flag USA (USCG MODU)

4. Environmental Criteria

Water depth		35'～55'
Air Temperature		-60 °F ～ +70 °F
Wind Speed		70 knots
Wave Height		17' (significant)
Ice Thickness		
	winter	6.5' first-year ice sheet
	summer	25' multi-year floe

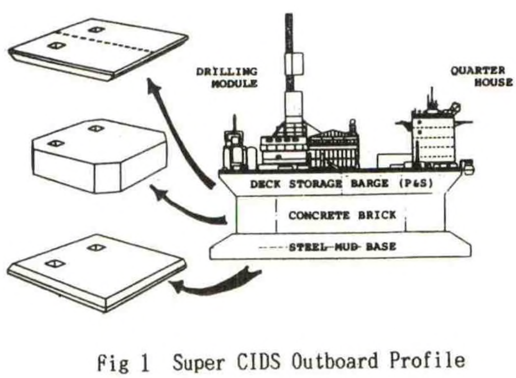

Fig 1 Super CIDS Outboard Profile

CONSTRUCTION

The project allowed only a very short construction time and the concept of the unit permitted the modularized construction method.

Components of the Super CIDS, SMB, BB-44 and DSB, and the Drilling module (separately ordered by Parker Drilling Company, USA) were constructed at all three shipyards of NKK. The final assembly of the unit was completed by the stacking at sea near Tsu works. (Fig 2)

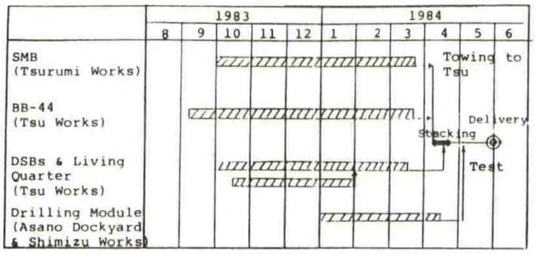

Fig 2 Construction Schedule

1. Steel Mud Base (SMB)
SMB is located at the lowest part of the structure and contains tanks and a pump room inside, 5ft-high anti-sliding/anti-scouring skirt at the bottom and 2ft-high shear curb on the top for transferring of ice force from BB-44 to SMB.
This square steel box was constructed on skids placed at the Central Building Birth of Tsurumi Works equipped with a 130 tons and a 50 tons jib cranes. As those cranes did not have sufficient reach to cover all of this 312 ft x 290 ft SMB, one crawler crane of 4000T-M was hired.
Considering the crane capacity availability, the number of prefabricated blocks of SMB were decided to be 124 pieces. The erection of these prefabricated blocks at the Building Birth proceeded at the rate of three blocks/day.
After the construction on the ground, SMB was skided on to the submersible barge of 147.4 m long, 40 m wide and 8.5 m deep. SMB was launched from the submersible barge at 20 m water depth and towed about 200 miles to Tsu Works.

2. Deck Storage Barge (DSB)
DSBs (Port and Starboard), the top structure, contain tanks, utility trunk for piping, cabling and passage, pump rooms, emergency quarters, etc.
Because of the short construction period, the two barges were constructed in the No.2 dock of Tsu Works at the same time. The 5-layer quarters building was fabricated into one piece and set on the starboard barge before the barge was launched.

3. Steel Material
Steel material for SMB and DSBs are shown in table 1. EH36-060 applied to DSB had already been proven as good material by previous application to ice-breaker built in Tsurumi Works and offshore structure built in Tsu Works.
The material has good weldability and much data had been developed for the welding procedure.
ASTM A537 Class II, the material for SMB, was modified for this project. The original ASTM specification required heat treatment of quenching and tempering. This tempering required the furnace which did not allow short delivery of 13,000 tons of steel. Also the carbon content of the original ASTM spec was so high that it did not allow high heat input welding.

The discussion between shipbuilding division engineer and steel division staff of NKK concluded to apply OLAC (One Line Accelleration cooling) process steel production system.

	SMB	DSNB
Material	ASTM A537- II Mod.	ABS EH36-060
Thickness	14.2 ~50.8 MM	6.0~31.7 MM
Tensile strength	51.6 ~70.4 kgf/m m²	50.0 ~63.0 kgf/m m²
Yield strength	min 42.3 kgf/m m²	min 36.0 kgf/m m²
Charpy test	Ave. 3.5 kg-m at. -30 ℃	Ave. 3.5 kg-m at. -60 ℃

Table 1 Steel Material

4. Basic Brick (BB-44)
BB-44 is located between SMB and DSB and is designed to resist the ice force. This octagonal box is covered by the top and bottom decks and the external wall. This structure has a double hull construction consisting of external wall, internal wall, and shear walls. The Center part forms honeycomb structure made up of silos and connection wall. (Fig 3)
Material of the structure is prestressed high strength light weight concrete as shown in table 2.
<Re-bar Arrangement> The BB-44 is the concrete structure with very high rebar content, ie. about 430 kg of rebar per cubic meter of concrete on arverage and 700 kg at maximum which is 4 to 7 times as dense as ordinary concrete structure.
Therefore, placing up work of the concrete was carried out very carefully and, for this purpose, spaces for tremie pipes and internal vibrators were maintained by providing spacer pipe when the rebar arrangement was made. (Fig 4)
<Concrete> The main feature of this concrete is its high strength and light weight with high durability in freeze and thaw actions.
To determine the concrete design mix, 28 different mixes were tested based on the parameter of W/C ratio, S/A ratio, kind of light weight coarse aggregate and kind of pozzolan; then, corresponding unit weight, air content, compressive strength and durability caracteristics were observed.
The concrete mix was finally determined after the workability tests of mock-up models.
As the conclusion, (1) moisture content of the light weight coarse aggregate should be low (2) When silicafume was applied as a pozzolan, the strength of concrete was increased and workability in fresh concrete was improved compared with the application of flyash.
Based on the experiments, the following particular measures were performed.
(1) To keep the moisture content low the light weight aggregate was transported by special barge and kept in silos with daily moisture content monitoring.

(2) To kepp concrete workable, high efficient water reducing agent together with super plasticizer was used.
(3) In summer, to reduce the temperature of fresh concrete, crushed ice was added.
(4) To cntrol curing method and period of concrete, thermostats were put in the concrete.
(5) Light weight concrete was poured by bucket to avoid water penetration into light weight aggregate due to the pressure by pumping.
(6) In winter, to keep the concrete temperature up, insulation sheets and jet heaters were applied.
<Silos> A silo element of 3 m dia and 12.5 m high were devided into 5 sections each of abt. 2.5 m high and precast in a subcontractor's factory. The shape of each piece was similar but different in its openings or fittings for pipes, ladders, etc, and they amounted to 30 kinds of patterns and 1,000 in total number. (Fig 5).
<Prestressing> Prestressing work was performed in the following procedure.
(1) After completion of the bottom deck, 25% of the total number of bottom deck prestress tendons were tensined.
(2) After completion of external wall, remaining 75% of bottom deck tendons and horizontal and vertical tendons for external wall were tensioned.
(3) After completion of the top deck, horizontal tendons for top deck and vertical tendons for internal wall and shear wall were tensioned.
<Floating> 6 months after the construction was started, the BB-44 floated successfully and smoothly with a highly precise draft as designed.

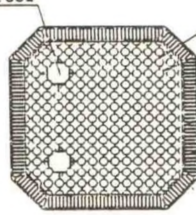

Fig 3 Section view of BB-44

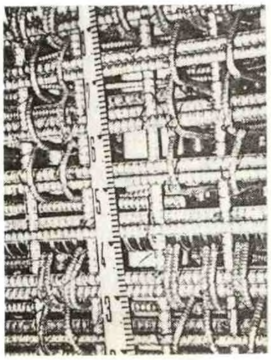

Fig 4 Rebar arrangement

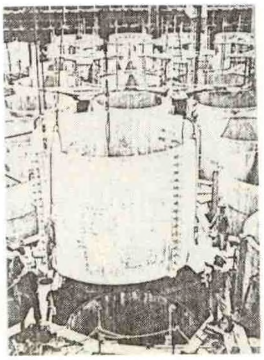

Fig 5 Erection of Silos

	Light Weight Concrete	Normal Weight Concrete
Application	Bottom deck, Top deck, External Wall, Silo, Connection Wall	Internal Wall, Shear Wall
fresh unit weight	115 lb./ft3	155 lb./ft3
Compressive strength	6,500 psi	8,000 psi
Air content	7 ±2%	
Freeze/thaw durability	more than 80% at 300 cycles (ASTM C666 Method A)	
Rebar material	ASTM A615 Grade 60	
Prestressing material	Wire strand JIS G3536 Bar ASTM A772	

Table 2 Concrete Material

5. Stacking

SMB constructed at Tsurumi Works and BB-44 constructed at Tsu Works were stacked at about 2.3 miles offshore of abt. 25 m water depth near the Tsu Works.
The stacking procedure was as follows (Fig. 6)

Step 1. Tow SMB & BB-44 to the site.
Step 2. Hook up the wire of 3,000 tons cranes and ballast the mud base.
Step 3. Lower the SMB into the sea and tow BB-44 just above the SMB.
Step 4. Hoist the crane and let SMB contact BB-44; confirm the position of BB-44 and deballast SMB to the complete afloat condition.

The advantage of this method is:
- By using cranes, SMB could be sunk or floated in the stable motion.
- When SMB rises and touches BB-44, rising speed can be controled by the crane. This enables the diver to check the clearance between SMB and BB-44 safely.
- As the SMB does not touch the sea bottom, the operation area can be chosen without restriction of water depth and the sea bed soil condition.
- Stacking time can be shortened.

Ballast pumps and valves in SMB were remotely operated from the control stand provided on the "contorl center" barge. All remote control lines including cables, air hoses and hydraulic hoses were connected to SMB through the sea. It took about 45 hours for filling up SMB with ballst water. Special care was taken to avoid leaving air in the tanks as a mooving water surface would unstabilize the crane hook load.
Trim and heel was remotely monitored by the inclinometer fitted on the SMB.

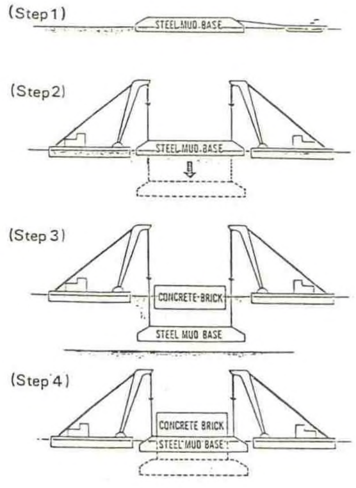

Fig 6 Stacking procedure

Stacking of BB-44 on top of SMB was performed by hoisting SMB by cranes, wherein BB-44 had to be set in the shear curb on SMB with a clearance of only 4 inches. Therefore, fine adjustments by means of winches on the floating crane between BB-44 and steel guide pieces provided on the SMB were observed and guided by divers.
Afrer the stacking of SMB and BB-44 was completed successfully, the combined structure was towed to the shipyard's quay side. Then, using two 3,000 tons floating cranes, the port DSB and the starboard DSB were successively mounted and stacked. (Fig. 7)

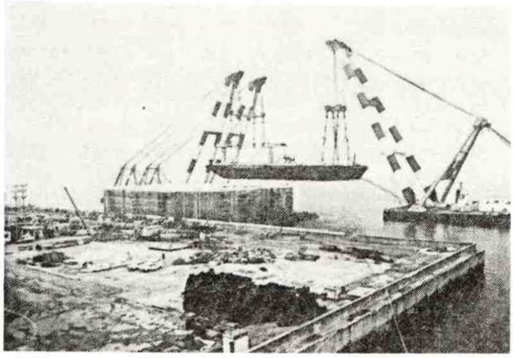

Fig 7 Mounting of a DSB

CONCLUSION

Super CIDS, named "Glomar Beaufort Sea I", was thus successfully completed and towed to Alaska by two 20,000 HP ocean tugs. It arrived at Harrison Bay in Beaufort sea and started drilling in November. Super CIDS has been bravely meeting the first harsh Arctic winter.

Steel material, Concrete material, High rebar content, Stacking work, etc.--- those in combination were new challenging experiences to designers and engineers involved in the project.

We trust that the successful completion of the Super CIDS within the very short delivery time of 9 months would encourage ourselves and others to be ready for more challenges. The Super CIDS was an example of what could be achieved by the concerted efforts of the Owner, the Builder and other various people involved in the design and construction of such huge projects. We trust that the successful delivery within only 9 months was the fruit of the good relationship between the Owner and the Builder.

SOME ASPECTS OF MARINE FOULING ON THE ARTIFICIAL STRUCTURES OFF JAPANESE COAST

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INTRODUCTION

Marine structures which are immersed underwater for long periods are susceptible to a wide variety of marine organisms which attack their surfaces. When tolerance levels, dependent on the quantity and type of organisms, are surpassed, a situation which has been called " Marine Fouling " develops.

Because of the problems that they cause, it has been necessary to take certain measures to combut these organisms. Formerly, the research and development of maintainence techniques has concentrated mainly on dry-land applications suitable for ships in dockyards. However, these techniques are of limited value in those underwater fields in which many types of artificial structures are immersed.

It has therefore become necessary to alter our approach from that of the dockyards to one of direct, underwater-field application. A lack of sufficient technical information and in-water working experience in Japanese fields has, up to the present, inhibited the development of such techniques.

As a first step, it is indispensable then, that present fouling conditions be practically researched. With this aim, the present paper provides some field research and measuring techniques.

This sutdy was performed through the Special Coordination Fund for Promoting S&T of the Science and Technology Agency of the Japanese Government.

METHOD

(1) Field studies of present fouling conditions.

These works were carried out underwater a total of eight times at six structures, all of which were of a gravity-type such as bridge posts. (see photo-1) The locations, and others were shown to the table-1.

name	location	depth	times
(1) Observation Tower	off Hiratsuka	21m	3
(2) Artificial Island No-1	off Ogata	7m	1
(3) Artificial Island No-4	off Ogata	22m	1
(4) Seaberth (for 200000t)	in the Port of Kashima	21m	1
(5) Seaberth (for 100000t)	in the Port of Kashima	16m	1
(6) Experimental exposure facility	off Oigawa	8m	1

table-1. The locations, and other items of the structures

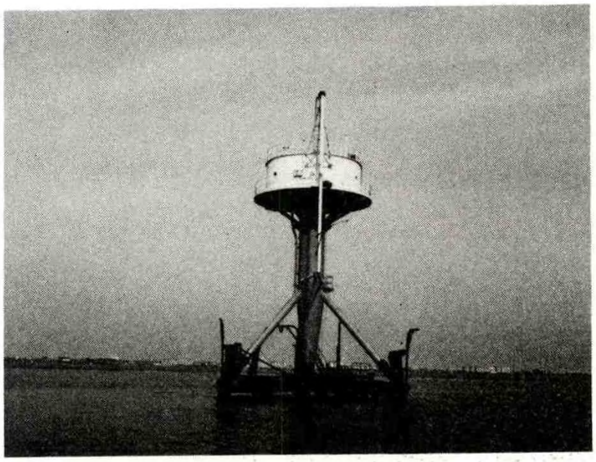

Photo-1. Observation Tower off Hiratsuka.

In each field we sampled, observed, and measured fouling communities, each in one meter of water measured from surface to bottom. These samples were taken from areas of 100cm² (10 x 10 cm quadrate method). After detailed observation, we measured these samples' wet-weight in g, and classified each species at our laboratory.

Thus the biomass, zonation, species composition and settling formation of the fouling animals at each sampling point were investigated.

We have memolized and taken many photographs underwater of the fouling conditions, while at the same time we have measured the thickness of the fouling assemblage at each sampling point by means of a steel measuring bar.

(2) Development of quantitative field research technique adopting the thickness-measuring device.

Our thickness-measuring device was developed as our prototype for another, similar works.

By using this unit we attemped to measure the thickness of the fouling assemblages at the pier of Yokosuka Harbor. The device consisted of an underwater measuring unit and its cables, a receiving-transmitting unit, and a data-processor (see photo-2, and -3)

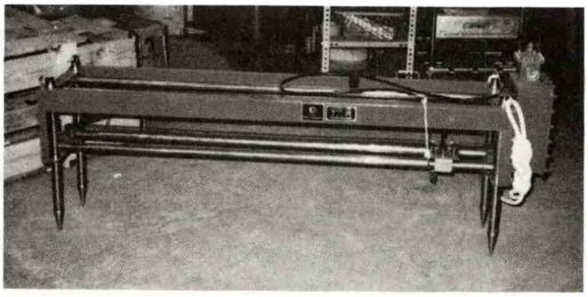

Photo-2. Underwater unit of the thickness-measuring device.

Photo-3. Data-processing unit of the device.

By means of the super-sonic wave method the device has been able to measure the distance from the probe to the surface of the base, and the thickness of the assemblage. The probe can be motordriven and measure up to a length of 120 cm on the rails of the unit's frame, and can be place to within several decades of a cm of the objects. Sufficient power is provided by units on the deck. All data were recorded, calculated and retrieved by personal computer.

As a means of verifying the findings while the exact technical process is being established, all examinations which presented certain problems -- such as those of data processing and underwater working methods, for example -- were repeated.

Field operations were undertaken by means of scuba diving.

RESULTS and DISCUSSION

(1) Field studies.

Biomass (wet-weight in g / 100㎠) and zonation.
Within the 1800 g, the fouling biomass varied greatly. In these structures some vertical zonations were shown clearly by the change in biomass, and the consequent change of dominant species. In the case of the observation tower, for example, change of biomass at designated water depths and avarage biomass of each zonation were provided by table-2 and -3, respectively.

These results suggest the possibility that there are some zonations, not only in the splash and littoral zones, but even in the immersed range. Information on changes of biomass and its zonation are essential for routine maintainance operations such as underwater cleaning and repair.

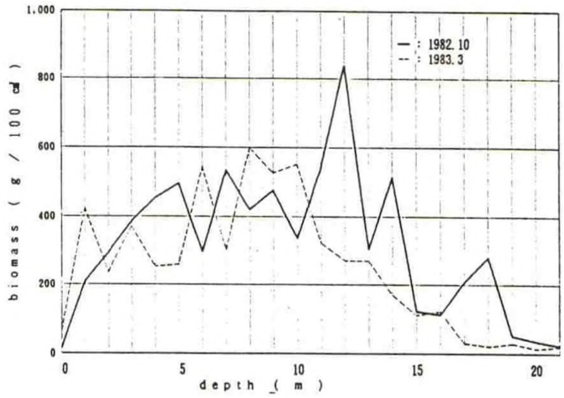

table-2. Change of biomass at designated water depths.

zone name	(1982.10) depth (m)	(1982.10) average biomass (g /100 ㎠)	(1983.3) depth (m)	(1983.3) average biomass (g /100 ㎠)
splash zone (animals rare)	0≦	0	0≦	0
littoral zone (red barnacle dominant)	0	62	0	14
first zone (red barnacle dominant)	1~13	379	1~14	436
second zone (oyster dominant)	14~16	134	15~18	181
near bottom zone (hydroid dominant)	17~21	24	19~21	36

table-3. Average biomass of each zonation.

Thickness

Data on thickness also provides useful information for understanding phenomena of fouling organisms. (Since these findings were provided by divers using a measuring bar, the results could be reported only at 0.5 cm intervals.)

The vertical distribution of thickness is shown by table-4 and -5, taken at the observation tower and sea berth (for 200,000t) respectively. In any case, changing situations have been paralleled in each case by similar changes in biomass. In the later it is necessary to separate the zonation for calculating the average thickness; this is not the case in the former. This situation is the result of a lack of clarity in zonation at the sea berth. Thus, the average values from the surface were 4.5, 9.1, 6.7, 5.5, and the later was 12.2cm. Concerning this item, more quantitative research method will be mentioned later.

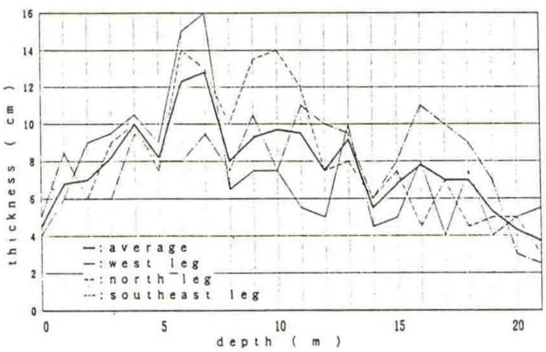

table-4. Changes in thickness at the observation tower using measuring bar.

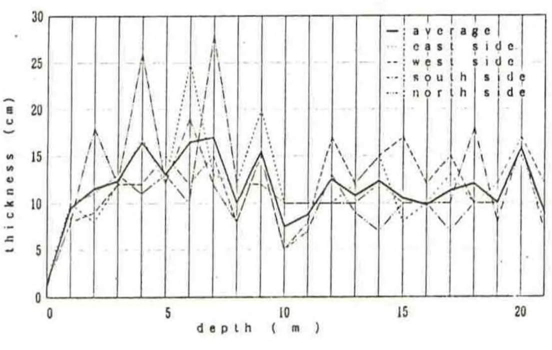

table-5. Changes in thickness at the Sea berth (for 200,000t) using measuring bar.

Species composition and dominant species

During classification a total number of around 70 species were found. While the number of species at each field varied from 10 to 40, about 20 species were found to predominate. Judging from a view of the biomass, the major groups in a species classification consisted of barnacles, bivalves, ascidians, tube worms, hydroids, bryozoans, and sponges. An example of species composition found at the observation tower is provided by table-6.

Four species have been found to dominate: Large red barnacle (Megabalanus rosa), marine mussel (Mytilus edulis galloprovincialis), large oyster (Crassostrea gigas), large ascidian (Halocynthia roretizi).

SPECIES NAME	APPERANCE	
	1982.10	1983.3
(barnacles)		
Megabalanus rosa	○	○
Balanus trigonus	○	○
Balanus amphitrite	○	○
Chathamalus challengeri	○	○
(bivalvia)		
Crassostrea gigas	○	○
Mytilus edulis galloprovincialis	○	○
Crenomytilus grayanus	○	
(hydroids)		
Salmacina dysteri	○	○
Loimai medusa		○
Hydroides elegans		○
Serpulidae sp1	○	
Serpulidae sp2	○	○
(ascidians)		
Halocynthia roretzi	○	○
Pyura vittata	○	○
Leptoclinum mitsukurii	○	○
(bryozoans)		
Bugula neritina	○	○
Dakaria subovoidea		○
BRYOZOA sp	○	○
(others)		
Haliclona permollis	○	○
Halichondria japonica		○
DEMOSPONGIAE sp	○	○
ACTINIARIA sp	○	○
Gaetice depressue	○	
Xantho reynaudii	○	
Pugettia nipponensis		○
Talitridae sp	○	
Pleustidae sp	○	
Janiropsis longiantennta	○	
Caprella scaura	○	○
Paracaprella crassa	○	
Nereis pelagica	○	○
Aphroditidae sp	○	
Muricidae sp	○	○
Cleantis planicauda	○	
Ascorhynchus sp	○	
Ophiocomidae sp	○	○

table-6. Species composition at observation tower

At the same time, many species were able to be separated into two groups: those of soft and hardshell animals. The hardshell animals usually have, naturally, a hardshell, wheras the soft animals normelly do not; the presence or absence of these shells greatly effects both the attaching strength and the fouling weight in the water, and hence figures significantly in calculating boyancy in floating structures and the problems of underwater cleaning.

Settling formation

At the main settling formation a triple fouling layer was observed. These layers have been tentatively named as follows: Basic layer, cored layer and covering layer.

The basic layer was present directly on the coating surface and consisted of tube worms and small barnacles, along with other small, hard animals. This layer supplied a good, rough attaching base for cored layer.

The cored layer ran from the basic layer to the covering layer and was comprised of large barnacles and/or mussels and oysters, (et al.) as the dominant species. Usually these animals were able to attach to the hard surface between the organisms of the basic layer. At the same time, cored layer organisms were able to pile upon one another in tree-like formations. So far, the maximum piling number observed is seven. Additionally, these cored-layer animals, all with large, monozoic shell formation, provided a main pillar with their strong clusters.

The covering layer formed above the cored layer and is comprised of soft organisms (hydroids, bryozoans, and sponges), and small, hard animals (small barnacles, tube worms and some hard bryozoans). The species composition of hard organisms in the basic and covering layer were found to be similar.

(2) Development of quantitative field research technique.

By using our measuring device it was possible to obtain several decades cm of continuous data (see table-7). The repeating of this method allowed us to accumulate a large quantity of thickness data which was far more objective than that obtained by the above-mentioned method of thickness measuring bar.

Since these data were stored on magnetic tapes, the useful, processed data was readily available. Much statistical information was provided, for example, such as average, maximum, minimum, stadard deviation, besides other calculations.

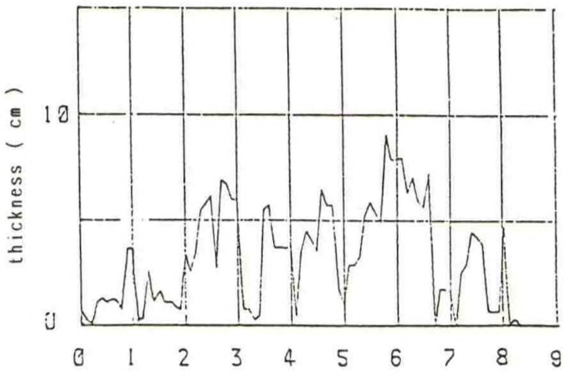

table-7. Change of thickness at the pier, using thickness-measuring device.

In the future, even more useful quantitative data may be provided if we are able to obtain and store information on the specific gravity of fouling clusters.

At the present there is some room for further improvement of this work. Among other thing, the operating and data processing method of underwater divers should be made more easy and effective. Once this has been accomplished, it will be necessary to gradually systemalize this process.

FUNDAMENTAL STUDY OF THE HUGE-SCALE FLOATING PLATFORM FOR USE OF SEA SPACE (2ND REPORT)

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Ocean Engineering Division
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ABSTRACT

This paper, as the successive report to that presented at the 12th Meeting of MFP in 1983, describes some results obtained by the first stage of the research project 1982-1984. A series of model experiments has been carried out by using models constructed from various combinations of element floating-bodies, and the following items have been investigated:

a) Hydrodynamic forces such as added mass and damping force,
b) Wave exciting force and current force,
c) Motion and stress distributions of the large-sized platform which should be considered as flexible structure,
d) Structural strength analysis of the main deck structures,
e) Buckling strength of the connecting parts between platform and the supporting column,
f) Mooring forces acting on the multi-anchoring system,
g) Berthing or mooring forces of a ship to the platform in waves,
h) Design and model experiments of the prototype platform to be offered to the at-sea experiment.
i) Design and sea-side experiment of a mechanical pile anchor.

Through these studies, the procedures estimating exciting and hydrodynamic forces acting on assemblies of various element floating-bodies have been established so that the motions, stress distributions as well as mooring forces can be predicted theoretically so long as the linear assumption be valid.

MODELS

Three medium-sized models(Fig. 1) and three large-sized models(Fig. 2) have been tested either in free-floating or moored conditions at the Offshore Structure Experiment Basin of SRI. The former models have been used to measure exciting forces induced by waves in order to study hydrodynamic interactions between element floating-bodies, while the latter ones were used to measure flexure responses as well as mooring force distribution of the multi-anchoring systems.

RESULTS

The experimental results together with the computation are summarized as follows:

a. Hydrodynamic Forces

Added mass and damping force coefficients for the assemblies of the element floating-bodies are estimated theoretically by means of three-dimensional singularity distribution method and the results showed good agreement with the measured values by means of the forced oscillation tests, by taking into account of the correction for the viscous damping force. The differences of the hydrodynamic forces on each element body due to the differnce of its position are clearly recognized both by the theory and experiment as shown in Fig. 3.

b. Wave Exciting Forces and Current Force

The wave exciting forces acting on the assembly of element floating-bodies can be estimated theoretically by sufficient accuracy for the practical use in spite of ignorance of the mutual interactions of hydrodynamic forces, as shown in Fig. 4 as an example of the results.

The drag force by current velocity can be evaluated by using drag and lift forces acting on the single element body by taking into account of the shielding effects amomg floating bodies which have been determined experimentally. Fig. 5 shows the current forces.

The berthing forces induced by the moored ship in waves are shown in Fig. 6. The effect of berthing places of the platform are observed.

c. Motions abd Bending Moments of the Platform

Motions of the large-sized models in waves can be calculated theoretically in good accuracy as shown in Fig. 7. Furthermore, the vertical motion amplitude and the bending moment distribution of the platform were measured and compared with the calculated values which take into account of the elasticity of upper structures. Both calculated and measured values agree well each other qualitatively in general, as shown in Fig. 8.

d. Mooring Forces Acting on the Multi- Anchoring Systems

Steady and oscillatory forces acting on the mooring lines of the large-sized models were measured experimentally both in regular and irregular waves together with the additional drifting forces corresponding to the current or wind forces which were applied mechanically on the platform, and the distributions of mooring forces or the maximum expectable force along the four sides of the platform were estimated, as shown in Fig.9.

The so-called slow-drift motion of a moored structure plays a significant role for estimation of probability distribution of maxima of mooring forces which remains still unsolved, because of the non-linearity of the phenomena, especially for such complex and huge structures.

e. Planning of the At-Sea Experiment of the Proto-Type Platform

To ascertain the validity or the reliability of the design procedure developed by the above mentioned studies, the at-sea experiment by using the large-scaled proto-type platform has been planned. The structures designed is as shown in Fig.10, and its motion characteristics and the related responses estimated by model experiment and theoretical calculation are shown in Fig.11.

THE SECOND STAGE OF RESEARCH

Following the first stage, the second stage of the research project is planned to start from 1985 fiscal year. The main themes of the research are as follows:

a) At-Sea Experiment of the Proto-Type Platform

The designed structure will be built and towed to the experiment site where the severe environmental condition can be expected.

Two types of mooring systems will be tested alternately, i.e. the catenary line mooring and tension leg mooring. The motions and related responses will be recorded together with the environmental conditions throughout a year continuously.

The mooring systems are shown in Fig.12.

b) Impulsive Loads Induced by Extreme Waves

The impulsive forces acting on the structures induced by extreme waves are investigated experimentally. The effectiveness of the wave breaking structures installed in front of the floating platform if necessary will be also tested giving attention to the mutual interactions between platform and wave breakers.

c) More Precise Estimation of Deflection of The Platform in Waves

The theoretical estimation method will be developed by taking into account of the hydrodynamic mutual interactions among element floating bodies supporting the upper structure.

d) Estimation Method of the Slow-Drift Motion

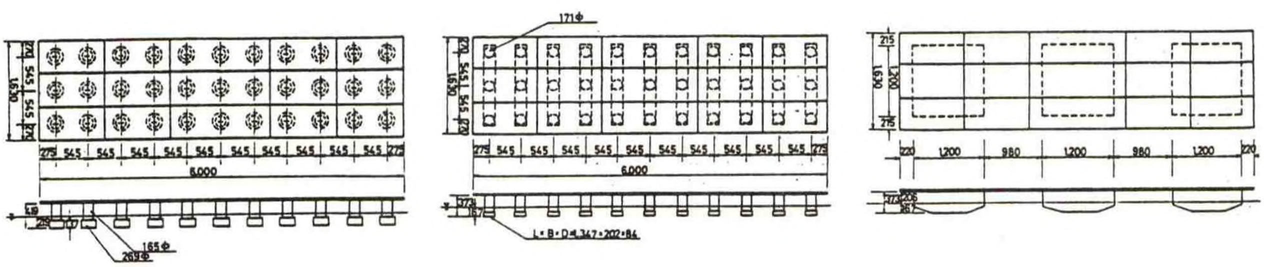
The non-linear motion characteristics of slow drift motion will be investigated to develop the estimation method of the maximum values of mooring forces of the huge-scale platform.

The at-sea experiment will contribute very much to obtain the actual data on this phenomena.

e) Mechanical Pile Anchor Experiment at Sea-side

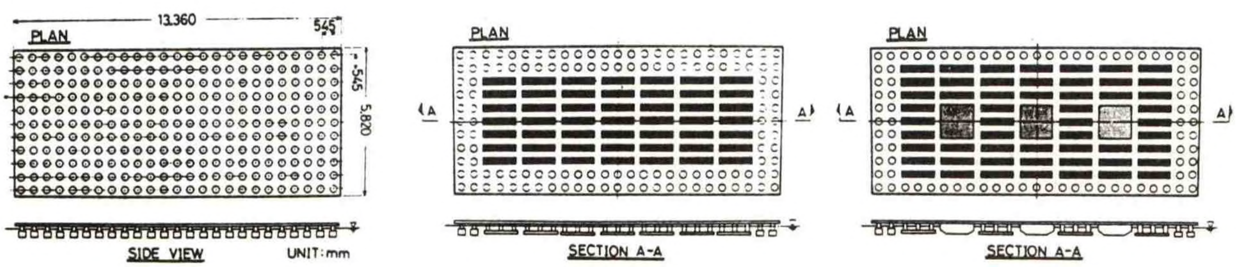
ACKNOWLEDGEMENT

This research was performed through Special Coordination Funds for Promoting S & T of the Science and Technology Agency of the Japanese Government, as a part of the Research on the Utilization of Marine Space by Coastal and Offshore Structures.



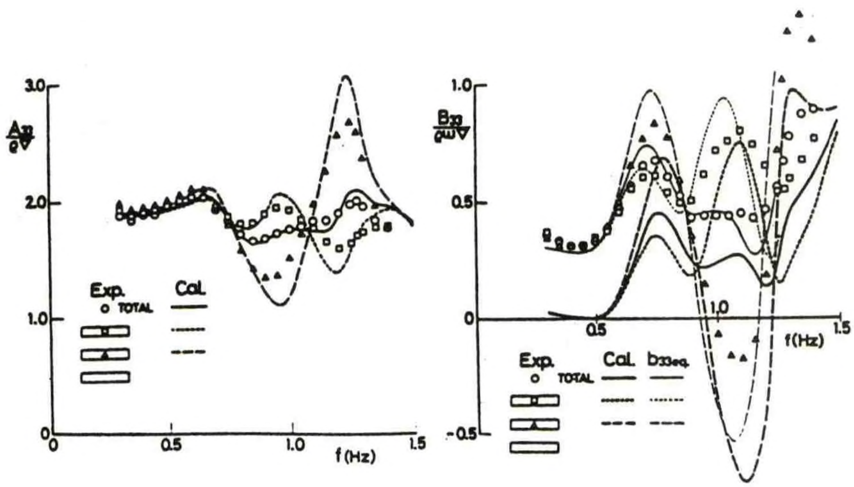
a) Footing type b) Lower-hull type c) Pontoon type

Fig.1 Medium-sized models tested



a) Model I b) Model II c) Model III

Fig. 2 Large-sized models tested



a) Added mass coefficient b) Damping force coefficient

Fig. 3 Hydrodynamic forces of lower hull assembly

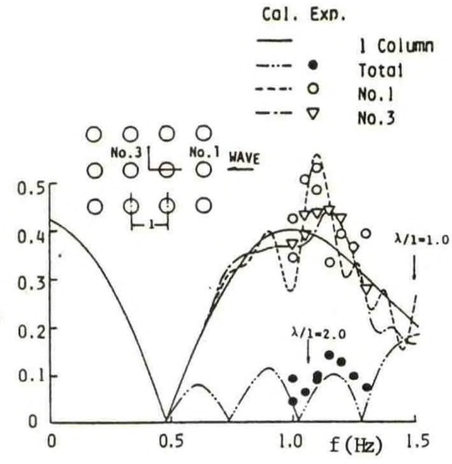


Fig. 4 Wave-excited heaving force acting on the assembly of footing type floating bodies

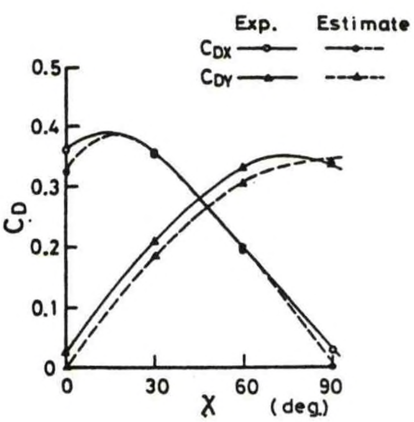


Fig. 5 Current force acting on Model II

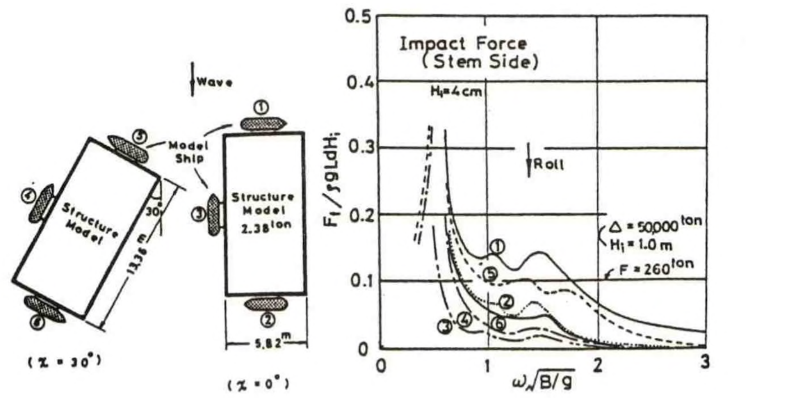
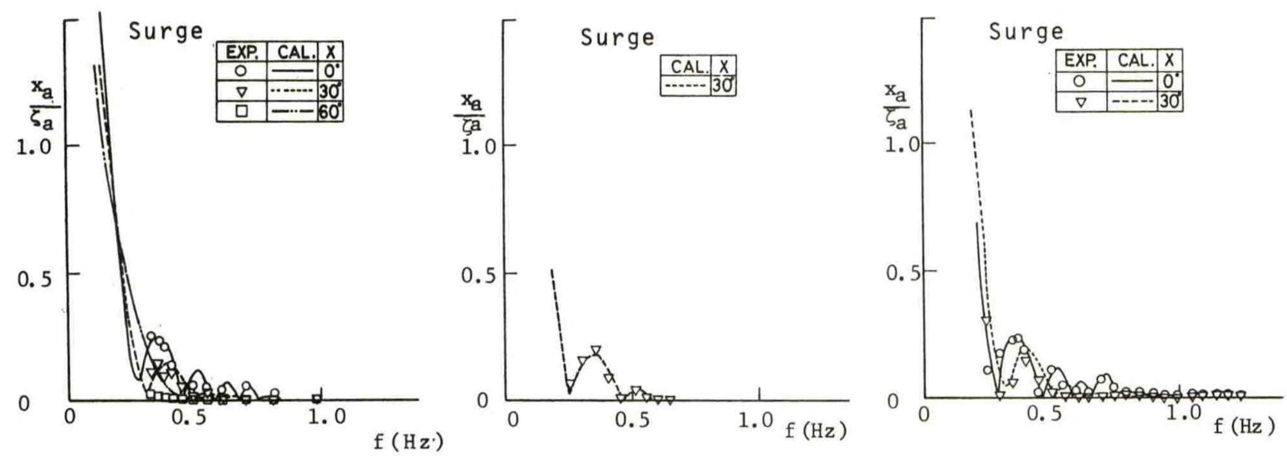
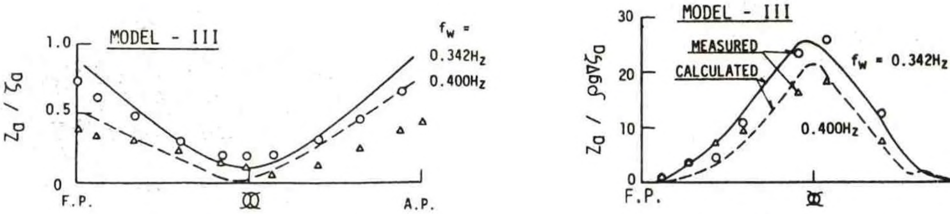


Fig. 6 Berthing forces of the ship to platform



a) Midel I b) Model II c) Model III

Fig. 7 Motion characteristics of the large-sized models



a) Vertical motion distribution

b) Vertical bending moment distribution

Fig. 8 Vertical motions and bending moment of large-sized model

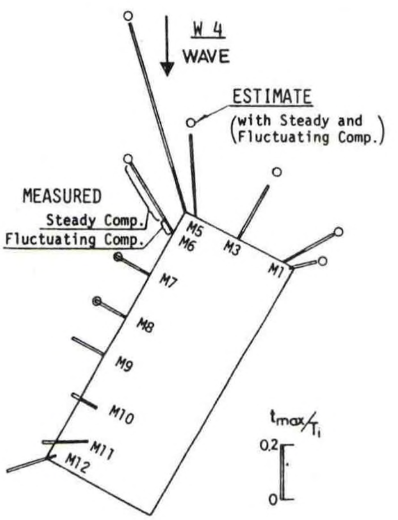


Fig.9 Mooring force distribution in irregular waves

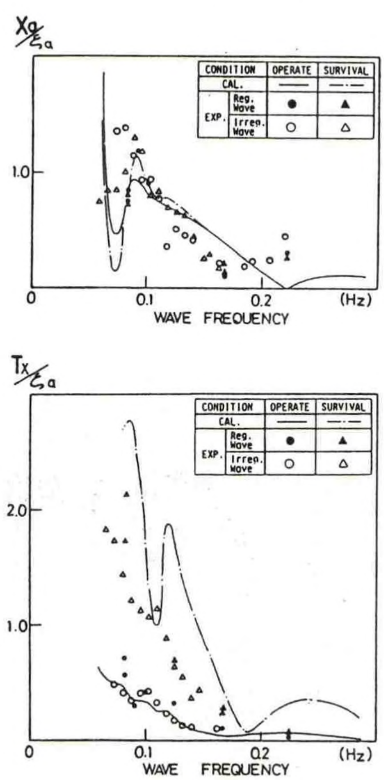


Fig.11 Motion and mooring force of the proto-type platform

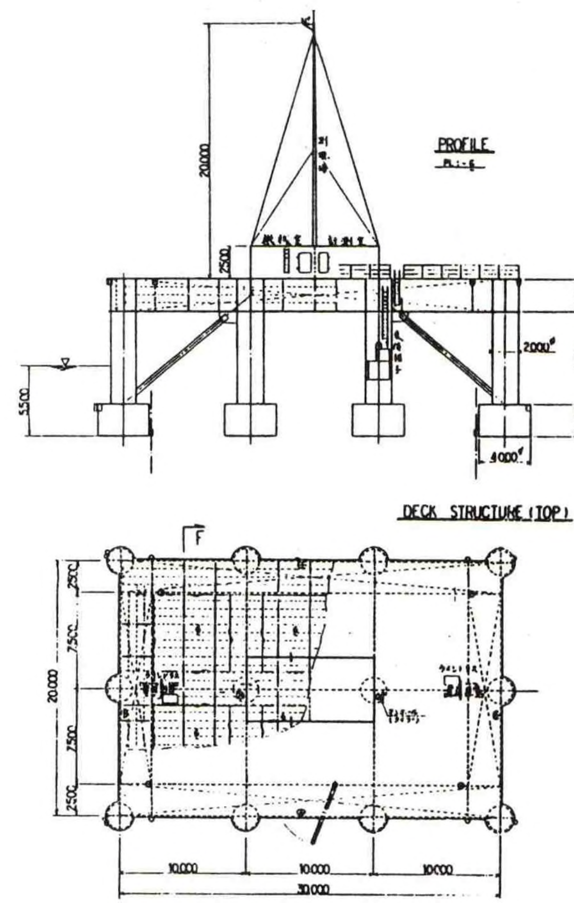


Fig.10 Proto-type platform designed for the at-sea experiment

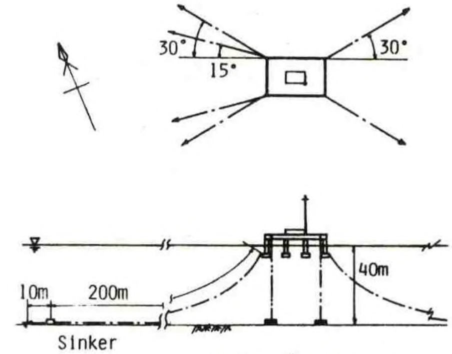


Fig.12 Mooring system of the at-sea experiment

RESEARCH PROJECT ON THE STABILITY OF OFFSHORE MOVING DRILLING UNITS OF INTACT AND DAMAGED CONDITION

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ABSTRACT

Stability research for semi-submersibles has been keenly requested by the governmental organizations since the disasters of some accidental overturnings of floating offshore structures. In Japan, cooperative research projects [1] have been started in 1983 for the establishment of the basis for stability assessment of semi-submersibles. SRI(Ship Research Institute) participated as a governmental institute in the projects. SRI also started by itself the stability research under the auspices of the Ministry of Transport. This paper will introduce the research projects of SRI which partly supplement the cooperative research projects and partly aim at the development of the method for assessing the stability criterion of semi-submersibles.

OUTLINE OF PROJECT

The main purpose of the stability research in SRI is to seek a procedure which enables us to estimate the stability of any semi-submersible drilling units at any designated conditions. So the estimation of overturning moment for a moored floating body under the action of combined external forces due to such as wind, waves and current, in both intact and damaged conditions, is one of the ultimate technical goals of our projects.

The main feature of the technical plans to the project is to devise several computer programs for the assessment of stability of floating bodies. They are computer programs for the statical and dynamical stability of a floating body affected by the steady and unsteady external forces. And the stability assessment program for the damaged conditions such as flooding to sub-compartments, unballanced ballast water allocation. This is for the statical case. Another assessment program is for the unsteady transient case which deals with the behavior of a floating body after the breakdown of mooring lines, impulsive forces due to high and low energy collisions, mishaps of ballasting control and so forth.

Apart from the technical aspects of the project, there should be another aspect in the field of application of the researches. Three objectives are contemplated for that. These are so-called the official purposes of the stability research for MODU in SRI.

Firstly, the consolidation of data concerning the stability of MODU is planned. The review of the rules for MODU of IMO and the classification societies has been appealed since the recent consecutively occured accidents. Many proposals have been made based on the extensive investigations of the accidents and the basic researches in model basins. It should be necessary to provide enough technical data for such proposals when the amendment of the rules will be advocated. So SRI thinks that it may be important to consolidate basic technical data for MODU's stability. As for the basic data, the relation between the overturning moment and the inclination angle, the inclinations caused by flooding of sub-compartment due to collision accident and the relation between GM value and the tilt, are considered to be collected by means of experiments and calculations.

Secondly, SRI is planning to have an experimental system which can pursue the simulation of the overturning of a floating semi-submersible. This aims at clarifying the final stages of the overturning phenomena of a floating body. For this, the development of experimental apparatus will be necessary. In connection with the phenomena the scaling problem between a model and an actual semi-submersible becomes another important problem.

Thirdly, SRI is hoping for policies to the prevention of accidents based on the stability deficiency. Some ideas to prevent a semi-submersible from the fatal accident should be devised based on the results from the basic data and the overturning analysis. However the prevention of the accidents usually contradicts with the economic side of construction and operation of semi-submersibles. So the ideas must compromise with the another aspect other than technical one. Some efforts will be directed to this problem.

In the research program of SRI, the development of computer programs for the assessment of stability of floating bodies is given a high priority. Then it seems to be necessary to explain the concept of the assessment of the stability of floating body.

A MODU which is constructed under the rules of governmental organization may be considered to have enough stability so that she can withstand the designated storm conditions when she operates in the normal operational condition. Then we say, from the view point of the assessment of stability, she satisfies a certain standard of stability. However even if she satisfies the standard at her normal operational condition, it does not necessaryly mean that she is entirely safe for her actual operational conditions other than the designated normal condition. In other words, different GM values can define different standards of stability. Usually a larger GM value tends to give a higher level of safety standard. These considerations lead to the safety standard for arbitrary condition of a semi-submersible.

It seems to be possible to define the degree of safety with relation to the stability quality for the arbitrary condition of a semi-submersible, if we can obtain the instantaneous GM value and environmental condition. At least in experiments of semi-submersible at a model basin we can control both the environmental condition and model condition, so that in principle we can define the safety standard with relation to the stability of a model at any conditions. Comparison of the safety standard gives some clue to the assessment of stability of a semi-submersible. Later a simple example for the safety standard will be given.

RESEARCH PROGRAM FOR 1983-1986

The project of the stability research mentioned here is one of four research items of the special project of the Ministry of Transport which is concerned with the evaluation method of mooring system for floating type offshore structures. The period for this special project is from 1982 to 1986, while the stability research started in 1983.

The following research programs are under way and under planning.

1) Experimental study of the wind force acting on upper decks whose plan forms have several variations.
2) Pressure distribution around a bare deck model without any appendix.
3) Three force components measurement for deck-column-derrick configurations by towing tests in towing tank.
4) Investigation of the behavior of 2-lower hull and 8-column type semi-submersible (Fig. 1) in storm conditions simulated by the combined external forces of waves, wind and current in model basin.
5) Inclination tests for various draft conditions at discretely varying GM values.
6) Effect of damage extent and statical stability and dynamical stability. Experiments and calculations.
7) Experimental study on the simulation of the breakdown of mooring lines.
8) Experimental and theoretical study on the transient response of moored semi-submersible due to various impacts.
9) Experimental study on the effect of the movement of heavy weight on deck and shipping water.
10) Simulation of ballast water control and effect of mishandling of ballast water on the statical and dynamical stability.
11) Simulation of overturning of semi-submersible by adding arbitraryly overturning moment both statically and dynamically.
12) Development of computer programs for the assessment of stability.
13) Probability study on the ultimate stability of MODU.

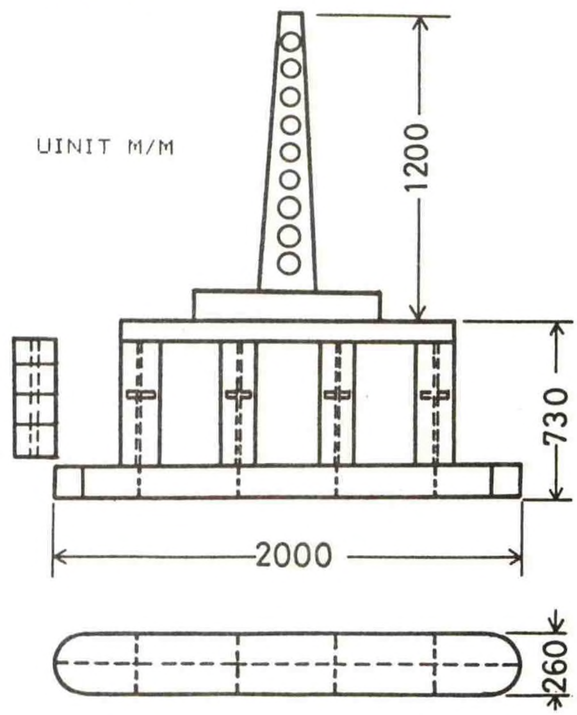


Fig.1 Semi-sub Model with Sub-compartments

ESTIMATION METHODS OF STABILITY

In order to attain the technical goal of the project, it is necessary to establish the estimation method for the stability of semi-submersibles.
And the simulation method for the overturning of a floating body is also needed. We describe simply the flow of research procedure for the estimation methods for the statical stability, the dynami-

cal stability and the over-turning simulation method.

Estimation method for STATICAL STABILITY. In Fig. 2 the main flow of the research program is shown. The most important item is the estimation of the steady over-turning moment due to external forces. And the equilibrium equations for forces and moments will be derived based on the steady over-turning moments. The equations must be derived for any conditions of a semi-submersible, for free and moored condition, for intact and damaged conditions. The steady overturning moment will cause a floating body to tilt. Usually a steady tilt is given by wind, wave, current, tension of mooring lines, movement of heavy loads and ballasting. The quantity of tilt will be determined from the strength of moments and the position of center of gravity of a body.
Steady tilt due to external forces of wind, wave and current is obtained from the experiments in wind tunnel and model basin equipped with wave maker and current generator. SRI has such a model basin, so at least the estimation of steady tilt is possible from experiments. Also some attempts will be directed to the theoretical estimation methods for the steady tilt of floating body in arbitrary conditions. These methods will be consolidated to establish the equilibrium equations for forces and moments. These process will be realized in the computer programs for the statical stability. The inclination test system for models may check the applicability of the calculation. The test system itself is useful to study the basic stability of semi-submersibles. The results from above mentioned processes will provide the data for the assessment of the statical stability, which may be utilized for the comparison with the rules and the proposals to new regulations.

Estimation method for DYNAMICAL STABILITY. In Fig. 3 the flow of the program is shown. This is a counterpart of the statical case. The forces considered here are unsteady ones.
So the motion becomes unsteady. In usual cases, the stability of a floating body may become worse when it is under motion due to waves.
Some comments seem to be necessary for the dynamical stability. It seems that there is no apparent definition for the dynamical stability. Here we define it as the stability related to the righting arm of a body which making motions. When a floating body is in motion, the arm changes from time to time. The time average of it is defined as same as the steady righting arm which is related to the steady statical stability. Only the changing part is treated in the dynamical stability.
The successively changing righting arm can be regarded as a time record, so that it can be treated by the statistical method applying the spectral analysis. Since the righting arm at an instant can be known from the relative motion of a body to the water surface, or the geometrical relation.
Therefore the motion response for the external unsteady forces becomes one

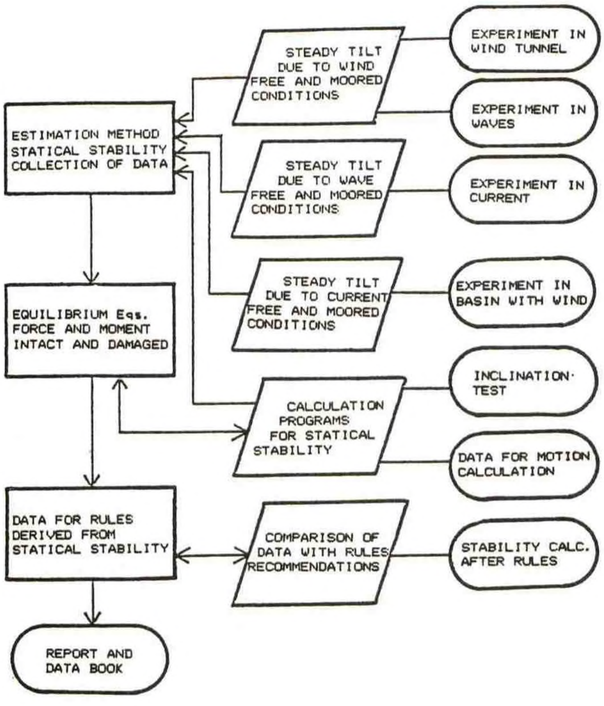


Fig.2 Flow of Statical Stability Research

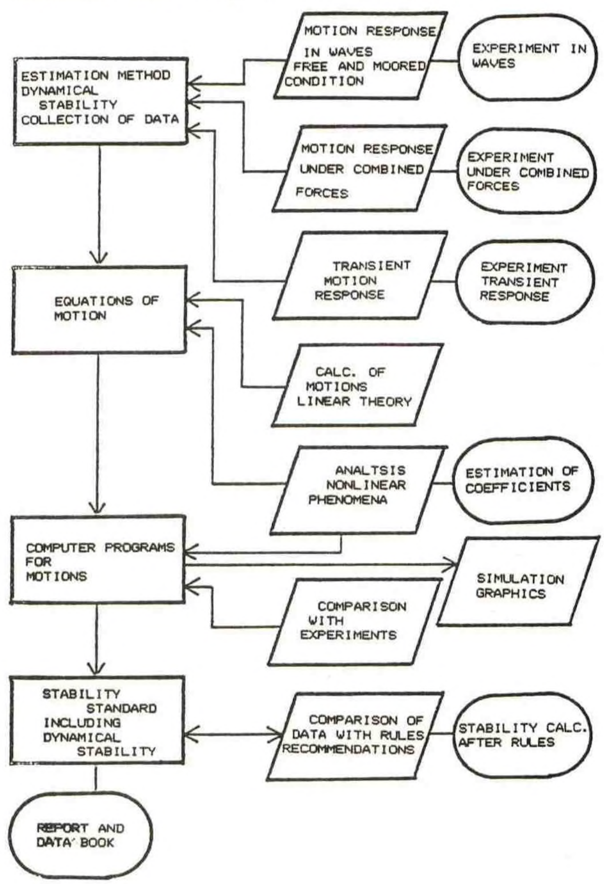


Fig.3 Flow of Dynamical Stability Reseach

of the important items for the dynamical stability. The research program consists of the estimation of the unsteady motion of a moored floating body under the combined forces of wind, wave and current. And the response for the transient and impulsive forces. This is for the cases such as the breakdown of mooring line, moving of heavy weight and transient ballasting and so forth.
Experimental estimation is possible covering most desirable areas. However, theoretical estimation is not always possible, because the motion of body becomes too large to treat it by the linearized theory, when the body is exposed to large unsteady excitation. Then we have to attack the nonlinear phenomena which have not been investigated throughly. In such situation, the experiments and calculations may be consolidated to a hybrid estimation method for motions. The estimation of motion is utilized to set a stability standard including the dynamical stability.

Simulation method of OVERTURNING. In Fig. 4 a flow of research program is shown. The study of over-turning consists of the experimental part and the computer simulation part. As it may not be possible to calculate the process of a over-turning phenomenon theoretically, test results should be utilized to compose the simulation programs. As for the experiments, it is not so easy to make a semi-submersible model sink into model basin under the controlled conditions. Then an experimental apparatus must be planned to cope with the requests for the statically contorolled over-turning moments. The over-turning experiment will be useful for the assessment of the determination for the extra bouyancy and the consideration of the method of prevention of accidents.

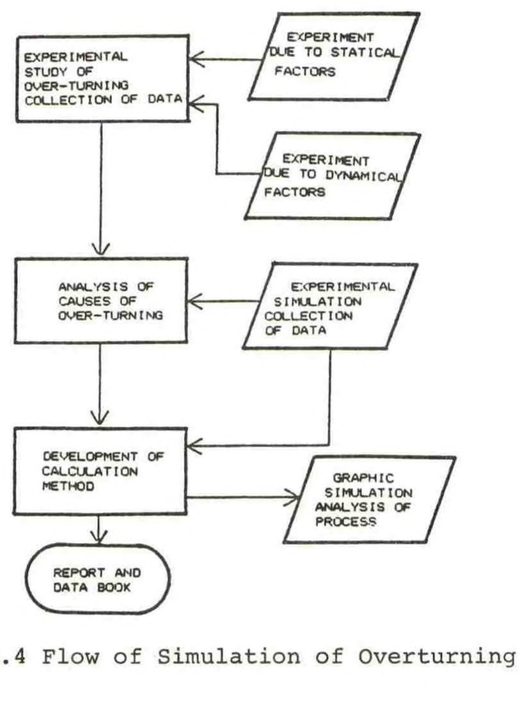


Fig.4 Flow of Simulation of Overturning

CONCEPT OF SAFETY STANDARD

The safety standard can be used to assess a semi-submersible from the point of the stability. Making use of a simple example, the concept of safety standard will be explained.

A floating body is forced to tilt when it is exposed to an external force. The quantity of the tilt will depend on several parameters such as strength and direction of force vector, point of action and GM value of body. A combination may make it incline over the flooding angle. In such case, the degree of danger is defined to be large. To such combination a high penalty point may be allotted.
Fig. 5 shows the calculated inclination of the model of Fig. 1 due to wind forces. The position of reaction of force is assumed to coincide with the center of gravity. Wind speed and the acting position of force are parameters shown in the figure. In this case the displacement of body is kept constant, so that KM is also kept constant at the initial inclination. It is obvious that a condition with initially small GM value is relatively more dangerous. But how dangerous is the our problem. If we set the flooding angle at 15 degree, the combinations of parameters by which the tilt is over 15° are known from the figure. Small initial GM value does not always give high penalty point if the other parameters are adequate. According to the given condition it is possible to set the safety standard by making use of the penalty point concept. With preparation of chart like Fig.5 for other external forces, with appropriate parameters, a synthesis of the penalty points for various cases will give a safety standard which will be used to assess the stability criterion of MODU.

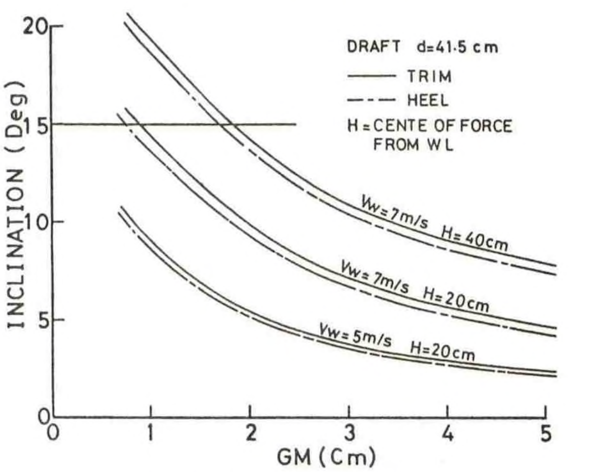


Fig.5 Inclination due to Wind Force

REFERENCE

[1] SR 192 Research Panel; Research Memoir of the Shipbuilding Research Association of Japan, No. 373, 1984

MOOS SALM (SINGLE ANCHOR LEG MOORING) TANKER TERMINAL

Ikuo Mutoh

Mitsui Ocean Development & Engineering Co., Ltd.

1. INTRODUCTION

Mutsu-Ogawara Oil Storage Co. (MOOS) constructed a crude oil storage system at Mutsu-Ogawara, Aomori Pref. as a first national oil storage system and it has commenced the operation in Sep. 1983. (Fig.1)

The MOOS project consists of 51 crude oil storage tanks on land of which capacity 5.7 million kl (36 mil. bbls) in total, offshore SALM tanker terminal, pipelines connecting the offshore terminal and storage tanks, operation control center, power and communication facilities etc.

The offshore transshipment terminal was a first SALM (Single Anchore Leg Mooring) system installed by a Japanese company. (Fig.2)

2. DESIGN CRITERIA

(1) Natural condition

Water depth : 45.3 m
Tide level : H.H.W.L. +1.9 m
H.W.L. +1.52 m
M.W.L. +0.93 m

(2) Tanker to be moored

Max. : 275,000 DWT
Min. : 100,000 DWT

(3) Oil

Kind of Oil : Low viscosity crude oil (50cst/15°C)
Sp.gravity : max. 0.886
min. 0.828
Oil transfer rate : Max 15,000 kl/hr
Max. oil transfer pressure : 9.4 kg/cm2

(4) SALM Buoy operating condition

	Moored cond.	Survival cond.
Wave height	2.5 m	7.8 m
Wave period	8.5 sec	16 sec
Wind speed	20 m/s	35 m/s
Current	0.75 m/s	0.75 m/s

Note: Wave height is significant wave ht (H1/3) and period is peak one. Wind speed is mean velocity of 10 min.

(5) Design loads on the buoy

The model test of 1/48 scale was carried out at Netherlands Ship Model Basin in various series changing and combining wave spectrum, wind speed and direction, current, tanker's draft.

After analyzing the test results, the design loads were determined as follows.

Mooring hawser force : 205 t
Anchor leg chain force : 375 t
Anchor leg chain horizontal force : 166 t
Anchor leg chain vertical force : 345 t
Anchor leg chain heel angle : 32 deg.

(6) Earthquake factor

Horizontal : Kh=0.204
Vertical : Kv=0.102

3. SALM SYSTEM (Fig.3)

(1) Mooring buoy

Out dia. : 5.18 m, Height : 15.24 m
Draft : 12.5 m
Submerged buoyance : 227 t

It is designed to maintain positive tension on the anchor leg chain at any sea conditions.
On the topdeck of the buoy, mooring hawser connecting brackets, fog detector, fog horn, navigation light, radar reflecter and antenna are provided.
In the upper compartment of the buoy, batteries, telemetering system and automatic control system are installed.
On the outside of the buoy, vertical rubber fenders are fitted.

(2) Mooring base

The base is a 15.3 m x 15.3 m square construction of two cylindrical tanks (3.1 m dia. x 15.3 m length) connected by girders.
It is anchored on seafloor by four piles which are rigidly grouted by cement with the base construction.
Each pile is 1.2 m dia. steel pipe and penetrated into seafloor 19.8 m depth.

(3) Anchor leg chain

Flush butt welded stud link chain (Oil Rig Quality)
152 mm dia. x 20 m length
Breaking Strength : 1,618 t

Upper end of the chain is connected to the universal joint under the buoy and lower end is connected to chain swivel and U-joint on the fluid swivel.

(4) Fluid Swivel

It is designed as an independent module unit, and connected on the mooring base by 16 high tensile bolts. Lower end of submerged hose is connectd to the fluid swivel which can rotate with the tanker and hoses around the buoy.
The fluid swivel is made of special metal so as to resist severe sea condition long time without lubrication.

(5) Universal joint

An universal joint is welded at the buoy's bottom and the top of fluid swivel respectively. The bush of the pin is self-lubricating type to minimize the underwater maintenance.

(6) Hose system

Hose system consists of two lines of floating hoses, submerged hoses and connection hoses.
The hoses are 24 inch dia. except the tail hoses of 16" connected to the tanker.
Each line of the hose is 325 m in length in total. On the submerged hose five adjustable buoyancy tanks are fitted so as to adjust the profile of the hose in the water. The connection hoses are flexible rubber hoses installed between fluid swivel and sea bottom pipes.
Necessary valves are fitted on the hose lines considering the hose exchanging and cleaning inside.

(7) Mooring hawser

The hawser consists of 2 line of nylon rope.

Circular length : 432 mm
Length : 55 m

(8) Load monitoring system

The actual load on each hawser is continuously monitored and transmitted to the control station on land. By this load monitoring system, they can make adequate decision to stop the operation or not. The load sensors are strain gage type built in the pin of the mooring bracket on the buoy.

4. INSTALLATION

Installation works of the SALM system started in May 1983 and finished in August.

To minimize the downtime due to heavy sea conditions, one of the largest Self Elevating Platform (SEP) in Japan was used for the main works. (Fig4)

During the installation period, the works were interrupted often by high waves, sometime 9 m wave height, however the works completed nearly as per schedule due to adoption of the SEP which could work up to 1.5 m significant wave height.

The procedures of the installation works were as follows; (Fig.5)

(1) Mooring base installation

The mooring base was transported beneath the SEP being on board a barge and lifted up once from the barge and ballasted by water up to 50 t underwater weight, then lowered to the sea bottom slowly using two 20 t winches on the SEP.
It was settled in a position within the required tolerance ±20 cm using temporary positioning jig and divers' guide.

(2) Pile driving

A long steel pile of 76 m was driven by vibrohammer on the SEP at first through pile guide on SEP and pile sleeve on the mooring base.
Finally, the pile was driven by large capacity air hammer to the required penetration depth.
After completion of all pile driving, unnecessary underwater parts were cut off by divers.

(3) Pile grouting

The piles were rigidly grouted with pile sleeve in the mooring base by pressure cementing system.

(4) Installation of buoy and anchor chain assembly

Horizontal afloat buoy with anchor chain was upended by filling the water into ballast tanks of the buoy, where the buoy was excessively submerged.
Lower end of the anchor chain was jointed to the lower universal joint on the mooring base.
All ballast water in the buoy was deballasted, then the required tension force could be got on the anchor leg chain.

(5) Installation of hose system

Connection hose was lowered from SEP between mooring base and sea bottom pipe end, then bolted up by divers.
Submerged hoses and floating hoses were assembled on beach near the site and towed out to the mooring buoy.
The lower end of the submerged hose was flange-jointed to a hose arm on the mooring base by divers. Then floating hose was connected to the upper end of the submerged hose, using floating crane.

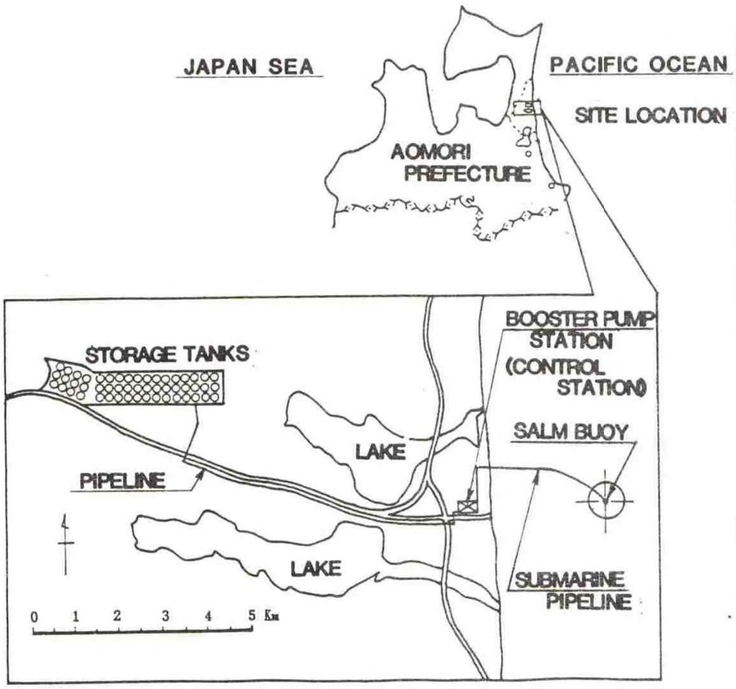


FIG.1 LOCATION MAP

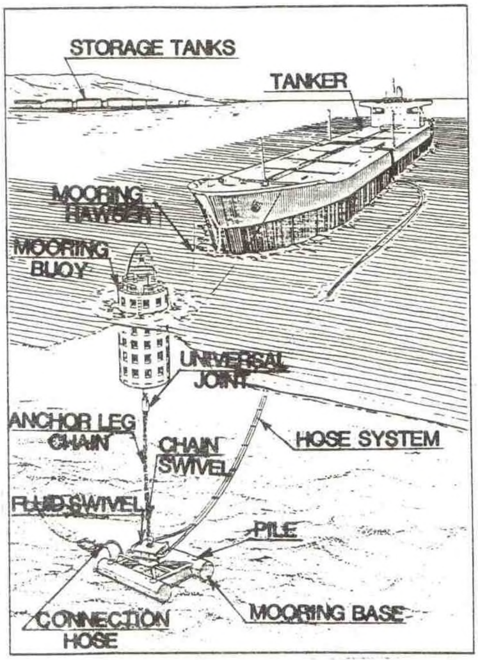


FIG.2 SALM SYSTEM

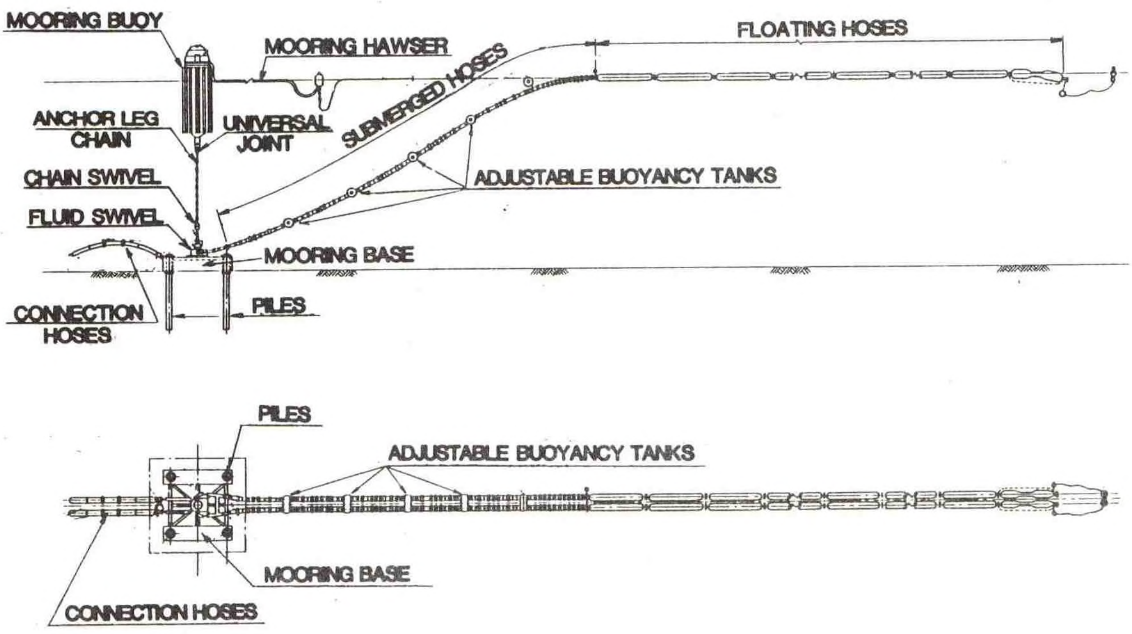


FIG.3 MOOS - SALM GENERAL ARRANGEMENT

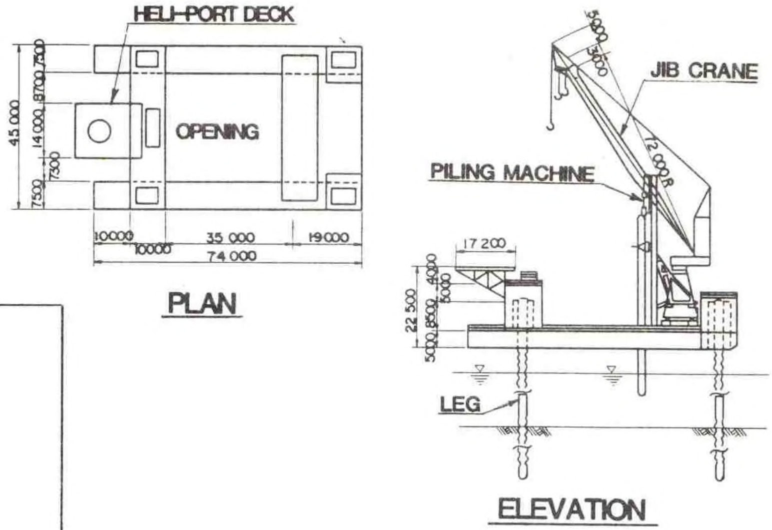


FIG.4 SELF ELEVATING PLATFORM

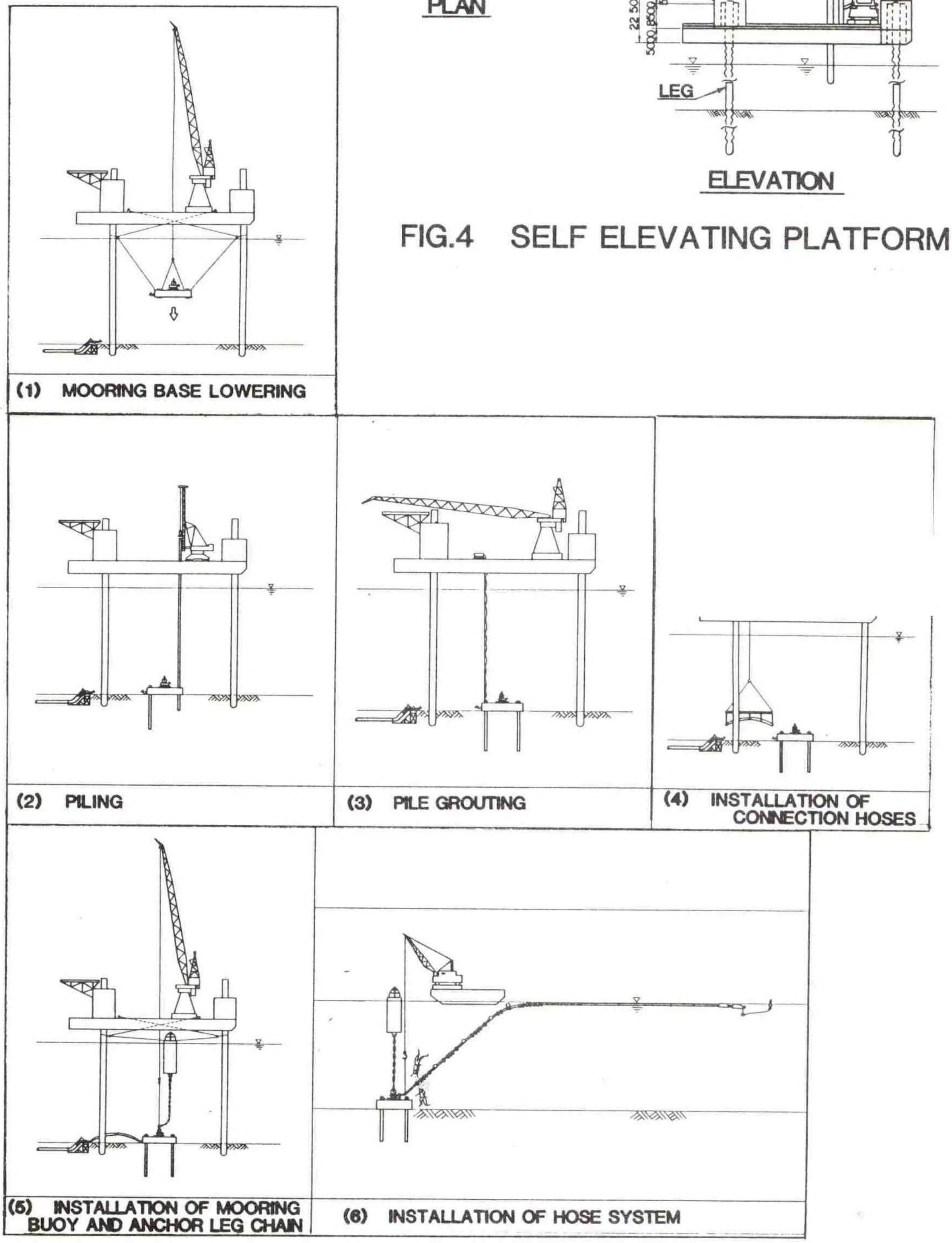


FIG.5 INSTALLATION PROCEDURES

SEAKNIFE II DEVELOPMENTS

Richard M. Shamp

President
Engineering Service Associates, Inc.

SeaKnife International, Inc. has recently acquired all rights to the SeaKnife.

SeaKnife (40 ft.) is currently undergoing tests and modifications.

In the immediate future, construction of a 65 foot SeaKnife will commence. Marketing of the SeaKnife as a ferry boat, workboat, patrol boat, search and rescue boat and interdiction vessel will begin upon completion of the testing of the 65 foot model.

Projected Performance Specifications

Monohull Ferry

Design Cruise Speed		50 Knots
Displacement	(Fully Loaded)	38 tons
	(Empty)	22 tons
Draft	(DIW Loaded)	25 inches
	(Planing)	6 inches
Length (Overall)		65 feet
Maximum Beam		29 feet
Range		450 NM
Passengers		60
Crew	(Captain, engineer, 2 deckhands - stewards)	4

65 Foot Workboat

Design Cruise Speed		52 knots
Displacement	(Fully Loaded)	38 tons
	(Empty)	22 tons
Draft	(DIW Loaded)	25 inches
	(Planing)	6 inches
Length (Overall)		65 feet
Maximum Beam		29 feet
Range		450 NM
Payload		6 tons
Crew	(Captain, Engineer, 2 deckhands)	4

Catamaran Ferry

Design Cruise Speed		40 knots
Displacement	(Fully Loaded)	52 tons
	(Empty)	36 tons
Draft	(DIW Loaded)	30 inches
	(Planing)	6 inches
Length (Overall)		55 feet
Maximum Beam		32 feet
Range		300 NM
Passengers		92
Crew	(Captain, engineer, 2 motormen, 3 deckhands - stewards)	7

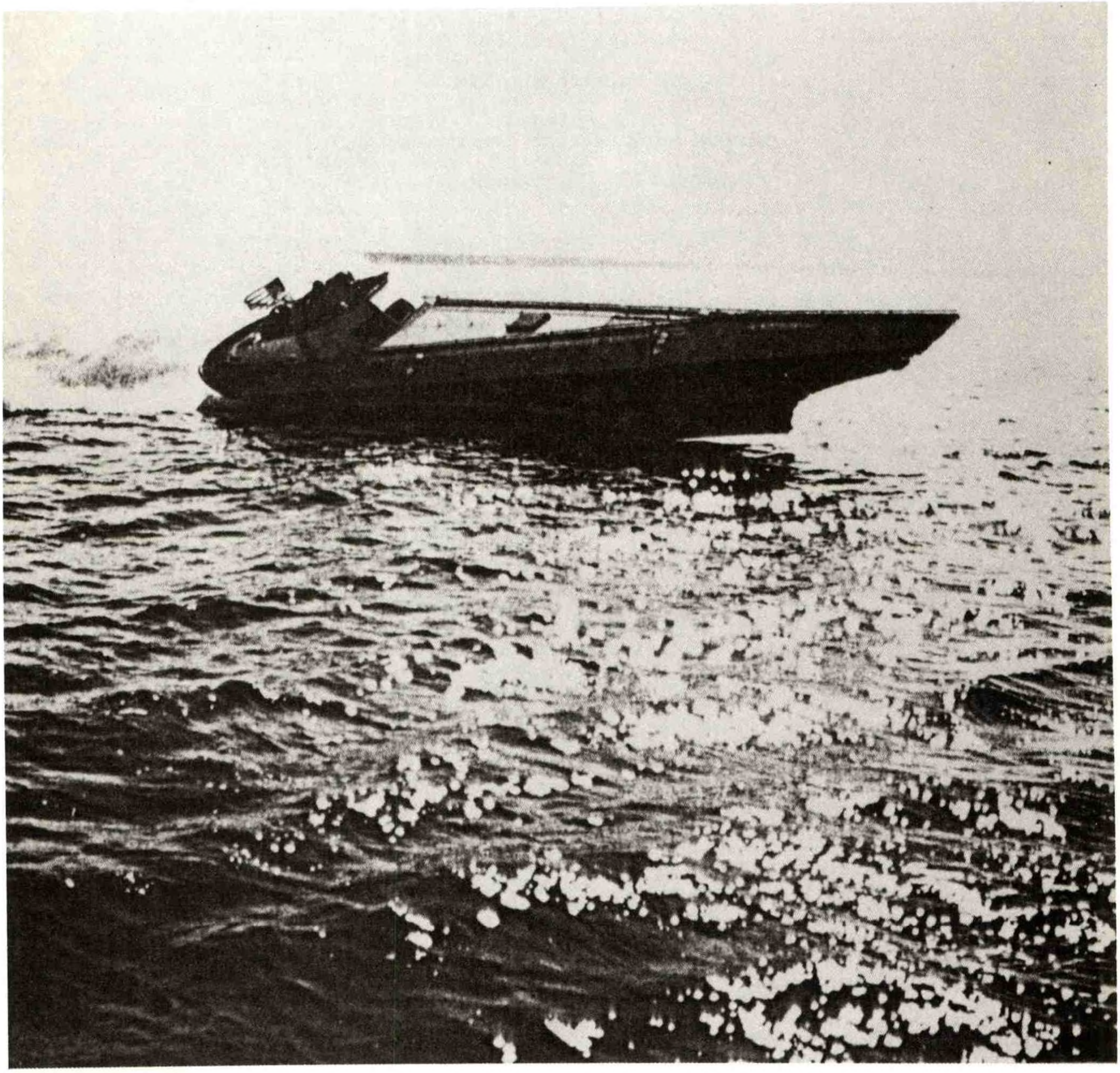


Figure 1 SeaKnife II, Currently Undergoing Engineering Tests. Speed in Excess of 80 Knots in Open Ocean.

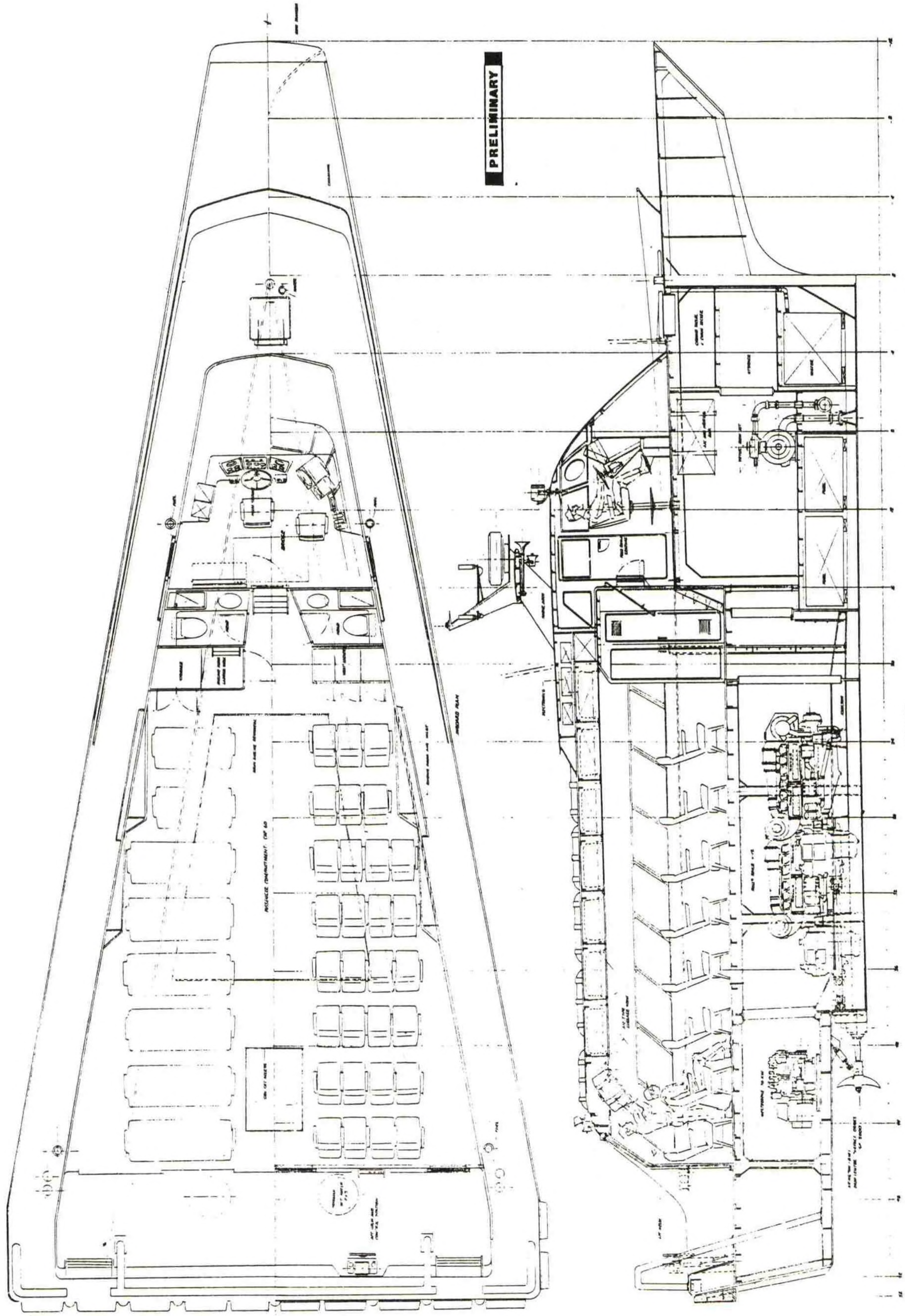


Figure 2 Drawing of 65' Workboat-Ferry

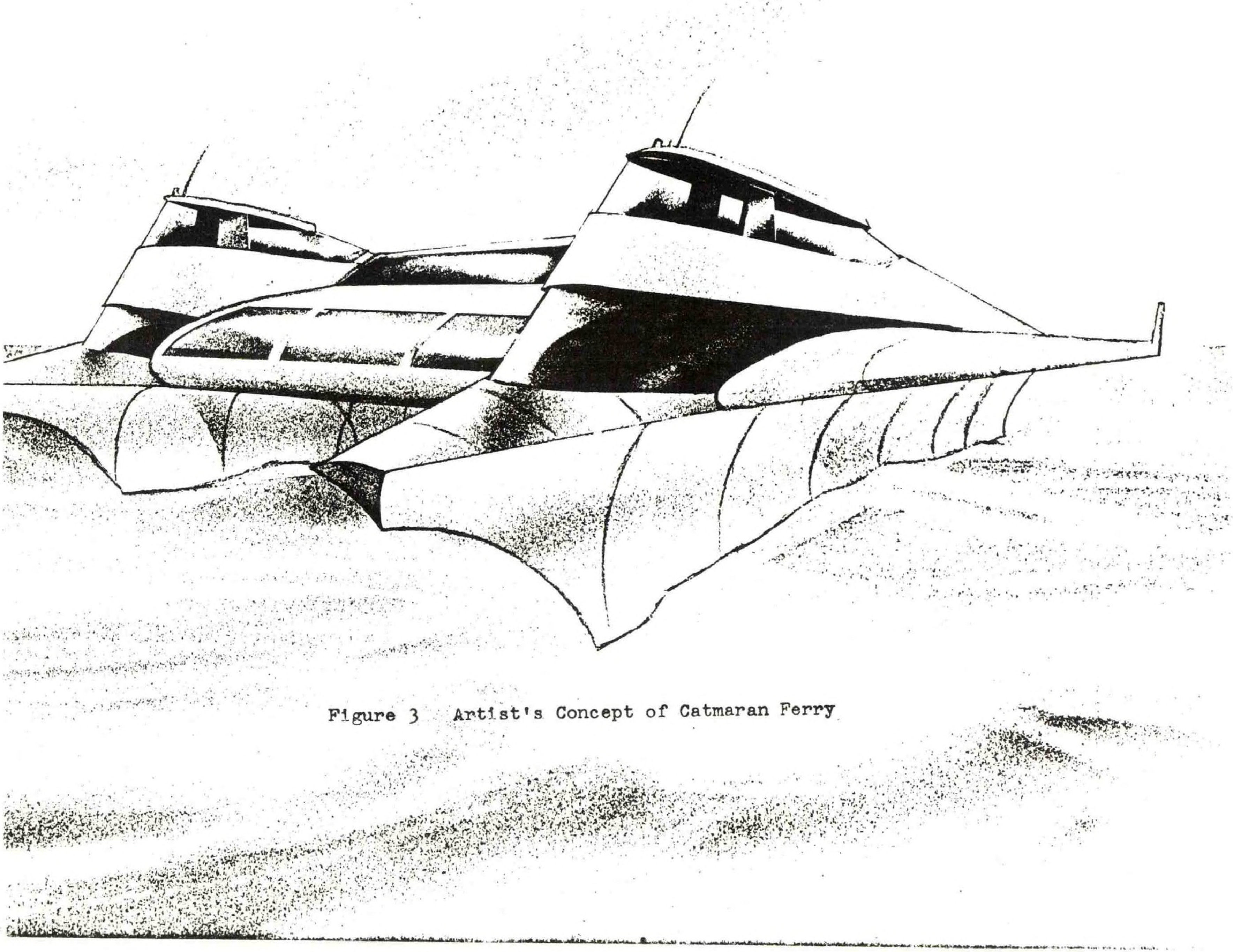
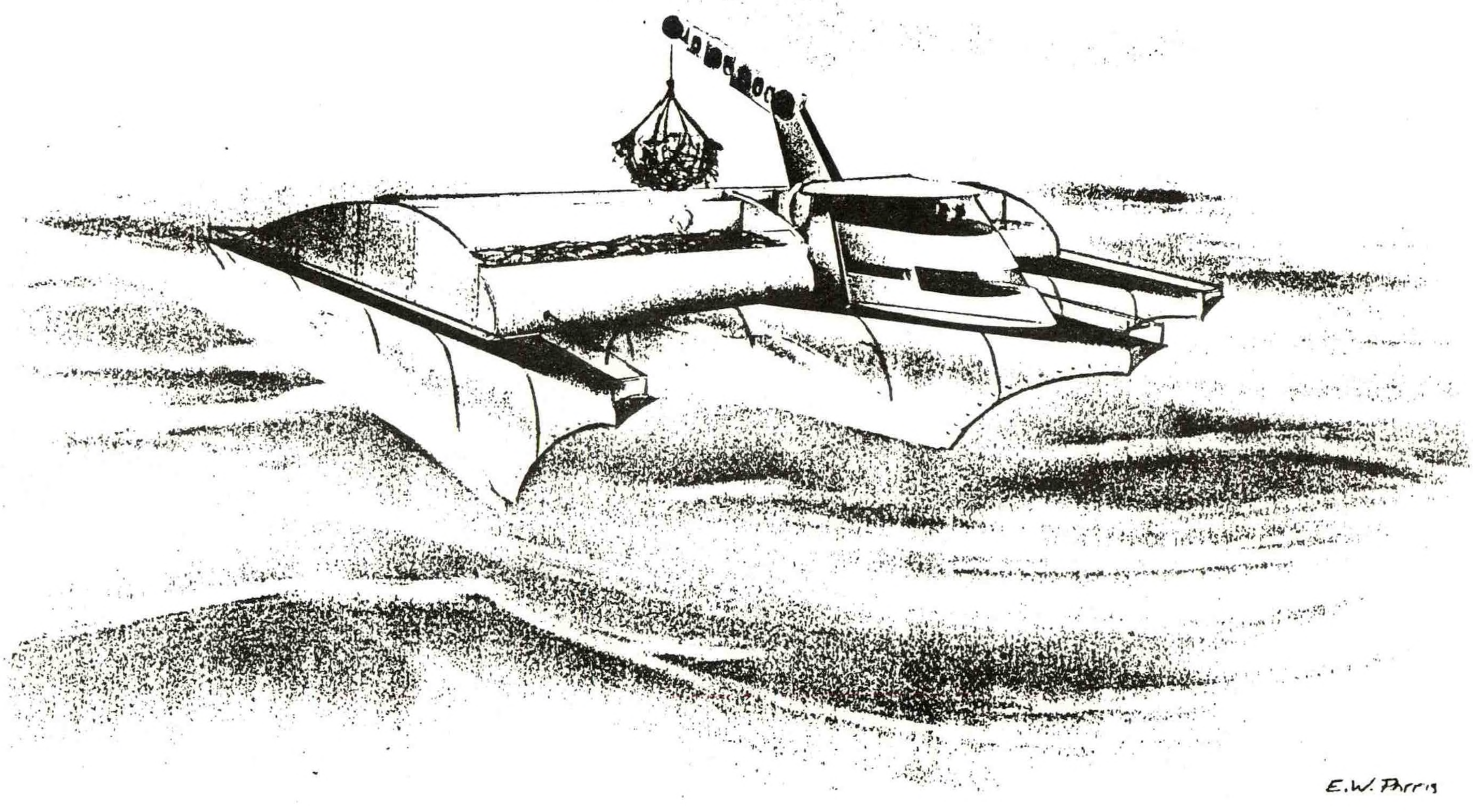


Figure 3 Artist's Concept of Catmaran Ferry

Figure 4 Artist's Concept of an Advanced Design Fish Unloading Vessel using SeaKnife Hull Design in Trimaran Confirmation.



PROCEEDINGS

U. S. Naval Institute

February 1985/$2.50

Figure 5 Front Cover of Journal containing article on SeaKnife.

A REVIEW OF NOAA'S OCEAN PROGRAM

JAMES W. WINCHESTER

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

ABSTRACT

One of President Reagan's top priorities is his Private Sector Initiative Program which is directed toward developing opportunities for greater private sector participation in government programs. He has urged leaders from all segments of our society to find new ways to revitalize our economy and to meet the needs of America. NOAA is examining several project areas which would be suitable for the creation of public-private partnerships between NOAA and the other organizations. Several areas under consideration include: the development of real-time information systems to improve safety and efficiency in guiding vessel traffic in ports and harbors; development of new fisheries products for domestic and foreign markets; and the establishment of regional ocean service centers.

Several NOAA programs which would be of interest to this panel are discussed including: Ocean Data and Services, Exclusive Economic Zone, Status and Trends, Delaware Bay Circulation Modeling, Project PORTS, Mean Sea Level, and Next Generation Water-Level Measurement.

INTRODUCTION

Before discussing some of the ocean programs at NOAA which would be of interest to the Marine Facilities Panel, I will briefly describe the current NOAA organization structure and NOAA policies in promoting the use of the private sector.

The principal components of the NOAA Organization are shown in Figure 1. Each of the components are involved in marine-related activities in varying degrees. The National Weather Service, the largest component (5100 employees) of NOAA, provides national weather service forecasts and severe weather advisories and warnings. Marine related services are provided to coastal states including marine forecasts for offshore activities and port operations and fisheries information. The National Ocean Service (NOS) with 2500 employees is the principal ocean-oriented component in NOAA concerned with Charting and Geodetic Services, Ocean and Coastal Resource Management, Oceanography and Marine Assessment, and Marine Operations. The National Marine Fisheries Service is about the same size as NOS with 2500 employees and is principally concerned with development and conservation of the fisheries resource, and conducts supportive research and development activities. The National Environmental Satellite and Data Information Service with 1200 employees provides supportive service in the form of satellite derived data applicable to both Weather Service and Ocean Service operations. The Oceanic and Atmospheric Research component with 1100 employees is mainly concerned with basic and long-range research activities in support of NOAA's atmospheric and ocean-related activities.

The budget appropriation for NOAA was approximately \$1.021 billion in 1984, and is approximately \$1.158 billion in 1985. Because of the large federal deficit, all government programs are faced with potential reductions and re-alignment of priorities, especially beginning in FY 86.

PROMOTING USE OF PRIVATE SECTOR

One of President Reagan's top priorities is his Private Sector Initiatives Program. He is personally committed to urging leaders from all segments of our society to join with him to find new ways to revitalize our economy and to meet the needs of America. At NOAA, we are making every effort to enhance private-sector activities as one way to increase productivity and to reduce costs to the taxpayers. NOAA is implementing a number of initiatives in support of the President's program and the Department of Commerce policy.

PUBLIC-PRIVATE PARTNERSHIPS

In order to work more closely with the private sector, NOAA is examining several project areas which would be suitable for the creation of public-private (Government-Industry) partnerships. Developing partnerships for a particular project or function involve identifying the government role and industry role and the terms of the partnership agreement. Typically, the partnership stipulates that government will cooperate with industry, agree not to compete with industry, and provide an opportunity for industry to obtain a reasonable return on investment. In any government-industry partnership, industry's participation is primarily based on profitability of their investment, mainly through development of value-added products aimed at special interest users. A major objective of any partnership is to develop an agreement where government-industry co-operation complement and strengthen the activity rather than compete with each other. Partnership agreements could range from one extreme where government retains full responsibility and is supported by industry, to where responsibility is shared, to where industry has most of the responsibility and government serves as a catalyst to promote industry participation.

In one case, a group of private companies composed of a natural gas company, and a food manufacturing company have provided resources and are participating with NOAA to develop a thermodynamic model for use in forecasting climate. This joint effort is directed by the National Climate Program Office.

Studies are currently underway to develop strategies and plans to create public-private partnerships in two other NOAA project areas. One area involves development of new fisheries products and the other involves the development of rapid-access information systems for port and harbor operations.

For a number of years, the vast majority of weather forecasts has been disseminated to the public by the private radio and television media. With the increasing availability of satellite communications and cable television, we expect that the trend will increase and even a larger percentage of weather forecasts will be disseminated in the future by the private media with no expenditure of public funds.

NOAA is also reviewing its ocean and environmental satellite services programs to determine if some portions of ship operations, hydrographic and oceanographic surveys, chart production, and satellite operations should be transferred to the private sector as commercial ventures.

In order to improve communications with the private sector and to help provide incentives to industry to expand into heretofore government services, NOAA has established an Office of Business Affairs and an Extension Service to avoid competition with the private sector and to assist industry in developing new businesses and new markets. NOAA's Office of Research and Technology Applications also assists the private sector and state and local governments in utilization of available technology.

The economic strength of the United States is determined by the viability of our competitive free-enterprise system. The federal government is the largest user of commercial-type goods and services of any organization in the world. Therefore, finding the most efficient and economic method of obtaining those needed goods and services can produce greater savings to the taxpayers than any other one effort.

OCEAN PROGRAMS

In my previous presentation to you in the 12th joint meeting of the Marine Facilities Panel in September 1983, I briefly described some of NOAA's activities that related to marine facilities. Since time does not permit describing the status and plans for all projects, I have again selected several projects which I would like to describe briefly.

Ocean Data and Services

Ocean observational data is acquired through various offshore collection networks including the collection of meteorological and oceanographic data from buoys, NOAA vessels, offshore platforms, and cooperating ships of opportunity. Marine data acquisition and processing is centralized at national centers including NOAA's National Meteorological Center, the Joint Navy/NOAA Center at Monterey, California, and the Joint Navy/NOAA Ice Center at Suitland, Maryland. The processed meteorological and oceanographic data and products developed at national centers are made available at selected regional ocean service centers. NOAA will provide improved services to users by eliminating the back logs of current data, tide and water-level data, and hydrographic-survey data, and by reducing the processing time required to prepare charts of hydrographic-survey data, tide, and current information.

NOAA is presently exploring the possibilities of creating partnerships with industry to operate the regional ocean service centers. NOAA will continue to acquire and process data through existing national and regional networks and make these data and products available at regional centers for use by the private sector in providing value-added products to special interest users including: Federal, state, and local governments; and the industrial/business sector including: fishing, agriculture, forestry, boating and recreation, construction (on shore and off shore), utilities, communications, maritime, emergency services, coastal planners, and many others. This plan would promote the development of businesses resulting in an economic stimulus in each region through business expansion, employment, and contribution to Federal and state revenues through taxes. In addition, the public sector as a whole would benefit by having this function performed by the private sector, not requiring any expenditure of public funds.

The National Research Council (Marine Board) is conducting an assessment of the concept of an Integrated Ocean Observation System for the Alaskan offshore area, especially the Exclusive Economic Zone. The offshore community has expressed interest in rapid access of meteorological and oceanographic data including:

- marine weather;
- sea surface and subsurface distribution of temperature and currents (including tidal); and
- present and forecast sea-ice edge, concentration, extent, thickness, and drift.

These data will facilitate their operation in the Alaskan offshore region, especially for ocean-resource development.

The Marine Board will make an assessment of the need for developing an integrated system to acquire, quality control, process, interpret, and disseminate unique Polar environmental data. This study will assess the state-of-practice to determine the applicability of existing systems and adequacy in meeting current and projected user needs. Deficiencies and additional needed development will be identified as they are determined. A systems approach will be considered for integrating existing acquisition sources with any required additions or improvements. This study will provide some guidance in technical and organizational decisions regarding the need for acquiring, processing, and disseminating marine-environmental data in the Alaskan region.

An integrated ocean observational system can benefit government (Federal, state, local) and industrial and academic sectors operating in the Alaskan region. A government-industry partnership arrangement will be considered as an effective and efficient approach for implementation of such a program.

Exclusive Economic Zone (EEZ)

In response to President Reagan's 1983 proclamation declaring the oceanic areas surrounding the United States and its possessions as exclusive territory, NOAA began a program of mapping the ocean floor. This territory, designated as the United States' Exclusive Economic Zone (EEZ), lies within 200 miles of the coastline and encompasses approximately 3.4 million square miles.

The EEZ program includes the collection, analysis, and distribution of bathymetric (water depth) and geophysical (gravity, magnetics, and seismic reflections) products within selected high priority areas of the EEZ. Initial NOAA plans are to survey areas of the west coast of the United States. Survey techniques will utilize state-of-the-art multi-beam swath-mapping techniques. These systems, in conjunction with precision navigation, will produce bathymetric maps at a scale of 1:100,000 with 20-meter contour intervals. These maps will provide such underwater features as canyons, ridges, sea mounts, and faults, many of which are not presently shown on existing bathymetric maps. Digital data sets of the bathymetric information will be available for scientific researchers to utilize in conjunction with other types of marine environmental data.

Status and Trends Program

Assessment of the effects of human activities on coastal and estuarine environments and development leading to improved use of these environments require a body of useful and reliable information regarding variations in environmental conditions. This information should be based upon systematic observations in carefully selected locations using meaningful indicators of environmental conditions in order to detect significant changes in environmental quality. In 1984, NOAA initiated a new program called the National Status and Trends (S&T) Program to quantify the current status and long-term, temporal and spatial trends of key contaminant concentrations, water-quality parameters, biological indicators of effects in the nation's coastal and estuarine environments. This program intends to determine the current conditions of the nation's coastal zone, and whether these conditions are getting better or worse. A nationally uniform set of measurement techniques will be employed to determine marine environmental-quality parameters.

Fifty sites along the coastal United States have been selected for surveillance of benthic organisms. These locations include urbanized industrial areas and a few pristine areas that will serve as reference points.

Measurements of toxic chemicals will be made in both surface sediments and bottomfish taken from the same areas. Sediments were selected because they are known reservoirs of contaminants; bottomfish were selected because they are reliable indicators of local pollution and because their exposure to toxic chemicals is linked primarily to bottom sediments. Lesions and disorders in the collected bottomfish will be evaluated as an indicator of biological response to toxic chemicals. The S&T Program will also collect mussels or other suitable bivalves from 150 sites nationwide. Of these, 37 will coincide with sites occupied by the former National Mussel Watch Program supported by the U.S. Environmental Protection Agency from 1976 to 1978. Bivalves will be analyzed for major and trace elements, PAHs, PCBs, chlorinated pesticides, size, weight, gonadal/somatic index, and percent lipids.

The S&T Program will construct a data base containing new measurements data (nationally uniform quality controlled, statistically reliable) and selected data from other monitoring programs. The data base will be available, to regulatory and management organizations, environmental scientists, and other interested parties.

Delaware Bay Circulation Modelling

A numerical model of Delaware Bay and River was developed using real-time oceanographic and meteorolgoical data to provide near-term water level and circulation forecasts.

The effort is based on a two-dimensional circulation model developed at Princeton University and adapted to the Delaware estuary. The model has several modes of operation which are presently being exercised to investigate enhancements to traditional NOAA circulation products. The model can be run in a non real-time mode to produce circulation and water level parameters required for atlas production. The model may also be used in real-time to predict near-term (0 - 36 hours) conditions in the bay. For this mode, real-time data from four water level gages and several meteorological stations are used to initialize the model. Using the real-time data as initial conditions, the model provides accurate near-time predictions of currents and water levels for users such as ship operators and pilots.

Project PORTS

Provision of up-to-date charting and mapping data is one of the responsibilities of NOAA. With the increased labor and energy costs of shipping and the desire to increase the capacity and keel depth of marine carriers serving specific ports, the need for accurate real-time data on depth, current, weather, and bar crossing data (wave and current conditions) has been recognized. At the present time, NOAA publishes tables of daily tidal and current predictions. These data, in conjunction with data on nautical charts, provide information on both the static and the dynamic environment for use by mariners for safe navigation.

In some locations, predicted data accurately reflect actual conditions. In others, local, short-term meteorological effects, estuarine flows, and other environmental factors significantly affect water depth, currents, and navigating conditions. NOAA is cooperating with state and local interests to determine their needs for real-time data for vessel traffic in port and harbor operations.

One such effort involves collaboration with the Maritme Association of the Port of New York, and has resulted in a demonstration system providing real-time tide and wind data. Real-time environmental and navigation systems for port and harbor operations are being considered for implementation via a partnership with industry.

Mean Sea Level

An improved system for measuring mean sea level is being proposed by NOAA that would link the tide-gauge network to a global geodetic reference frame. The system utilizes existing Global Positioning System (GPS) and Very Long Baseline Interferometry (VLBI) technology to measure, and thus eliminate, vertical land motion as a major source of uncertainty in estimates of sea level change derived from tide guage data. The improved sea-level monitoring system is a cooperative international effort aimed at providing the first true measure of "absolute" sea level by distinguishing real sea level change from spurious trends which appear as the result of land uplift and subsidence. The need for such a system stems from the fact that global sea level appears to be rising in response to global climate warming due to increasing concentrations of atmospheric carbon dioxide and other so-called "Greenhouse" gases. Indications of sea-level rise include the fact that three-fourths of the world's beaches are eroding at rates ranging from 10 centimeters to over one meter per year. In some regions, such as the gulf coast of Louisiana and Texas, the combination of eustatic rise and land subsidence is causing a relative sea-level rise of as much as a half inch per year with consequent land losses approaching 50 square miles per year.

Another important application of the improved global sea-level monitoring network will be to validate and blend with satellite altimeter data from projected U.S. and European altimetric satellites.

Next Generation Water Level Measurement System

The obsolete systems in the existing National Tide and Water Level Observation Network (NTWLON) are being replaced with a fully integrated system known as the Next Generation Water Level Measurement System (NGWLMS).

NTWLON is composed os 225 permanent primary control tide- and water-level stations located in the marine waters of the United States and its territories and approximately 150 temporary stations. Permanent stations, those which have been in continuous operation for one or more years and will continue to be in operation indefinitely, provide the long-term mean values which are required to establish tidal datums and marine boundaries. Temporary stations are usually operated less than a year to support hydrographic surveys, circulation surveys, and special projects. Data from the NTWLON are processed and analyzed in a central office located at Rockville, Maryland,to provide tidal information products.

NGWLMS consists of five major subsystems: sensor/measurement, data collection and recording, data transmission, data processing and analysis, and data and information dissemination. NOAA proposes to integrate its sea level/tide/Great Lakes measurements networks (including the Tsunami Warning System) and modernize them with new technology sensors, satellite transmission subsystems, and a central data receiving/processing subsystem. The integration effort will include near real-time capability and links with other NOAA centers and systems for ocean, weather, and climate services.

SUMMARY

There is considerable activity and interest in supporting the development and management of ocean resources through acquisition and dissemination of ocean data and information, modernization of equipment, and improvement in coastal facilities and operations. This will require establishment of priorities and planning including close cooperation and partnerships with government, industry, and academia.

THE SECOND TERM PLAN OF WAVE POWER GENERATOR "KAIMEI" PROJECT

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ABSTRACT

The objective of this project is to advance the state-of-the-art in the area of wave power electricity generating units by testing air turbine-type wave power generating systems. The second term plan are roughly divided into the following two parts:

(1) On-board equipment:
Miniaturization and simplification of power generation equipment, intensification and improvement of the out-put.

(2) Hull: Improvement of out put transformed from wave to air.

In the development of on-board equipment concerning item (1) above, maximum efforts will be made to effectively utilize the present KAIMEI. Comparative studies will be carried out simultaneously to examine the performances of various types of on-board equipment.

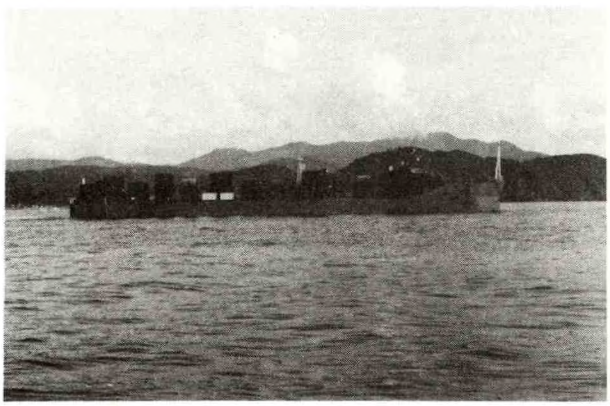


Fig 1. Wave Power Generator KAIMEI

In regard to hull improvement, the correlation between the results of ocean experiment of the model shall be initially clarified. Data are already available regarding this matter, however, additional experiments will be performed in the case the need arises.

POWER GENERATION EQUIPMENT

The double rotor valveless turbine of the U.S. had been manufactured through efforts extended by the U.S., and basic experiments have already been completed. This turbine is an ideal valveless turbine to be used on KAIMEI from the beginning. The tests are to be performed on-board KAIMEI.

The Wells turbine was invented by Queens University in the U.K..

The size of the equipment has been reduced through the use of the Wells turbine. It is easy to manufacture, and its high-speed revolutions are extremely effective in somthing of the power generation. However, on the other hand, it is accompanied by such defects as large shaft thrust and difficulties in designing the bearings.

The tandem-type Wells turbine shown in Fig 2 emerged to improve the aforementioned Wells turbine. It is intended to offset shaft thrust by positioning a pair of Wells turbines tandemly and by letting airflows blow against each other from opposite directions. This turbine (40kw umit) was tested on shore fixed Air chamber in successfuly at winter of 1983. The same unit (scale up to 60kw) is tested on KAIMEI.

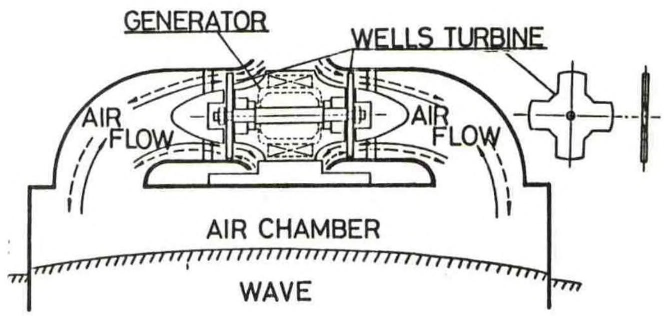
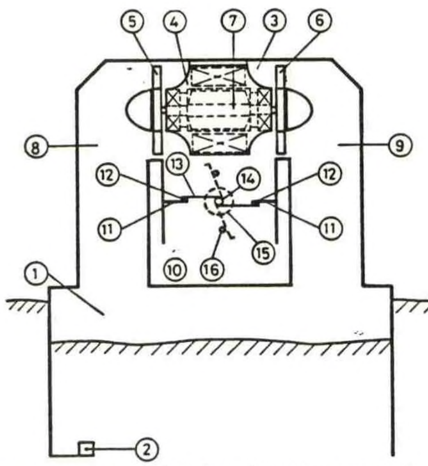


Fig 2. Tandem-type Wells Turbine

(2) Airflow Phase Control Test

Waves with long period possess large amounts of energy. Nevertheless, all wave power generation devices up to the present have hardly produced any power output when exposed to waves with long period. A similar situation waa observed in the air turbine system. The following airflow phase cotrol air turbine system. The phase control system was proporsaled by Professor Budal of Norway who was successful in substantially increasing power output by stopping and removing the vertically moving buoys(point absorbers). This idea can be applied to the air turbine system. Fig 3 shows the application of the system to the tandem-type Wells turbine. In this case, a butterfly valve is installed at the air channel, and airflow is controlled by the opening and closing the valve through the hydraulic signals sent by the waves.



(1)Air Chamber (2)Hydraulic Pressure Detecting Section (3)Wells Turbine(4)Wells Turbine(5)Rotor (6)Stator(7)Valve Seat(8)Packing(9)Butterfly Valve (10)Righting Weight (11)Shaft (12)Servo Motor

Fig 3. Tandem-type Wells Turbine with an Airflow Phase Control System

So the vertical oscillation of the water colum in the chamber will be modulated to the natural frequency period of the air chamber, and by selection appropriate timing for opening the butterfly valve.

When the airflow phase control is implemented, efficiency is increased for long period waves as shown by the dotted line in Fig 4. The air pressure period in each air chamber are similarly distributed in a considerably long period of 8-9 seconds, and efficiency is expected to be increased through phase control.

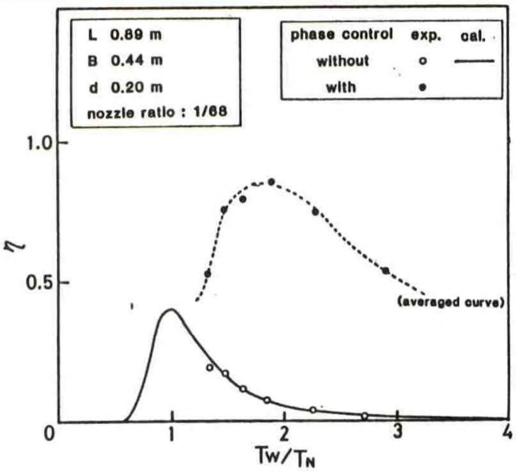


Fig 4 Example of Correlations between Wave period Efficiency with and without Controls

(3)Four Valves Impulse Turbine

Four valves type power generation units with impulse turbines are tested in continueing from first sea trial.

(4)Hull Of KAIMEI

The hull of the KAIMEI, 80m in length and 12m in width, will be reused after undergoing thorough repairs.

OPEN SEA EXPERIMENT METHOD.

The sea experiment is planned one year, several performance improvement programs will be tested and compared one by one on KAIMEI. The experiment will be conducted in 1985.
The site of the experiment will be offshore of Yura, Tsuruoka City, Yamagata Prefecture at a depth of 40m . This is the same experimental site as the previous one.

OTHERS

This project is accomplished as sub-task C: open sea test under IEA wave power conversion system study. We wish to express oun gratitued to participation of USA to sub-task C. IEA study includes Sub-task A wave information and sub-task B research and development.

The Japan Marine Science and Technology Center will work as the Opearating Agent to advance the area of wave power electricity generation with IEA wave power participation countries. Since wave power is abundom on sea, wave power generation is applicable to source of power at sea, power supply for isolated Islands and power supply for electric power systems.

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The International Program of Scientific Ocean Drilling

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Abstract

Texas A&M University is the operating institution for the new $30 million per year, 10-year program of scientific Ocean Drilling. This program is likely the most ambitious basic research program in the earth sciences today.

The responsibilities of TAMU as Science Operator include implementing the science plans under the guidance of JOIDES, providing logistical and technical support for a shipboard science team, managing post-cruise activities, the long term curation and distribution of core samples, and coordinating, editing and publication of the final research product. The scientific programs will be carried out with the drilling vessel JOIDES RESOLUTION (registered name SEDCO/BP 471), a dynamically positioned drillship capable of deploying 30,000 ft. of drill string and operating with a riser in 6,000 ft. of water.

Introduction

In 1964, four of the major marine geoscience institutions (Lamont-Doherty Geological Observatory of Columbia University [L-DGO], Scripps Institution of Oceanography of the University of California at San Diego [SIO], Woods Hole Oceanographic Institution [WHOI], and the Rosenstiel School of Marine and Atmospheric Science of the University of Miami [RSMAS]) signed a memorandum of agreement which inaugurated the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES) and led the way for the development of a unified program of deep ocean drilling.

Now an international scientific organization, JOIDES currently includes six additional U.S. institutions: Texas A&M University; the University of Texas at Austin; Oregon State University; the University of Rhode Island; the University of Hawaii; and the University of Washington. JOIDES institutions representing 10 other countries include: the Bundesanstalt fur Geowissenschaften and Roshstoffe of the Federal Republic of Germany; the Centre National pour L'Exploitation des Oceans of France; the Department of Energy, Mines, and Resources of Canada; the Natural Environment Research Council of the United Kingdom; the University of Tokyo Ocean Research Institute of Japan; and the European Science Foundation which represents Italy, the Netherlands, Norway, Sweden, and Switzerland.

The initial effort of JOIDES was the drilling of several deep holes on the Blake plateau off of northern Florida. The drilling vessel was M/V CALDRILL I, a converted 54-meter, AKL-type vessel equipped for rotary drilling. [1] This first successful effort of scientific ocean drilling paved the way for a more ambitious program: the Deep Sea Drilling Project (DSDP). This 15-year, globe-encircling scientific program of ocean drilling commenced in 1968, with SIO as the operating institution. The drilling vessel was the D/V GLOMAR CHALLENGER, which logged 375,000 nautical miles, drilled 1092 holes at 624 sites and recovered 96,000 meters of core.

The results of DSDP have led to revolutionary scientific achievements in the areas of paleo-oceanography, plate tectonics, and crustal evolution [2-4]. It demonstrated that a new program with additonal expanded facilities (e.g. more laboratory space and scientific/technical quarters, longer drill string, riser capabilities, capabilities for high latitude drilling, greater seakeeping ability, etc.) was warranted. In March 1983, the Board of Governors of the Joint Oceanographic Institutions, Inc. (JOI), a non-profit organization composed of the ten U.S. members of JOIDES, selected Texas A&M University (TAMU) to become the Science Operator of the new Ocean Drilling Program (ODP). TAMU is funded by JOI, who in turn, is funded by the National Science Foundation (NSF), an independent Federal Agency. NSF receives partial support for ODP from the countries representing the non-U.S. JOIDES members.

Role of the Science Operator

TAMU's ultimate responsibility as science operator of the Ocean Drilling Program is to collect cores from beneath the floors of the world's oceans and to assure that adequate scientific analyses are performed on these samples. In order to properly discharge this major responsibility, TAMU (under the scientific guidance from the JOIDES community) has been charged with the procurement and conversion of a dynamically positioned drillship with riser capabilities (including the purchase of scientific and drilling equipment and the design of scientific laboratories) for scientific ocean drilling. In addition to the selection and conversion of the drilling vessel, TAMU's responsibilities include:

i. Staffing of the scientific and technical support crew. These personnel include: a) The shipboard scientific staff; typically about 25 in number, they represent a team of specialists in the various fields of geosciences (e.g. paleontology, petrology, sedimentology, geophysics, etc.), drawn from universities, government, and industry; and b) A highly technical support crew, also about 25 in number, who are TAMU/ODP employees. These include Electronic and Marine Technicians, Curatorial representatives, computer experts, and an experienced drilling superintendent, who will oversee the drilling operations and act as a liason between the drilling and scientific activities.

ii. Maintaining shipboard laboratories necessary to meet the needs of the shipboard scientific staff. These include laboratories for sedimentology, paleontology, geochemistry, paleomagnetics, physical properties, meteorology, and geophysics, which will be equipped with state-of-the-art research equipment and computer facilities. Also included are technical facilities such as computer, electronics, word processing and photographic.

iii. Developing an operations plan and drilling schedule which includes, among other activities, ensuring equipment availability, defining operational limitations, providing an adequate supply of consumables (beacons, drillbits, etc.), assessing safety and operational procedures prior to drilling, and ensuring organized transition of personnel and supplies between cruises.

iv. Improvement of existing drilling and downhole techniques and development of new ones which may be useful to the needs and goals of the JOIDES Scientific Community and the engineering community at large. These include understanding the physical characteristics of the drilling system, so that the operating limits of very long drill strings may be established; improving core quality, orientation and recovery; and developing the capability of hard rock spudding at sea.

v. Storage, archiving, and dissemination of core and other scientific data collected during the course of the program. TAMU will be curator of all cores obtained in the Ocean Drilling Program. It will maintain core repositories and state-of-the-art shorebased scientific laboratories and computer facilities for the study of the cores.

vi. Publication of an authoritative series of reference books which will summarize the objectives and results of each cruise. The reports will include pre-drilling geological/geophysical site surveys, objectives, planning documents, core records, descriptions of physical and geochemical measurements, logging data, core photographs, core descriptions, paleontology and petrological reports and syntheses. Shipboard post-cruise science documents will also be included. These volumes will be a modified version of the <u>Initial Report Series</u> [5] previously published by the Deep Sea Drilling Project. In addition, TAMU will provide public information such as press releases, informational brochures, films, shipboard tours, and speaking engagements presented by the scientific and technical staff.

Drillship Selection and Conversion

TAMU had made a contract award in March 1984 with Undersea Drilling, Inc. for the use of the drillship SEDCO/BP 471 (to be commonly referred to as the JOIDES RESOLUTION, Figure 1). This 470-foot long drillship is under contract for 5 years with options to continue for an additional 10 years.

The JOIDES RESOLUTION will be capable of deploying 30,000 feet of drill string, and of drilling in water depths up to 27,000 feet. It will utilize a computer-controlled dynamic positioning system to keep the ship stabilized over a specific location. The ship is 70 feet wide, has a displacement of 16,596 long tons, and has a derrick that towers 200 feet above the waterline. The JOIDES RESOLUTION will also be capable of seasonal operations in high altitudes.

Although the initial phase of the Ocean Drilling Program will involve only riserless drilling, drilling with riser will be required to address some of the problems that have been targeted for scientific ocean drilling. The drillship is capable of deploying a riser up to 6,000 feet long.

The complex job of converting an existing drilling ship to a floating scientific research center was started immediately after the contract award. In order to meet the tight schedule, a group referred to as the JOIDES Advisory Group on Equipment and Laboratories (JAGEL) was formed to provide advice to ODP/TAMU. ODP also contracted with an architectural firm with experience in laboratory design to assist in the development of laboratory plans. Frequent meetings were held between ODP/TAMU, JAGEL, SEDCO, and the architect. The scientific facility arrangement plans were "finalized" in late April 1984. Minor changes were made thereafter.

The main laboratory structure has been built on the starboard side of the vessel in the area between the rig floor and the bridge/accommodation house (Figure 2). Three levels of the structure have been constructed below deck by taking over a part of the casing hold. A three-story laboratory structure has been constructed on the main deck and is connected to the below deck spaces by a stairway and by an elevator. A downhole measurements lab overlooking the rig floor is on top of the lab house. A library and study area has been installed on the main deck forward of the Bridge House. An underway geophysics lab has been constructed on the fantail under the helicopter deck. Additional scientific office and storage space is located on other parts of the ship.

General Scientific Plans

The primary scientific focus of the Ocean

Drilling Program will be in studying the following areas [6]:

a. The composition, origin and evolution of the oceanic crust
b. The early rifting stages and evolution of passive type continental margins
c. The active margin processes of fore-arc subduction, accretion and erosion, and back-arc spreading, compression, and volcanism
d. The origin and evolution of marine sedimentary sequences
e. The study of the long-term changes in the atmosphere, oceans, cryosphere, biosphere, and magnetic field
f. The development of new tools and technology for deep ocean exploration and drilling (such as bare rock spudding and riser drilling in deeper than conventional water depths).

In order to address these objectives, drilling plans are now being formulated by the various panels and committees of JOIDES. These plans are being fit into a schedule that is geographically fixed at two points is time, namely in high latitudes of the North Atlantic in the summer of 1985, and in the Antarctic during the Austral summer of 1986-1987. In Figure 3, the drill site areas for the first two years of the drilling program are shown. Tentative long range plans call for the JOIDES RESOLUTION to proceed soon afterward to the Indian Ocean.

Scientific ocean drilling has produced spectacular results over the last fifteen years. It is reasonable to expect that with the powerful and sophisticated technology now available to us, that the advances over the next fifteen years will similarly improve our understanding of fundamental processes occurring within the earth.

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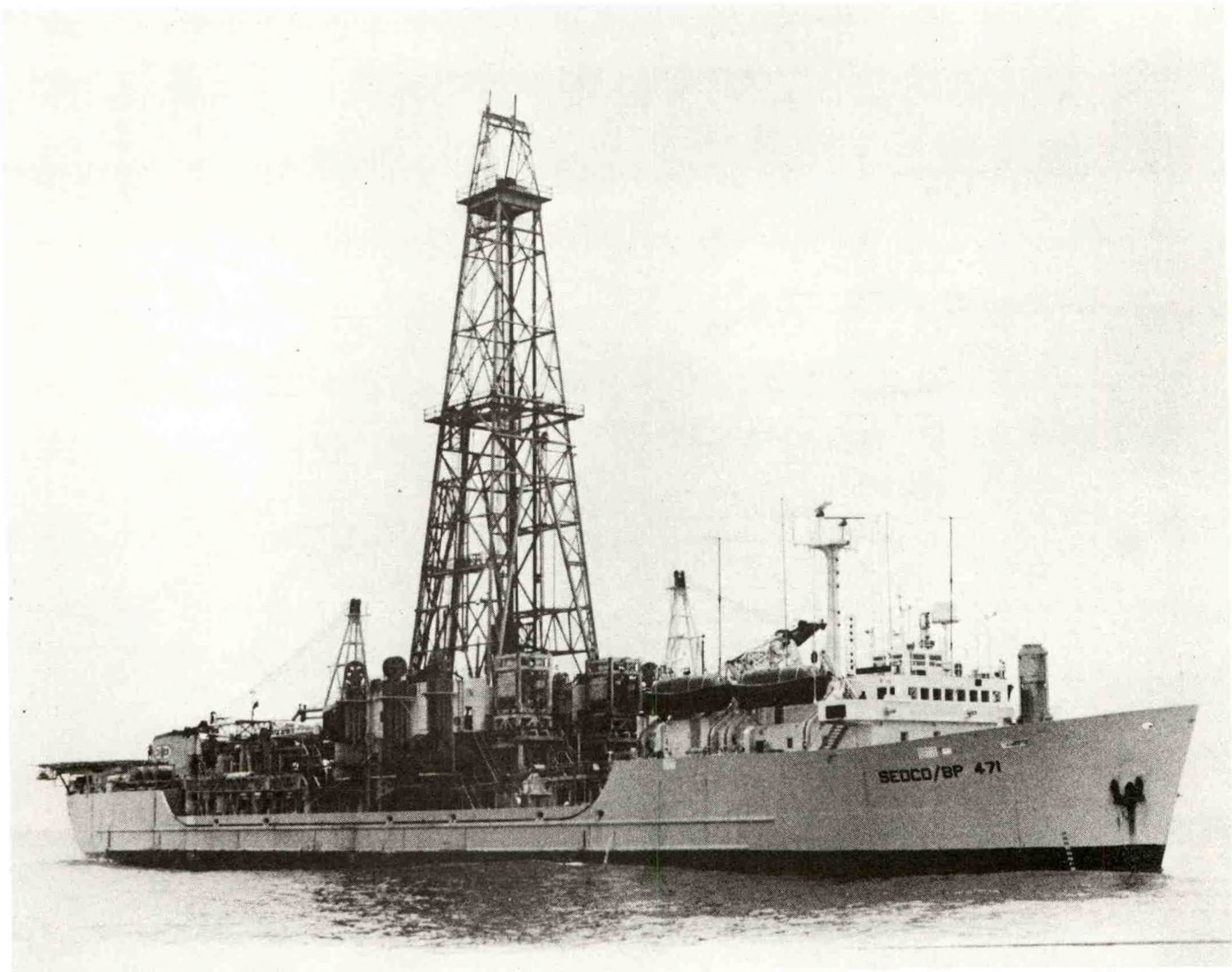

Figure 1. The JOIDES RESOLUTION (registered name SEDCO/BP 471) is 470 feet long and 70 feet wide and has a displacement of 16,596 long tons. The derrick towers 200 feet above the water line. A computer controlled dynamic positioning system can be used in water depth as great as 27,000 feet. The ship which was built in Halifax, Nova Scotia in 1978 is among the top worldwide dynamically positioned drillships due to its rating of drilling depth capabilities. The rig will have a 30,000 foot drill string and will be able to use a riser system for drilling in 6,000 feet of water. Approximately 12,000 square feet of shipboard space is devoted to science laboratories and science storage. A scientific party of 50 persons can be accommodated for the approximately two-month voyages.

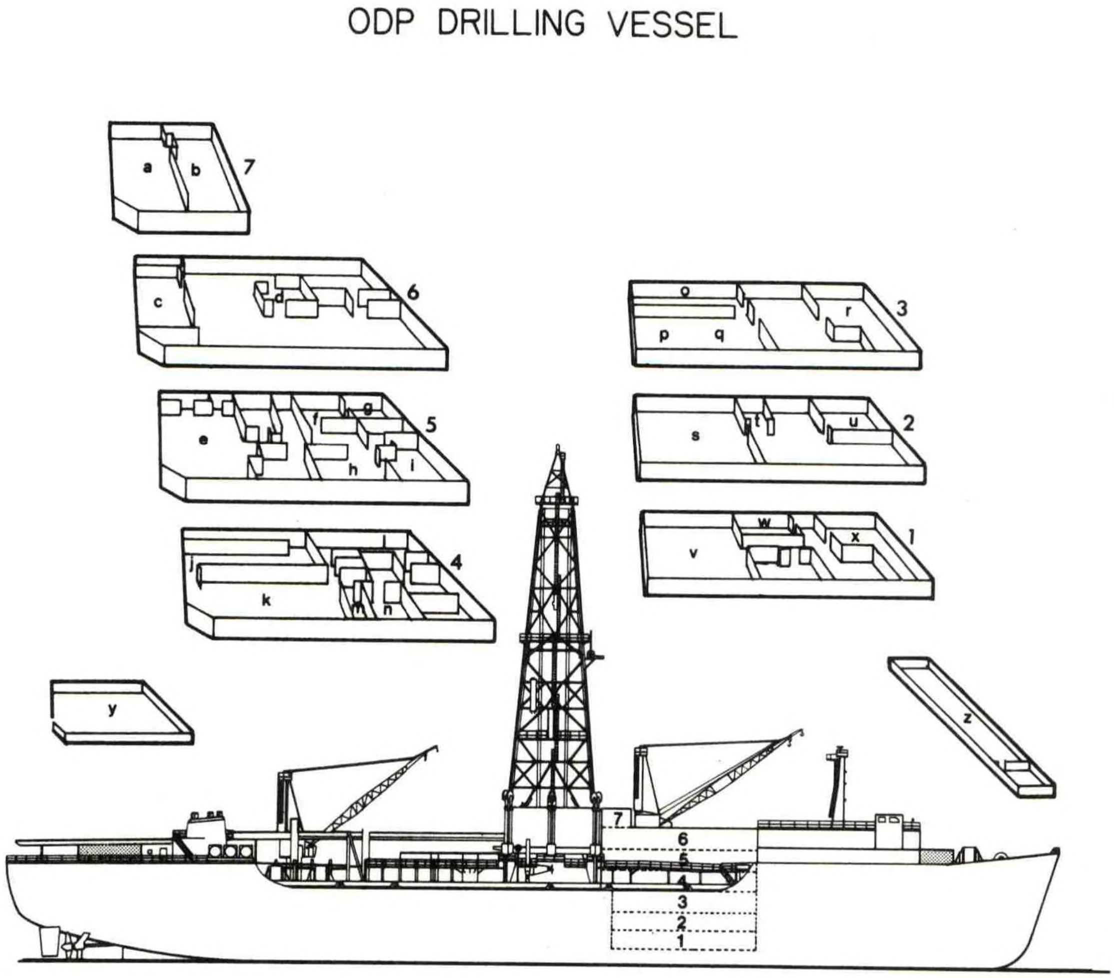

Figure 2. Scientific work spaces aboard the JOIDES RESOLUTION (SEDCO/BP 471).

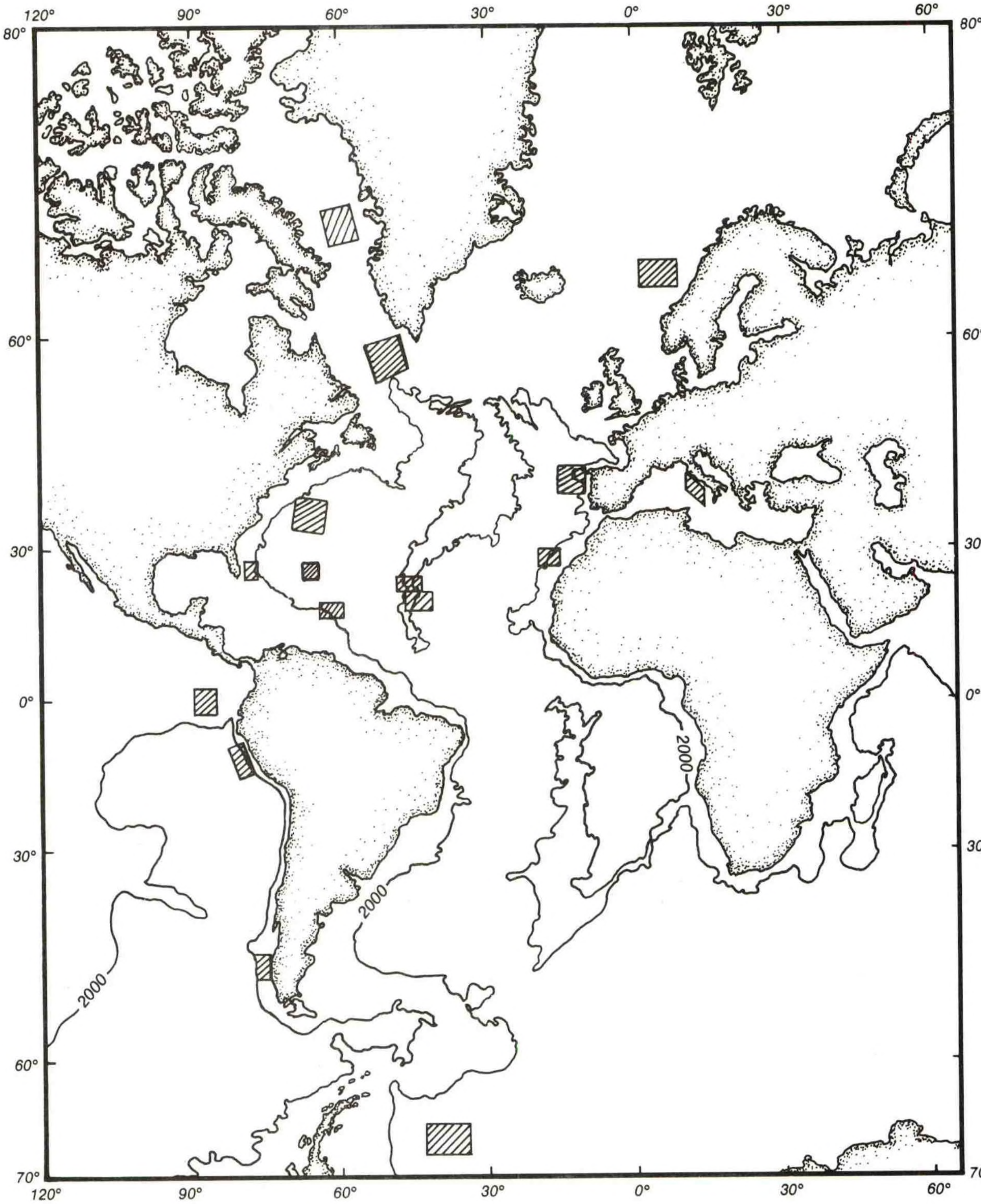

Figure 3. Candidate drillsite areas for the first two years of the Ocean Drilling Program (January 1985 - January 1987).

Developement of Wave Power Extraction System with Vertical Breakwaters

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Abstract

A wave power extraction system is under developement at the Port and Harbour Research Institute. The extractor is a pneumatic type wave power converter to be fitted to a vertical breakwater. The power conversion from waves to air flow by the extraction system was investigated theoretically and experimentally. The stability of the breakwater against storm waves was also studied. The focus of the research is now on the developement of turbine-generator system. The research project was started in the fiscal 1982 and will be continued until the fiscal 1986.

Introduction

Among various ocean energy resources, wave power is the most readily-available and plentiful resource. The total amount of wave power is estimated at 2.7×10^{9} kW in the world. Japan is one of the countries which are rich in the wave power resource. Figure 1 shows the geographical variation of wave power around Japanese islands. The figure was prepared by Tabata et al.(1) from the four-year data of 17 wave observation stations which belong to the Bureau of Ports and Harbours, Ministry of Transport. The total amount of the wave power in Japan is $3\ 1 \times 10^{6}$ kW which is almost one third of the amount of electricity used in Japan. The average value of the wave power is 6 kW/m per unit length of the surrounding lines of 5,200 km in the figure.

A number of wave power extracting mechanisms (2) have been invented and tested in many countries. In the U.K., which is also rich in wave power resource, several devices such as "Salter's Duck", "Oscillating Cylinder", "Flexible Bag", and "NEL Breakwater" are about ready to be put on full-scale sea trials. The "Kaimei" of the Japan Marine Science and Technology Center has made two field experiments and is now on the second stage of its developement. Several other institutions in Japan are also developing their own devices. At the Port and Harbour Research Institute a five-year special research project was started in 1982 to develope the technology for utilizing the wave power. The outline and the progress of the project are introduced in the present report.

Concept of Wave Power Extraction System

A vertical breakwater illustrated in Fig.2 is now under developement at the Port and Harbour Research Institute. This breakwater has a so-called oscillating-water-column (abbreviated as O.W.C. hereinafter) type of wave power extractor, which is attached to the front of the ordinary concrete caisson. The O.W.C. type is one of very promising devices for wave power extraction. The device is essentially a caisson with a large submerged opening at the front and a small nozzle at the ceiling. The caisson is rested on a sea bottom. An air turbine with an electric generator is connected to the nozzle.

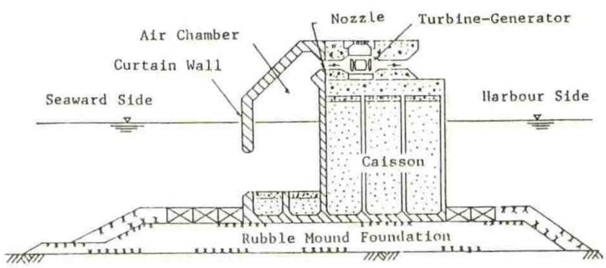

Fig.2 Conceptual Figure of a Vertical Breakwater with Wave Power Extraction

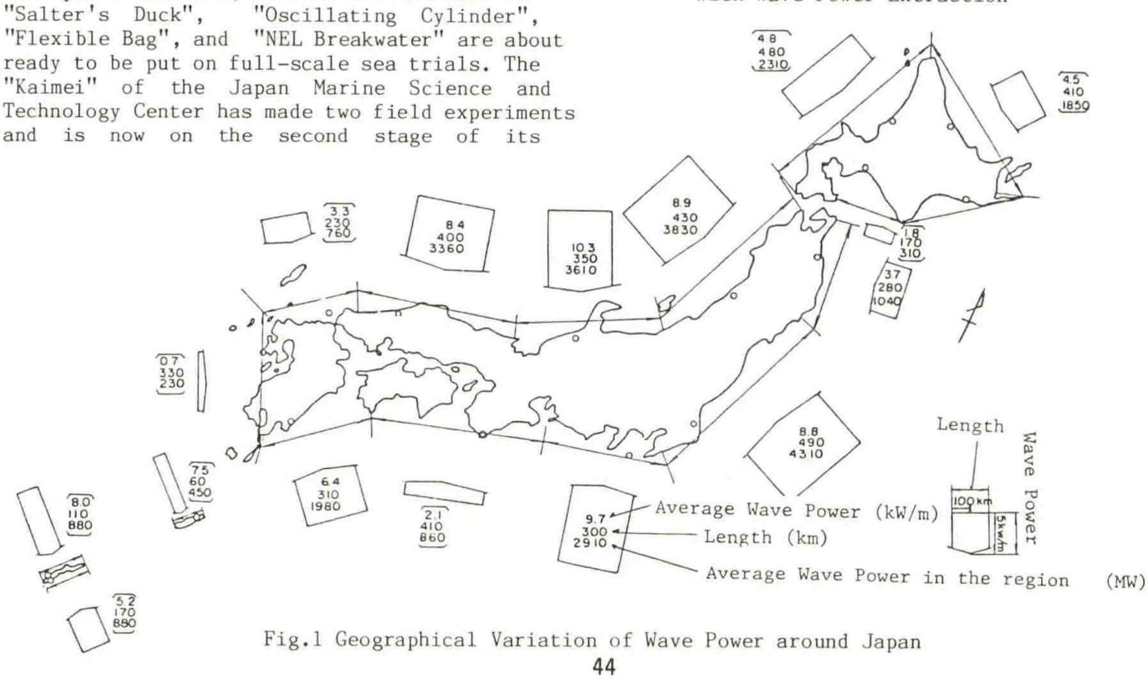

Fig.1 Geographical Variation of Wave Power around Japan

The water column within the lower half of the caisson is caused to oscillate vertically by incident waves through the opening, and it induces the compression and expansion of air mass within the upper half (air chamber) of the caisson. The air motion generates the high-velocity flow through the nozzle, which activates the air turbine and generates electricity.

The O.W.C. type wave power extractor can be quite easily fitted to a vertical breakwater, because the latter is mostly built with a large concrete caisson rested on a rubble mound foundation. Some of vertical breakwaters already have perforations and slits in the front walls to dissipate incident wave energy and to reduce wave reflection. A combination of the O.W.C. type wave power extractor and the vertical breakwater is also attractive from the viewpoint of economical feasibility of wave power extraction, because the construction cost of the total system can be jointly borned by the accounts for power generation and harbour protection. Japan has about one thousand commercial ports along her coastline, and the total length of the breakwaters amounts to nearly 800 km with new addition of about 20 km every year. Most of these breakwaters are built with concrete caissons on rubble foundations. Therefore the possibility is high for the adoption of wave power extracting caissons as breakwaters. High level of already accumulated technology for the construction of vertical breakwaters in Japan also encourages the developement of the wave power extracting caisson.

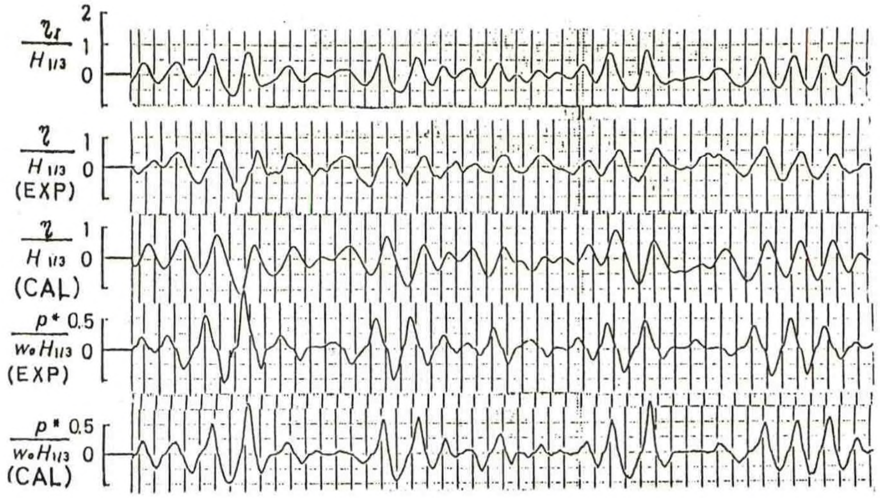

Fig.3 Time Variation of the Response in the Extractor to a Train of Irregular Waves

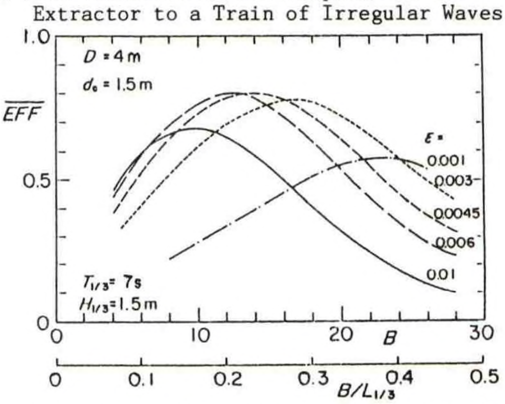

Fig.4 Variation of Efficiency by the Width B

Outline of the Research Project

The project consists of the following three major research subjects :

1) the power conversion efficiency from waves to air flow
2) the power conversion efficiency of the total system including an air turbine and a generator
3) the stability of caisson against storm waves.

Research efforts for the first two years were on the subjects of the power conversion efficiency from waves to air flow and the stability of caisson against storm waves. The studies on the two subjects will be continued in the following years. However, the focus of the research would be placed on the power conversion efficiency of the total system in the following years.

Study on the Power Conversion Efficiency from Waves to Air Flow

A theory based on thermodynamics was derived to describe the response of air mass and the conversion efficiency of the extractor for given wave conditions (3). The validity of the theory was confirmed by a series of experiments. The theory was then extended so that it can include the irregularity of real seas in the analysis (5). The validity of the extended theory was also confirmed by another series of experiments. The theory developed here deals with a extractor having an air nozzle alone without an air turbine. Figure 3 shows an example of the time variations of the water surface elevation of incident waves η_I, the water surface elevation η in the extractor and the air pressure p^*. Both the measured variations and the variations calculated by the theory with the measured incident wave profile are shown in the figure. The theory provides not only the conversion efficiency but also the time-varying response in the extractor.

Figure 4 shows the variation of conversion efficiency of an extractor against the variation of the air chamber width B. The calculation was made for the irregular waves of the significant wave period $T_{1/3}$ = 7s and the height $H_{1/3}$ = 1.5m. The height of the extractor above the still water level is 4 m and the depth of the front wall from the still water level is 1.5 m. The opening ratio ε is defined as the area ratio of the opening area of the nozzle to the horizontal area at the still water level. For this wave condition the conversion efficiency is estimated to be larger than 80 % if B = 12m, and the efficiency is about 60 % even if B = 6m.

A new series of experiments are being prepared to examine the effect of wave direction on the efficiency. The experiments will be conducted in a basin with wave makers which generate not only uni-directional random waves but also random waves with directional spectrum. Several minor changes in the shape of the extractor may increase the efficiency. This will be investigated experimentally in the following fiscal years.

Study on Power Conversion by an Air Turbine and a Generator

The efficiency of the conversion from the air power to turbine power of wave power extractors is not high in general, because the air flow is always oscillating and fluctuating. Conventional turbines to be used for wave power extractors usually require complicated valve systems to rectify the air flow direction. However, Wells invented a novel turbine which can produce rotational power of uni-direction without a valve system even when the air flow reverses its direction. The turbine has several aerofoils around a rotor hub as shown in Fig.5. When the air flow changes the direction from upward to downward, the axial component of the lift force reverses the direction from upward to downward. However, the tangential component of the lift force is always in the same direction as the rotational direction. Because this turbine has the relatively high conversion efficiency despite of its simple mechanism, it is selected as the air turbine of the present extracting system of wave power.

Fundamental characteristics of the various types of Wells turbines under steady air flow were already investigated by several researchers. Figure 6 shows an example of variation (6) in the torque coefficient Ct and the pressure-drop coefficient ψ against the attaking angle α. The attaking angle is defined as

$$\tan \alpha = w / u ,$$

where w is the air flow velocity and u is the speed of rotation at the tip of the aerofoil. The term σ is the solidity, which is the ratio of the total aerofoil width to the circumferential length at the tip. The conversion efficiency is also shown in the figure. The turbine should have high efficiency for the wide range of the air flow velocity, i.e. the attacking angle.

A series of experiments were conducted to investigate the interaction between an air turbine and wave-generated air flow. The results are being analyzed. In the analysis a mathematical model is presented which gives the time variation of turbine torque under a train of irregular waves. The model is essentially another extension of the theory on the conversion of wave power into air power and includes the characteristics of the torque and pressure-drop of the turbine such as shown in Fig.6. The experiments will be followed by another series of model experiments with a large scale model which comprises an air turbine and a generator. The optimum design of the total system of the wave power extraction will be discussed with the experimental results. The devices to protect the turbine and generator from heavy storm waves will be tested in the latter part of the experiments.

Study on Stability of Caisson against Storm Waves

The characteristics of the wave forces on the wave power extracting caisson were studied

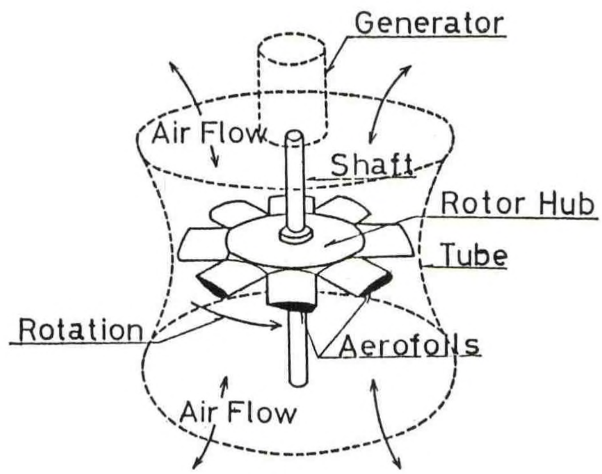

Fig.5 Schematic Diagram of Wells Turbine

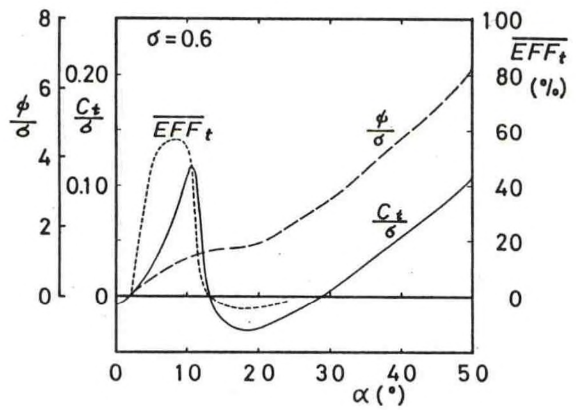

Fig.6 Characteristic Curves of Wells Turbine

experimentally (4). It was found that the caisson receives the wave forces smaller than those on the conventional breakwater caisson and that the stability of this type of caisson against wave forces is almost equivalent to that of a well-designed perforated-wall caisson. The wave force on the caisson can be calculated by utilizing Goda's formula (7) for caisson breakwaters. It was also found that a bypass opening is necessary when the turbine opening is shut down to protect the turbine and generator from strom waves. This is because the wave force increase significantly when all openings are closed. The opening ratio of the bypass opening should be equivalent to that of turbine nozzle because the water mass might hit the ceiling of the extractor from inside if the opening is too large.

The effects of wave direction on wave forces will be also studied simultaneoustly when the experiments in a basin are conducted. The effects of minor changes in the caisson shapes on wave forces will be studies in the following fiscal years.

Illustrative Calculation for a Prototype

A cross section of the vertical breakwater with wave power extractor is designed here to illustrate an overall idea of the prototype, although the design is very preliminary. The depth of the location is 19.1m and the design wave height and period are H = 14.55m ($H_{1/3}$ = 8.1m) and $T_{1/3}$ = 10s at the high water level +1.4m. The shape of the caisson is the same as shown in Fig.2. The sizes of caisson are listed in Table 1. The total width of the caisson is 23m and the height is 8m above the still water level. The width B of the extractor is 8m.

Figure 7 shows the cumulative density function (dash line) of wave power measured near Kashima Port for one year of 1981. The solid line in the figure shows the wave energy below a certain level of wave power in the year. The observed significant wave height ranged from 0.19 to 5.92 m , and the average significant wave height and period were 1.32 m and 7.8s. The total wave energy for one year was 69,800 kWh/m and the average wave power was about 8 kW/m. One can read from the figure that the wave energy for the wave power less than 8 kW/m is about 30 % of the total wave energy, whereas the cumulative frequency is 63 %. The cumulative density function of air power calculated by the theory is also shown by the dotted line in the figure. The dash-dott line indicates the air energy in the year below a certain level of air power. The total air energy is 37,300 kWh/m which is 54 % of the total wave energy. The average air power is 4.3 kW/m.

The following assumptions are made to calculate the total electric energy:

1) The length of the caisson is 20m and is devided into two parts, each of which has one turbine-generator system. The capacity of the generator is 40 kW, i.e. 4 kW/m.
2) The efficiency of the turbine-generator system is 60 % which is rather an optimistic value at this stage.
3) The allowable air power, therefore, is less than 6.7 kW/m and when the air power exceeds the limit the excess part of air power is removed through a bypass opening.
4) The generator stay stopped when the air power is less than 0.5 kW/m.

As the result, the total electric energy in a year will be 17,700 kWh/m. The average electric power is 2 kW/m which is 50 % of the generator capacity.

Use of the Generated Electricity

Electric power generated by the extractors can be used for many purposes, such as melting of the snow, production of pure water from salt water and purification of polluted sea water in harbours. Because the rate of production of electricity by the extractors varies according to the wave conditions, use of wave power will be limited to those which need electricity not steadily. The limitation can hopefully be removed by a electric device which can store a large amount of electricity economically. The cost of produced electricity by means of the vertical breakwater with wave power extractor is expected to be not more than that of elctricity generated by oil fuel, if only the additional cost for the part of wave power extractor is taken into account.

Table 1 Seizes of the Caisson

Total width of Caisson	23 m
Width of extractor	8 m
Total Height of Caisson	22 m
Height above Still Water Level	8 m
Length of Caisson	20 m
Weight of Caisson in Open Air	800 tf/m
Buoyancy of Caisson	282 tf/m
Thickness of Rubble Mound	5.1 m

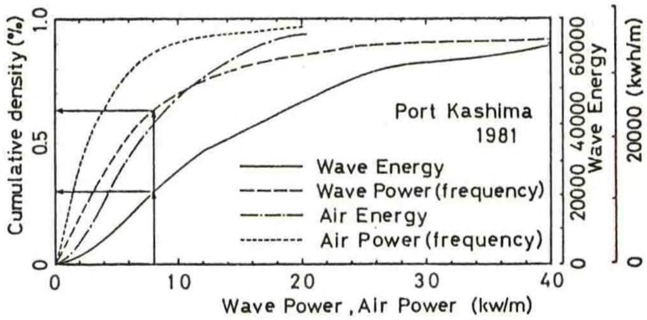

Fig.7 Wave Power and Air Power

The five-year project would be followed by field experiments which will give us many vital informations including the cost of the electricity.

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TECHNOLOGY TRENDS FOR U.S. DEEPWATER AND ARCTIC OFFSHORE OIL AND GAS RESOURCE DEVELOPMENT

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ABSTRACT

The technology for oil and gas resource development in deepwater and Arctic offshore areas exists. Industry has demonstrated the capability to safely drill in 7000 feet of water. The record for deepwater production is 1025 feet, limited only by lack of commercial discoveries. Experience derived from numerous installations in shallower water coupled with extensive research provide a solid basis for safely employing novel production systems in water depths well beyond 1000 feet. In the Arctic, proven technology and capability is available to proceed with operations in water as deep as 650 feet in the Southern Bering Sea, and to about 200 feet in the more severely ice-covered areas of the Northern Bering, Chukchi and Beaufort Seas.

DEEPWATER TECHNOLOGY

As exploration for oil and gas progressed from marshlands out to 7000 feet of water a family of mobile drilling rigs, shown in Figure 1, were developed. Today there are approximately 733 of these units (28 submersibles, 446 jack-ups, 56 drillships, 32 barges and 171 semi-submersibles) available of which 88% are in operations around the world. Forty-four rigs are capable of drilling in at least 2000 feet of water. Figure 2 shows the drilling water depth records for the last several years culminating in the current record of 6952 feet achieved off the U.S. east coast in 1984.

The special features of deepwater dynamically positioned drillships are shown in Figure 3. The blowout preventer stack and marine riser are used to control the flow of drilling fluids returning from the bottom of the hole. The lower marine riser package provides for disconnecting the riser from the BOP stack. Tensioners and buoyancy distributed along the riser support the weight of the riser. Flex and slip joints accomodate riser movement due to rig motions. The dynamic positioning system uses an onboard computer which receives acoustic signals from seafloor beacons through hydrophones. Using these signals, the computer determines the position of the ship in relation to the subsea wellhead. Power is directed to the thrusters to maintain ship position against the forces of winds, waves and currents.

Although the industry's capability to drill exploratory wells in 7000 feet of water has been proven, deepwater production system experience has been limited to about 1000 feet by the lack of commercial discoveries in deeper water. Both platforms and subsea systems can be used to develop deepwater fields. Over the last several years the petroleum industry has invested millions of dollars in designing equipment, developing analytical tools, performing model tests and conducting full scale field tests in preparation for producing oil and gas in great water depths.

Nearly all offshore fields have been developed with fixed leg platforms. Figure 4 shows how fixed leg platforms have evolved to meet the needs of United States deepwater locations. Shell's Cognac platform in the Gulf of Mexico holds the current U.S. and world water depth record of 1,025 feet. The economic water depth limit for fixed leg structures is expected to be about 1500' in the Gulf of Mexico due to the very large amount of steel required and limitations of fabrication and installation methods.

Several deepwater field development options with their probable water depth ranges in the Gulf of Mexico are shown in Figure 5. The guyed tower is a tall, slender structure that requires less steel than a fixed leg platform. Guy lines are used to hold the tower in its vertical configuration. Exxon's Lena guyed tower was installed in 1000 feet of water in the Gulf of Mexico in 1983. The buoyant tower uses buoyancy chambers near the surface rather than guy lines to maintain the tower in a vertical position. This type of structure has been used for tanker loading in 500 feet of water in the North Sea. The tension leg platform is a large floating platform, similar to a semi-submersible drilling rig, which is connected to the sea floor by vertical tension members. Conoco's Hutton tension leg platform was installed in 1984 in 485 feet of water in the North Sea.

Relative cost trends versus water depth for fixed leg platforms, guyed/buoyant towers and tension leg platforms are shown in Figure 6. All three concepts offer the important advantages of drilling, completing, producing and maintaining wells in a conventional manner from the platform deck. These and other innovative platform concepts being studied represent what might be termed "new" deepwater technology. They certainly employ the most advanced technology for offshore structures; for example, sophisticated wave models, state-of-the-art dynamic structural analyses, and finite element analyses of critical components. But their designs have also evolved from years of experience with these same fundamental technologies employed in fixed platforms, ships and sem-submersibles.

The other major type of deepwater production technology involves subsea systems where the wells are drilled from a floating rig and subsea trees are installed on the sea floor. Production from the subsea wells can be handled on any of the structures shown in Figure 5. The Shell/Esso Cormorant underwater manifold system installed in 1982 in the North Sea and currently handling 30,000 B/D production from three sea floor wells is shown in Figure 7. Worldwide, about 300 wells have been completed on the sea floor since the first remote subsea completion in the open sea was made by Shell in the Gulf of Mexico in 1960. Nearly all produce through flowlines to nearby platforms. The current water depth record for subsea wells is 1007 feet offshore Brazil. A tree has been built and is scheduled for installation in 2500 feet of water offshore Spain in 1985. Designs have recently been completed for subsea well systems in 7500 feet of water.

In recent years several systems, using subsea wells producing to floating facilities, have been installed which offer potential for application in deepwater. Experience gained from numerous installations clearly indicates that subsea wells and floating production systems can be installed and operated in a safe manner. Although these actual systems are in relatively shallow water, considerable design and development work has been done to extend the concepts to deeper water. Technical problem areas to be resolved by further development work are primarily aimed at increasing cost effectiveness by hardware designed to provide ease of installation, highly reliable operations and efficient maintenance and repair.

Since subsea installations will eventually be made in water depths which exceed the range where wet divers can work effectively, the system components will be maintained and repaired by unmanned remote controlled vehicles, or workers in dry, one-atmosphere vehicles similar to those in Figure 8, or by recovery to the surface. Many of the subsea wells and manifolds installed to date have utilized variations of these repair methods.

Transportation of production from deepwater fields will be similar to that from existing shallow water fields. Depending on field location and other factors, gas production will be transported by pipeline to a gas gathering system or re-injected into the producing formation. Oil production will be transported by pipeline to an offshore gathering system, shore terminal, or to a platform or tanker loading facility in shallow water. Figure 9 shows several pipelaying vessels that can be used in deepwater. A semi-submersible laybarge has installed a 20 inch pipeline in a record water depth of 2,000 feet in the Mediterranean Sea. Studies have shown no technical barriers to pipeline installation in water depths of 8000 feet and more.

Over the past several years many equipment designs, model studies and offshore installations have been made by various companies throughout the world. The net result of all of this development and installation work is that the offshore petroleum industry is confident that no technical barriers exist for safely exploring, developing and producing oil and gas fields in water depths out to 7000 feet and beyond.

ARCTIC OFFSHORE TECHNOLOGY

Industry has been actively working in the Arctic waters of Alaska and Canada for a number of years. Alaskan activity, which had its start in Cook Inlet in the 1960's, was primarily in the Beaufort Sea in the 1970's. A number of milestones have occurred in exploration and production in Arctic waters, as shown in Figure 10. In 1964, the first of many ice-resistant production platforms was installed in 90 feet of water in Cook Inlet, Alaska. In 1973, the first exploration well in the Canadian Beaufort Sea was drilled from an artificial island. The first exploratory well was drilled from a floating ice platform in 1974 and the first Arctic subsea completion was installed from an ice platform in 1978. A new type of artificial island -- a caisson-retained island -- was installed in 1981.

During the 1980's, Arctic exploration and development activity will increase as a result of scheduled state and federal offshore sales. Figure 11 shows the major geological basins and the probable type of offshore structures that will be used for drilling and producing operations. Gravel islands are expected to be economical solutions for water depths of 60 to 100 feet in the Beaufort, Chukchi, Hope, and Norton Basins. Between 100 and 200 feet in these basins, ice-resistant fixed platforms - such as steel or concrete cones - will be used. In the Bering Sea, conventional jacket structures or ice-resistant concrete or steel towers may be used. In water depths of more than 650 feet, and possibly in some shallower locations, compliant structures and subsea completions, such as those discussed earlier, may be used.

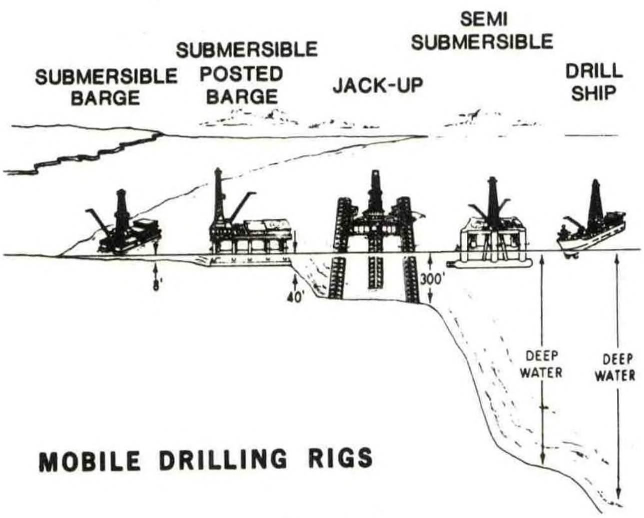
Transportation will usually be by pipeline to shore, then to tankers or existing pipelines. An offshore pipeline depth limitation for ice covered Arctic regions is not presently assessable and is the subject of intensive industry research and development programs.

Otherwise, the pipeline systems capability discussed earlier will apply in the Arctic. Offshore storage and loading facilities may be used in deepwater and remote locations.

Arctic offshore research and development has been underway for more than a decade. Ice research has concentrated on ice strength and stress-strain behavior, ice feature occurrence, ice movement, and ice structure inter-action. Field programs to measure oceanographic parameters in the Arctic offshore have been underway for a number of years and will continue. Work will continue in evaluating the environmental exposure (forces) and platform concepts required to extend Arctic offshore capability.

This has been a brief review of the technology trends for U.S. deepwater and Arctic offshore oil and gas resource development. In closing, I would like to make these final points:

- The oil industry has historically developed the required technology to meet the needs that have arisen from lease offerings and hydrocarbon discoveries.
- Because of extensive research and actual experience with key equipment systems over the past 25 years, industry has the basic technology for drilling and production in deepwater and Arctic offshore areas.
- Opportunities and economics, not technology, will limit future developments.



MOBILE DRILLING RIGS

Figure 1

WATER DEPTH RECORDS FOR DRILLING

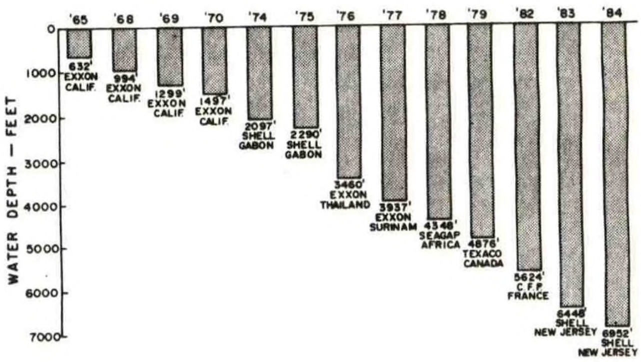
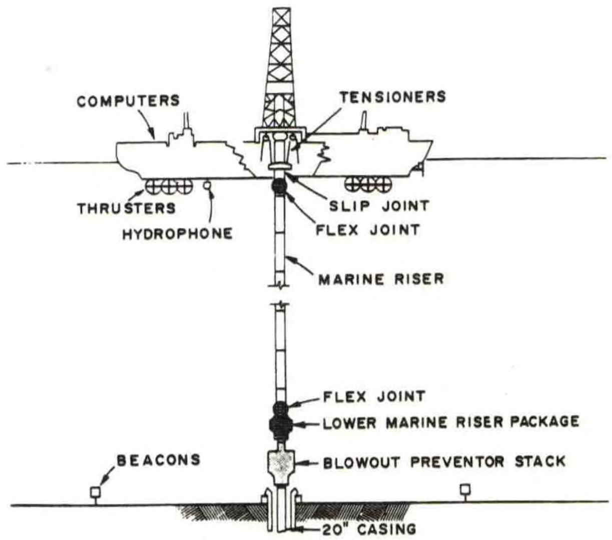
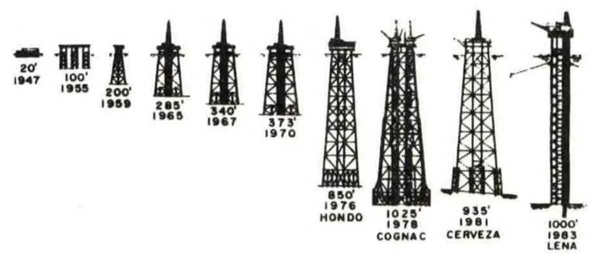


Figure 2



DYNAMICALLY POSITIONED DRILLING RIG

Figure 3



U.S. PLATFORM MILESTONES

Figure 4

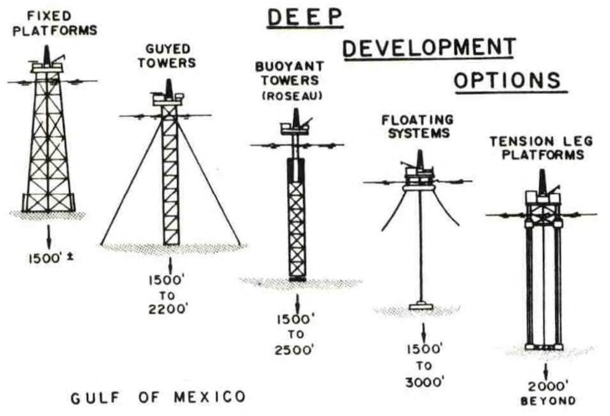


Figure 5

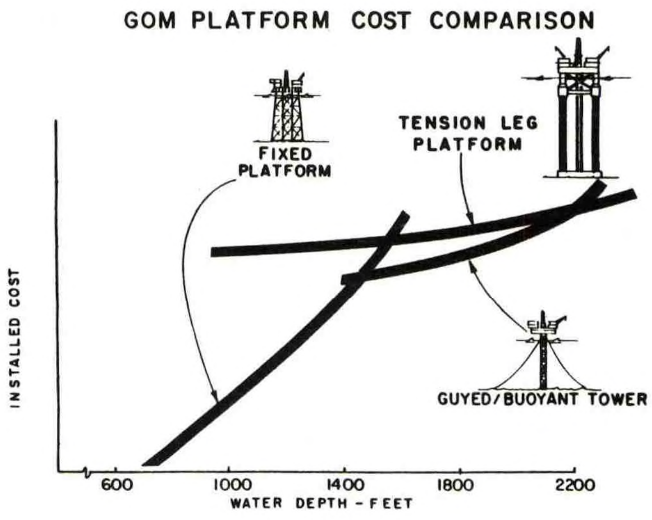


Figure 6

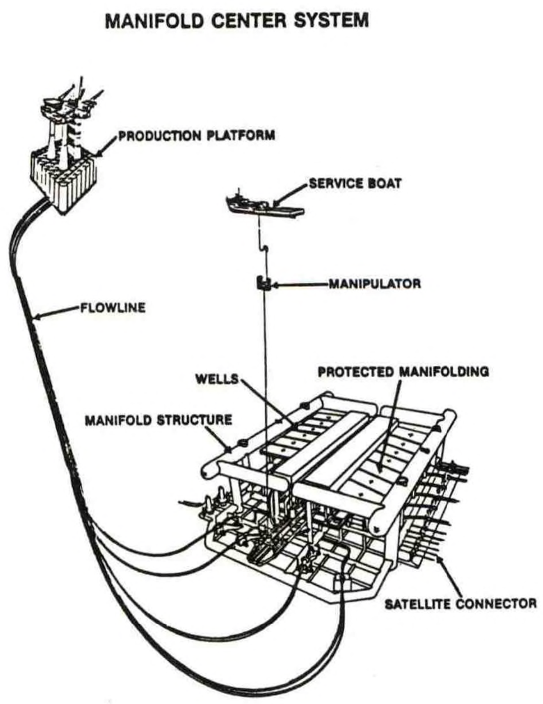


Figure 7

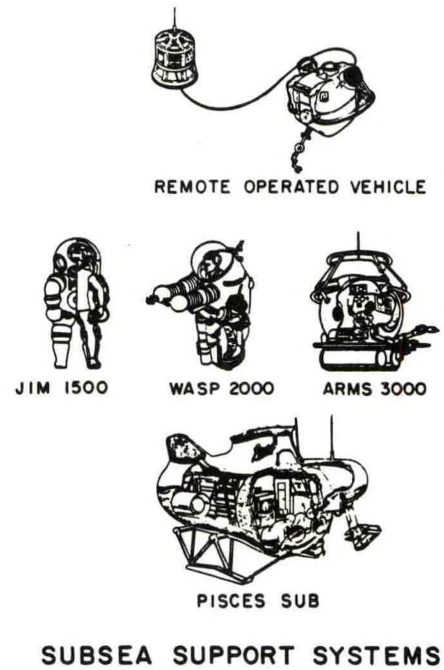
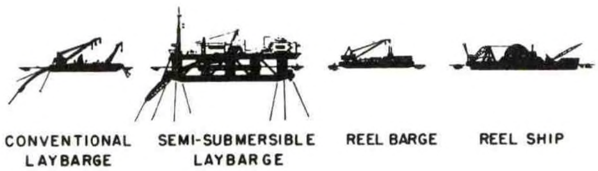
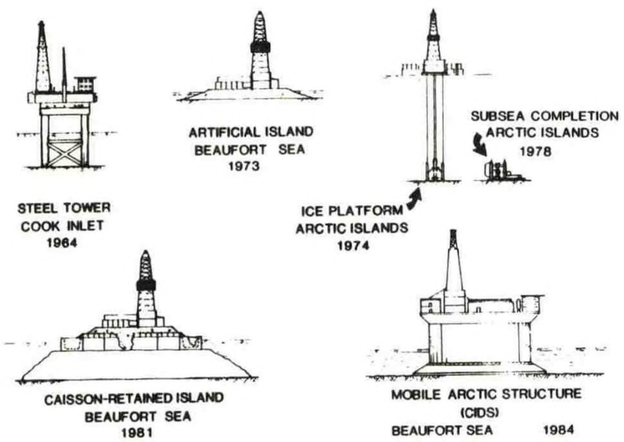


Figure 8



PIPELAYING VESSELS

Figure 9



ARCTIC DEVELOPMENT MILESTONES

Figure 10

ALASKAN ARCTIC BASINS & STRUCTURES

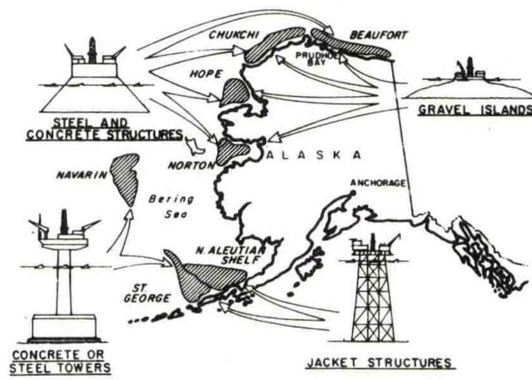


Figure 11

Recent Developments in Technology for Oil and Gas Drilling and Producing Operations in Record-Setting Water Depths

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Minerals Management Service

ABSTRACT

The U.S. Department of the Interior is now providing the opportunity for the oil and gas industry to select and purchase drilling and producing rights on acreage of their choice on the U.S. Outer Continental Shelf (OCS). As a result, several areas of interest underlying deep waters have been leased. Recent drilling activities and the discovery of oil and gas in deepwater areas of the U.S. OCS have provided an impetus for the development of technology and innovative design both for drilling operations and the implacement of marine structures.

DEEPWATER DRILLING

Shell Offshore, Inc., recently drilled four exploratory wells in water depths ranging from 5,000 to 7,000 feet on the Atlantic OCS. The technologies used to successfully operate in these record water depths are among the most sophisticated in the world. Previous to Shell's program, the maximum demonstrated capacity of any exploration facility was 6,000 feet of water. However, through changes in geohazards survey equipment and refurbishment of Sonat Offshore Drilling, Inc.'s, drillship, Discoverer Seven Seas, this limit has been extended to 7,500 feet. Several other technical modifications to the drillship enhance aspects of safety, well-control, and formation evaluation in deep water.

Technical developments responsible for enhanced data quality from deepwater geohazards surveys include design of a deep-tow vehicle with associated electronics, specialized towing requirements, improved navigation systems which allow for the precise positioning of the deep-tow system, and a multiplex system which provides data acquisition and electronics control over long cable lengths.

The most outstanding change to accommodate drilling in 7,500 feet of water is the introduction of a marine riser system which uses two complete risers. The primary riser is entirely new and utilizes 5,500 feet of syntactic foam floatation riser with 2,000 feet of air can riser. The backup riser consists of Sonat's previous 6,000-foot air can riser and 1,500 feet of syntactic foam.

Syntactic foam was chosen as a floatation riser because it is easier to use than air cans. There is no need to provide positive buoyancy by filling the joints with air during deployment. Air cans were not completely eliminated so that buoyancy could be varied for different operating conditions. Additionally, a new system for suspending the entire string of riser from the moonpool area was developed especially for this program.

Associated with the marine riser are components that add to the efficiency of operating in ultra-deep water. A backup emergency disconnect is installed above the primary disconnect which is located within the lower marine riser package. An instrumented riser joint (IRJ) just above the backup disconnect provides direct information on ball joint angle, riser tension, pressure, and temperature. Instrumentation is also available on the upper 44 degree flex joint to provide readings of angle and tension. A riser fill valve at 2,000 feet below sea level operates both manually and on signal from the IRJ to prevent riser collapse in the event of complete loss of drilling fluids. Riser tensioners now provide over 1.2 million pounds of pull and are equipped with a riser recoil protection package. Finally, the telescopic joint can stroke to 55 feet and was strengthened for increased bending and tension.

Another feature of the hydraulic controls is the ability to program disconnect functions. Activation of one button results in several sequential operations occurring to safely secure the well. This includes the closing and blocking of such valves as the annular preventer, rams, wedge locks, and choke- and kill-line valves. The sequence operates automatically in less than 30 seconds and reduces the opportunity for human error and hesitation. To back up the already redundant blowout preventer controls, an acoustic control system can be used to close all rams and unlock the riser connector and wellhead connector. These acoustic controls are used if all hydraulic lines on the riser become severed or malfunction. This system is designed for water depths to 8,000 feet.

Various aspects of the well-control equipment were changed to adequately drill in these great water depths. On the blowout preventer stack, four tension rods extend from the wellhead connector to anchoring sleeves on the lower annular preventer. These supports add strength to the stack to prevent failure of any connection from the severe stresses caused by bending, tension, and pressure. In order to avoid the costly and time-consuming operation of pulling the riser, redundancy of several components are present. Variable bore rams for 2 7/8-inch to 5-inch drill pipe are installed as the lower-most ram. Two blind shear rams are in the upper cavities. Also, two 5,000-pounds per square inch (psi) annular preventers are used above this 10,000-psi stack.

For underwater support to the deepwater operations, Shell uses the Dual Hydra 2500 System developed by Solus Ocean Systems, Inc. This consists of two remotely operated vehicles and a cage for deployment. Power and operating signals are sent to the cage by means of an umbilical connection. The cage transmits signals to the vehicle through a 400-foot tether. The vehicles were used for site surveys, reentry of pipe, connection of riser and stack, recovery of equipment, cleaning debris from the wellhead area, replacement of equipment, and cutting cable or rope. The system provided a capability for inplace maintenance of equipment which resulted in not having to pull the blowout preventer assembly in more than one case. Through its use and its remotely operated mechanical capability, a ring in the blowout preventer system was replaced with the stack in place. These vehicles have extended diving-support capability to more than double the previous depth.

DEEPWATER PRODUCTION

Although the Shell wells were not successful in discovering hydrocarbon resources, other deepwater oil and gas exploration on the U.S. OCS has enjoyed some measure of success over the last several years. A recent surge in activity in the Gulf of Mexico has led to a number of hydrocarbon discoveries in water depths exceeding 800 feet. This surge has been spurred in part by the introduction of the areawide lease sale concept which has made available for exploration huge amounts of offshore acreage. It is also caused by the deepwater success stories of companies such as Shell, Exxon, Union, and others who, in the mid- to late 1970s, discovered oil and gas deposits on deepwater California and Gulf of Mexico tracts. These companies developed the necessary technology to design, fabricate, and install platforms of mammoth proportions in order to produce those deposits. Such structures as Shell's Cognac, Exxon's Hondo and Lena (guyed tower), and Union's Cerveza and Cerveza Ligera proved to industry that the problems of deepwater oil and gas production could be technically and economically overcome. Figure 1 provides a summary of all platforms installed to date or planned for installation in the near future in water depths exceeding 800 feet. Exxon's Hondo and Shell's Cognac jackets were fabricated in two and three pieces respectively, then joined together in the marine environment. Union, however, fabricated and installed their jackets in one piece, thereby realizing substantial savings in the costs of those structures.

Considering the large number of recent announcements concerning deepwater discoveries, it is logical to expect the rate of deepwater platform installations to increase in the next few years. In fact, some companies have already completed designs for tension-leg platforms (TLP) and others are contemplating the use of floating production systems (converted semisubmersibles). Still others have conventional jacket-type structures on the drawing board. One joint industry project presently underway is looking at the design of such a structure for 1,600 feet of water depth in the Gulf of Mexico. This involves the use of a compliant structure featuring large bouyancy chambers just below the water line to support topside weight. Just a few years ago, such a design would not have been considered economically feasible, even if technically possible. To a large extent, the introduction of the one-piece jacket concept for deepwater structures such as Union's Cerveza platforms has greatly reduced fabrication and installation costs, thereby enabling this design concept to be competitive in ever deeper water.

Figure 2 provides a summary of several recent OCS deepwater discoveries for which further drilling is either planned or underway to determine if the fields are commercial. While such news is certainly encouraging, some of these discoveries will probably not culminate in the installation of a platform. Deepwater production of oil and gas deposits requires enormous financial investments, and the fields produced must therefore contain substantially more hydrocarbon deposits than fields in shallower waters. It has been estimated that a field in 1,200 feet of water must contain 100 million barrels (bbl) of oil equivalent to approximate the development economics of a 20-million bbl field in 300 feet of water. Development costs for the former are on the order of $450 million, $90 million for the latter. Further, it has been estimated that as much as 1 year may be required to determine whether or not a deepwater field is commercial and another 4 years to initiate production. Considering that some estimates of deepwater wildcats to be drilled in the Gulf of Mexico this year are as high as 40, this list of deepwater discoveries is certain to grow.

Once the decision to develop a deepwater field has been made, selection of a particular type of production system is based on several factors. For large fields where the water depth is less than 1,500 or 1,600 feet, one- or two-piece jacket-type structures will probably be the most economical choice for many operators. Further, the experience base for this structural type is large which weighs heavily in its favor with smaller operators. Beyond 1,600-feet water depth, however, the choice of systems narrows to guyed towers to 2,000-feet, TLP to 3,000-feet, or floating production systems to 3,000-feet. For marginal fields, the floating production system will probably be the choice of most operators since it can readily be moved to another location when the field is depleted. For larger fields, this system will also be attractive to operators with limited capital and little or no experience with TLP's and guyed towers since these structures are technically complex and require very large economic investments. As such, their use will probably be limited to the "giant" fields of large operators in water depths exceeding 1,600 feet. However, as experience is gained in the design, construction, and operation of these structures, economics will dictate the type of structures to be considered. Eventually, the use of TLP's and guyed towers is expected to become more widespread.

While the great majority of deepwater discoveries have been in U.S. waters, there have been two such discoveries abroad, both in Norwegian North Sea waters. The most recent of these is a discovery where the water depth is 945 feet. Testing is continuing at that location. Another discovery was made in 1979 in the West Troll field where the water depth is 1,140 feet. For some time now, three different platform designs have been undergoing intensive review, and while no decision has yet been made, it is anticipated that the choice will probably be a Condeep T-300 concrete structure with the skirts extended to a depth of 8 to 10 feet. The long skirts will solve the anticipated soft bottom problem of differential settlement and eliminate the need for base piles. Production of this field will rely heavily on subsea technology because of the large size and shallow depth of the reservoir. It is anticipated that as many as 30 subsea oil and 30 gas wells will be tied into this platform.

Conclusion

The technology for developing and producing oil and gas from reservoirs underlying deep water has been demonstrated. The application of this technology for specific projects will be constrained by the hydrocarbon reserve inventory, costs of development and production, and the world oil prices.

Figure 1

DEEPWATER (≥ 800 FEET) STRUCTURES IN PLACE

OPERATOR	LOCATION	DATE INSTALLED	PLATFORM NAME AND/OR TYPE	WATER DEPTH	NUMBER OF SLOTS
Exxon	Pacific OCS-P 0188	1976	Hondo (Jacket)	842'	28
Shell	GOM OCS-Mississippi Canyon Block 194	1978	Cognac (Jacket)	1,023'	62
Exxon	GOM OCS-Mississippi Canyon Block 280	1983	Lena (Guyed) (Tower)	1,000'	58
Union	GOM OCS-East Breaks Block 159	1982	Cerveza Ligera (Jacket)	924'	21
Union	GOM OCS-East Breaks Block 160	1981	Cerveza (Jacket)	935'	40

DEEPWATER (≥ 800 FEET) STRUCTURES PLANNED OR BEING FABRICATED

OPERATOR	LOCATION	PLATFORM NAME AND/OR TYPE	WATER DEPTH	NUMBER OF SLOTS
Exxon	Pacific OCS-P 0182	Pescado (Jacket)	1,075'	60
Exxon	Pacific OCS-P 0190	Hondo B (Jacket)	1,200'	60
Placid	GOM OCS-Green Canyon Block 29	Not named (Converted semisubmer-sible)	1,650'	24-40
Shell	GOM OCS-Green Canyon Block 65	Bullwinkle (Jacket)	1,350'	40
Conoco	GOM OCS-Green Canyon Block 184	Not named (TLP)	1,800'	30-48
Exxon	GOM OCS-Mississippi Canyon Block 397 (Alabaster)	Not named (Jacket)	600' to 1,100'	20

Figure 2

DISCOVERIES IN 800 FEET OR GREATER WATER DEPTH

(DELINEATION DRILLING PLANNED OR UNDER WAY)

OPERATOR	LOCATION (GULF OF MEXICO)	WATER DEPTH (FEET)
ODECO	Green Canyon Block 21	1,270
Placid	Green Canyon Block 39	2,200
Sohio	Green Canyon Block 60	1,100
Shell	Green Canyon Block 63	1,150
Marathon	Green Canyon Block 110	1,300
Tenneco	Green Canyon Block 136	1,300
Sohio	Mississippi Canyon Block 109	1,100
Sohio	Mississippi Canyon Block 110	1,500
Exxon	Mississippi Canyon Block 354 (Zinc)	1,500

DEVELOPMENT OF WAVE POWER LIGHT BEACON INSTALLED ON SUNKEN ROCK

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INTRODUCTION

The light beacon which is installed on the sunken rock, etc., as navigation aid has great difficulty in securing power supply because of its installing location. It can therefore be said that to utilize wave energy that exists in its surroundings as power source for light beacon is very effective measures.

The research project concerns both with the experimental investigation on the performance of circular air chamber and that of air turbine, which means a technical extension of the light buoy technology which already has been realized as only case successfully utilizing wave energy[3].

This paper deals with the first stage of the investigation, i.e., the power absorbing characteristics of circular air chamber in order to squeeze wave energy efficiently even in the calm or moderate sea state throughout a year.

The circular air chamber is attached around circular base as shown in Fig.1 and is divided into two or four chambers. In the experiment a 1/5 scale model has been used in the Offshore Structure Experimental Basin of Ship Research Institute, and the wave power absorbing efficiencies for each air chamber have been measured for various wave directions, wave periods and heights, water-line levels and so on. As the results, it is clarified that this system can generate sufficient power for use of the light beacon. Furthermore, absorbed wave energy was calculated by use of the equivalent floating body concept and compared with experimental values

EXPERIMENTAL METHOD

DESIGN CONDITIONS OF AIR CHAMBER

Based on wave and tidal observation data in the sea area where the light beacon is to be constructed, the air chamber was designed under the following conditions:

			(Frequency of Occurrence)
Wave height	$H_{1/3}$	0.35 m	50 %
Wave period	$T_{1/3}$	4 sec	
Sea Level	ΔH	+1 ~ -0.6 m	80 %

The necessary wave energy to be absorbed, which is able to produce electric power of 300W for light beacon, on the assumption that the air turbine efficiency is 50% and the generator efficiency 40%, was estimated by the reverse calculation as follows:

$$E_a = 300 / (\eta_{H1/3} \cdot \eta_{\Delta H} \cdot \eta_T \cdot \eta_G) = 3.75 \text{ KW}$$

where,

$\eta_{H1/3}$; 50% (Frequency of occurrence of wave)
$\eta_{\Delta H}$; 80% (Frequency of occurrence of sea level)
η_T ; 50% (Air turbine efficiency)
η_G ; 40% (Generator efficiency)

AIR CHAMBER MODEL

The circular air chamber model is illustrated in Fig.2. The model is constructed by the circular foundation section and the air chamber section located around it. The 1/5 scale model is made of 2.3 and 4.5mm thick steel plates. Part of the top and side of the air chamber section is made of transparent acryl plate so that the behavior of water surface in the air chamber can be visually observed. Also, in order to minimize the consumption of wave energy to be introduced into air chamber, a 16 ϕ round steel bar was welded throughout the circumference at the lower end of the front part of the air chamber.

The air chamber section can be divided into two or four air chamber in the direction of its diameter. Moreover, to change the incident angle of wave against the air chamber, the air chamber section can be rotated to any angle.

The load on the air chamber which takes the place of an air turbine or generator was changed by changing the area of the nozzle on the top of each air chamber. The principal dimensions of the model are as follows:

Outside diameter of air chamber section D_1	: 2.56 m
Inside diameter of air chamber section D_2	: 1.24 m
Height of air chamber	: 0.70 m
Water plane area of air chamber(4 air chamber type)	: 0.985 m^2
Water plane area of air chamber(2 air chamber type)	: 1.970 m^2

The photo of the model is shown in Fig. 3 .

EXPERIMENTAL CONDITIONS

Using the model shown in Fig. 2, experiments were conducted by changing the number of air chamber, the depth of front of air chamber d (change of sea level), the direction of incident wave χ , the ratio of nozzle to water plane area of air chamber R , and so on.

Table 1 Experimental Conditions

Items			Conditions	
Number of air chamber			4	2
Direction of incident wave χ			0° 22.5° 45°	0° 45° 90°
Depth of front of air chamber		d(cm)	12 32 2	
Ratio of nozzle to water plane area in air chamber		R	1/100 1/150 1/270	
Wave	Regular	T (sec)	1.0 1.5 2.0 2.5 3.0	
		H_1 (cm)	5 10	
	Irregular	T_m (sec)	1.2	
		$H_{1/3}$ (cm)	6 11	

Experimental conditions are shown in Table 1 . The direction of incident wave to air chamber is shown in Fig. 4 .

MEASURING ITEMS

Measuring items included incident wave, water level and air pressure in air chamber, etc.

The air pressure was measured by use of a miniature pressure gage on top of air chamber. Also, variation in water level in air chamber was measured with capacitance type average water level gage.

EXPERIMENTAL RESULTS AND CONSIDERATIONS

ABSORBED WAVE ENERGY IN EACH AIR CHAMBER

The absorbed wave energy E_a calculated in terms of the full scale model by Froude's law is shown in Fig. 5 and Fig. 6. In these figures, E_{a1} , E_{a2} , E_{a3} and E_{at} indicate the absorbed wave energy in air chamber No.1, No.2, No.3 and all air chambers respectively. The values correspond to the case where direction of incident wave $\chi = 0°$, the depth of front of air chamber d = 0.6 m, the ratio of nozzle to water plane area R = 1/100 and the height of incident wave H_i = 0.25 and 0.5 m . Also, the air chamber output E_a = 3.75 KW that satisfies the generating output 300 W is indicated in these figures as a target value.

In the 4 air chamber type model, the absorbed wave energy in the air chambers No.2 and No.4 is about 1/2 of that in the air chamber No.1 and that in the air chamber No.3 is about 1/4 . With regard to the 2 air chamber type model, the absorbed wave energy in the air chamber No.2 is about 1/2 of that in the air chamber No.1 .

In either case, when H_i = 0.25 m , the absorbed wave energy fails to reach the target value 3.75 KW . When H_i = 0.5 m, however, it fully satisfies the target value. Also, the total absorbed wave energy is almost similar in both cases even if the number of air chamber is different.

VARIATION OF ABSORBED WAVE ENERGY OWING TO THE DIRECTION OF INCIDENT WAVE

Fig.7 and Fig.8 show the variation of absorbed wave energy of the air chamber No.1 (A.C. No.1) and all air chambers in the 4 and 2 air chamber type full scale models in the case where the direction of incident wave χ is changed. In case of the 4 air chamber type model, there is no major variation of absorbed wave energy from whatever direction wave may come, as shown in Fig.7 . In case of 2 air chamber type model, the total absorbed wave energy undergoes little change as shown in Fig.8 . But, the absorbed wave energy in the air chamber No.1 becomes about 1/2 of the value $\chi = 0°$ when $\chi = 90°$.

VARIATION OF ABSORBED WAVE ENERGY OWING TO THE DEPTH OF FRONT OF AIR CHAMBER

Fig.9 shows the variation of absorbed wave energy in full scal model, corresponding to the variation of the depth of front of air chamber in the 4 air chamber type model. These values are described when H_i = 0.5 m, R = 1/100 and $\chi = 0°$. The absorbed wave energy in the air chamber No.1 is the largest when d = 0.6 m (optimum depth of front of air chamber obtained from the results of two dimensional experiment), while the maximum value of total absorbed wave energy in all air chambers is showing a similar value when d = 0.6 and 1.6 m . When d = 0.1 m, the value is small because the lower end of the front part of the air chamber is exposed to the air. Also, the maximum value at d = 1.6 m is produced on the longer period side than that of others, and this is attributable to that the resonant period of a water column in the air chamber is large.

CALCULATION OF ABSORBED WAVE ENERGY

The absorbed wave energy was calculated by the equivalent floating body concept which is a method of making approximate calculation by replacing a water column in the air chamber with a floating body to be equivalent to it . The heaving motion of the water column in the air chamber is expressed by the following equation.

$$(m+m_z)\ddot{z} + (N+d_o)\dot{z} + \rho g A z = F_z e^{i\omega t}$$

Where, m and m_z are mass and added mass of the equivalent floating body respectively, N is a wave damping coefficient, d_o is a linearized load damping coefficient, A is a water plane area of the equivalent floating body, and F_z is an amplitude of wave exciting force.

The values m_z and N were calculated by the finite element method with respect to the doughnut-shaped floating body having a core in the center as shown in Fig.10 . The nondimensional values of their calculated results are shown in Fig.10 . Also, F_z was obtained by integrating the pressure acting on the bottom surface of the floating body calculated by the finite element method, over the water plane area of each air chamber. Since experimental values of load damping coefficient d_o shows almost constant against a wave period, this linearized value was used for calculation.

The experimental values of absorbed wave energy in the full scale 4 air chamber type model are compared with the calculated value in Fig.11. The tendencies of both values agree very well in each air chamber, though the experimental values are slightly larger than calculated ones in the vicinity of T = 3 and 4 sec. .

Fig.12 shows the values in the 2 air chamber type model, and indicates that the experimental values are larger than calculated ones on the whole, while both agree well qualitatively.

CONCLUSIONS

From the results of experiments, the following can be said with respect to the wave energy absorption characteristics of circular air chamber.

(1) The absorbed wave energy in the air chamber in front of wave is the largest. In the rear air chamber, absorbed wave energy is from about 1/2 to 1/4 of that in the front of air chamber.

(2) The circular air chamber can absorb almost constant wave energy for any wave directions when the energy of all chambers are summarized.

(3) The absorbed wave energy becomes the largest in the depth of front of air chamber d = 0.6 m. Hence, the air chamber must be designed in such a way that the mean water level will come to this position.

(4) The absorbed wave anergy becomes the largest in the ratio of nozzle to water plane area R = 1/100.

(5) The absorbed wave energy in circular air chamber as well as two dimensional air chamber can be calculated by the equivalent floating body concept.

(6) Assuming the total absorbed energy of the air chamber in the design wave ($T_{1/3}$= 4sec., $H_{1/3}$= 0.35 m) from the experimental value, it can be considered that the 4 air chamber type model satisfies output target value 3.75 KW of the absorbed wave energy of the air chamber, while the 2 air chamber type model may have difficulty in reaching the target value in all conditions.

ACKNOWLEDGEMENT

This work was carried out partly with the support of the Grant-in-Aid of Japan Foundation for Ship Building Advancement. The authors acknowledge the favor for this research received from Navigation Aids Department of Maritime Safty Agency and Japan Association for Aids to Navigation, and thank Mr. H.Kagemoto for the assistance of the calculation by Finite Element Method.

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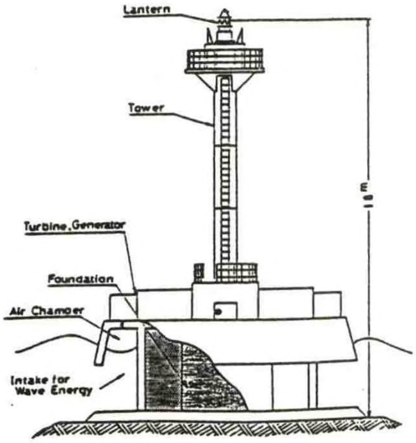

Fig.1 Wave activated generating system for light beacon

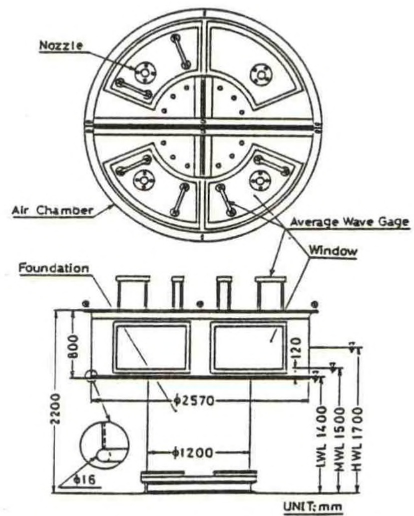

Fig.2 Circular air chamber model

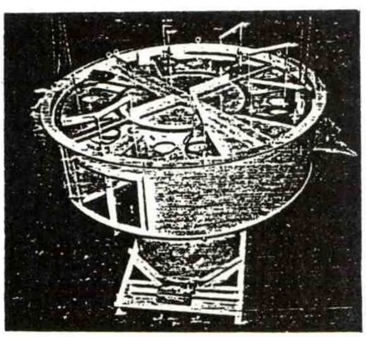
Fig.3 Circular air chamber model

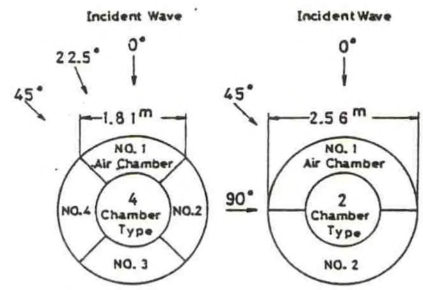

Fig.4 Direction of incident wave

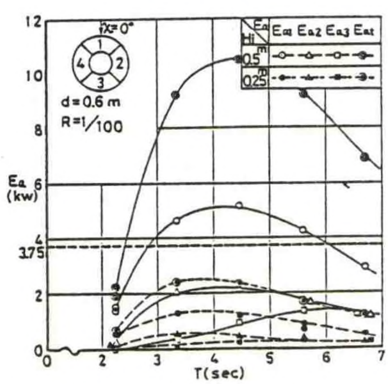

Fig.5 Absorbed wave energy in full scale model

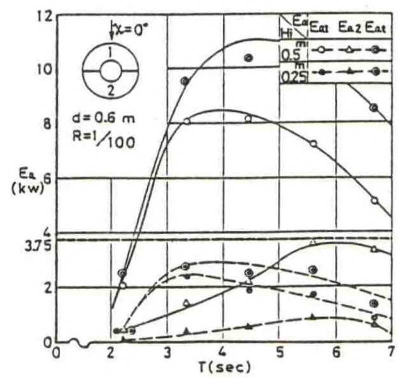

Fig.6 Absorbed wave energy in full scale model

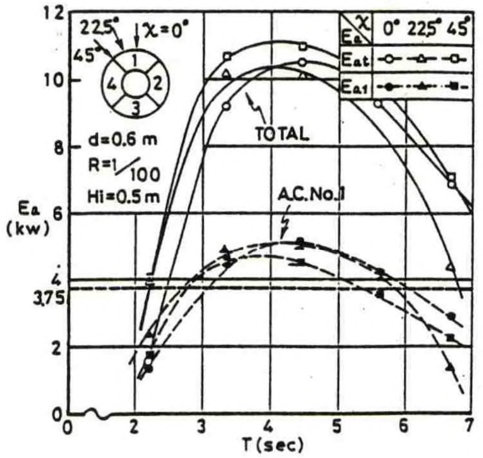

Fig.7 Variation of absorbed wave energy in full scale model owing to direction of incident wave

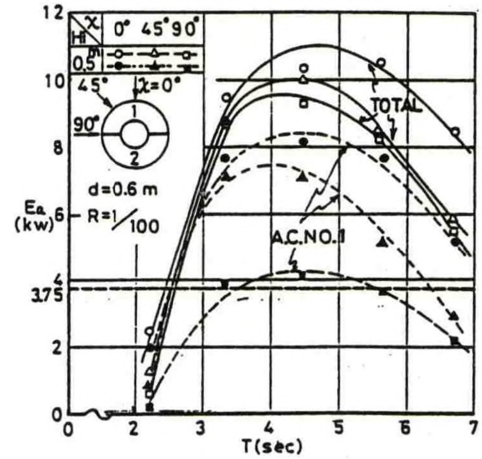

Fig.8 Variation of absorbed wave energy in full scale model owing to direction of incident wave

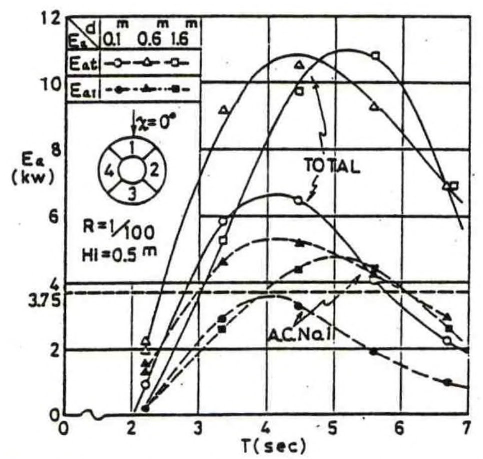

Fig.9 Variation of absorbed wave energy in full scale model owing to depth in front of air chamber

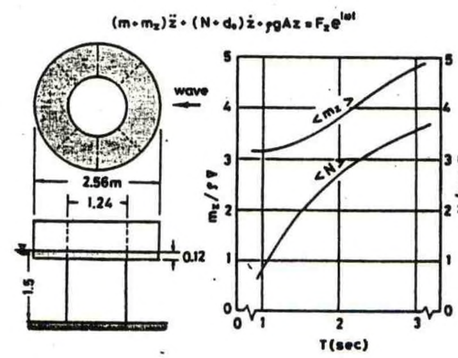

Fig.10 Water column in air chamber and calculated values of added mass and wave damping coefficient

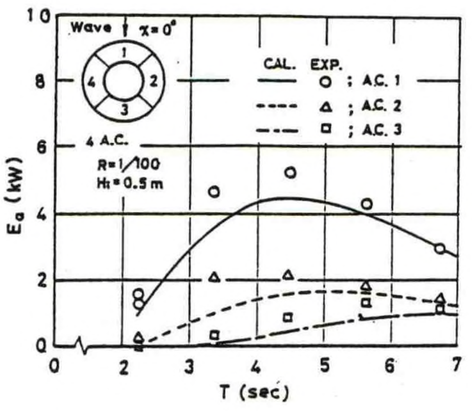

Fig.11 Comparison between experimental and calculated values

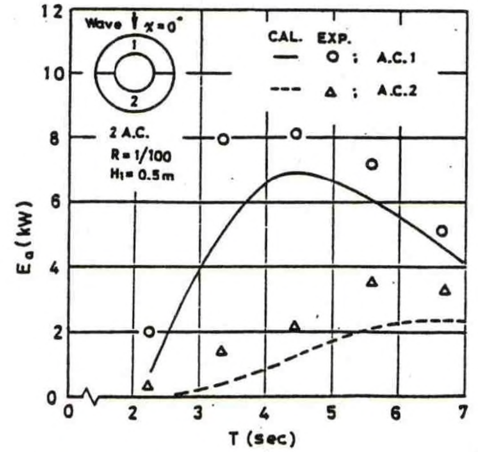

Fig.12 Comparison between experimental and calculated values

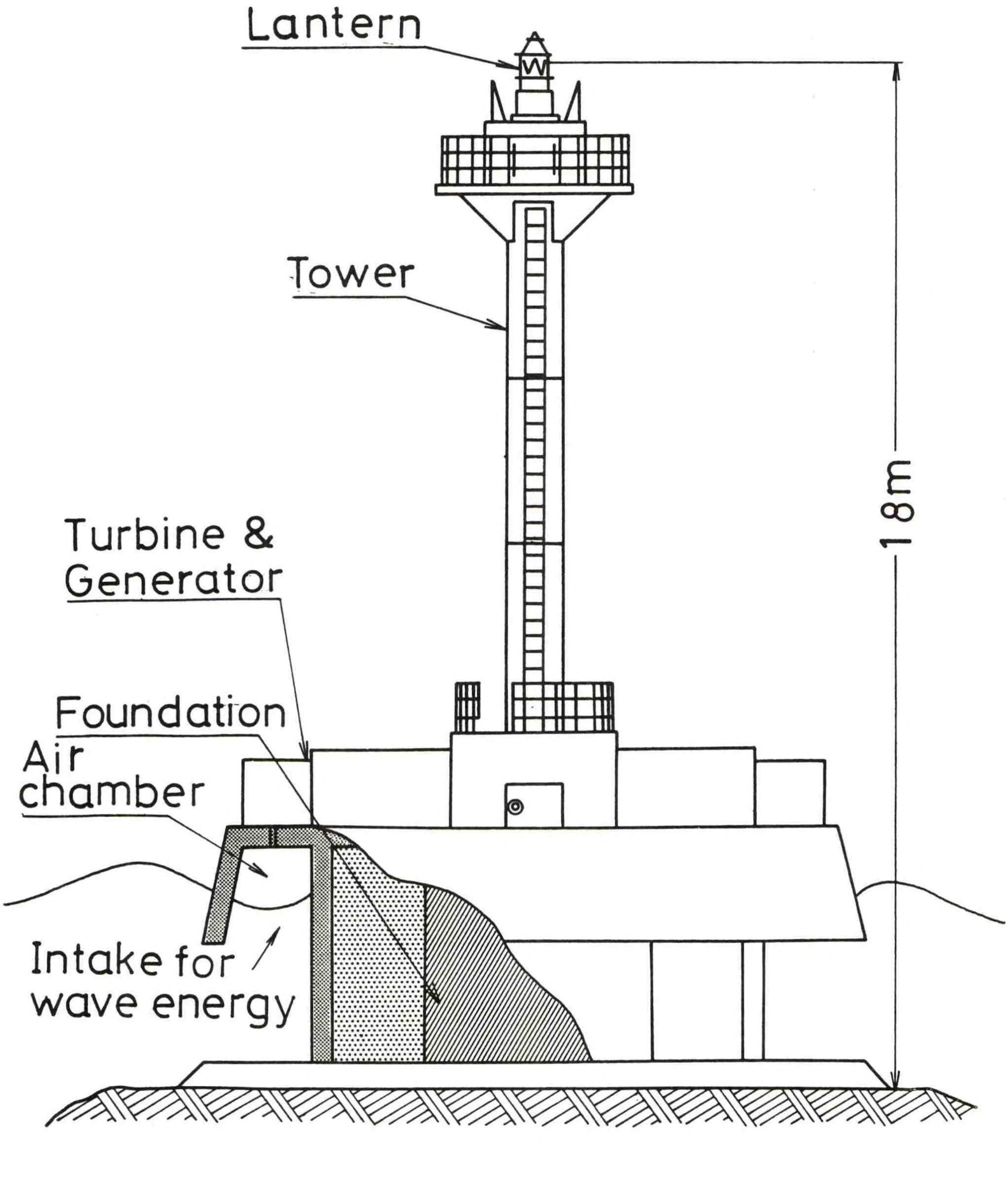

Fig. 1 Wave activated generating system for light beacon

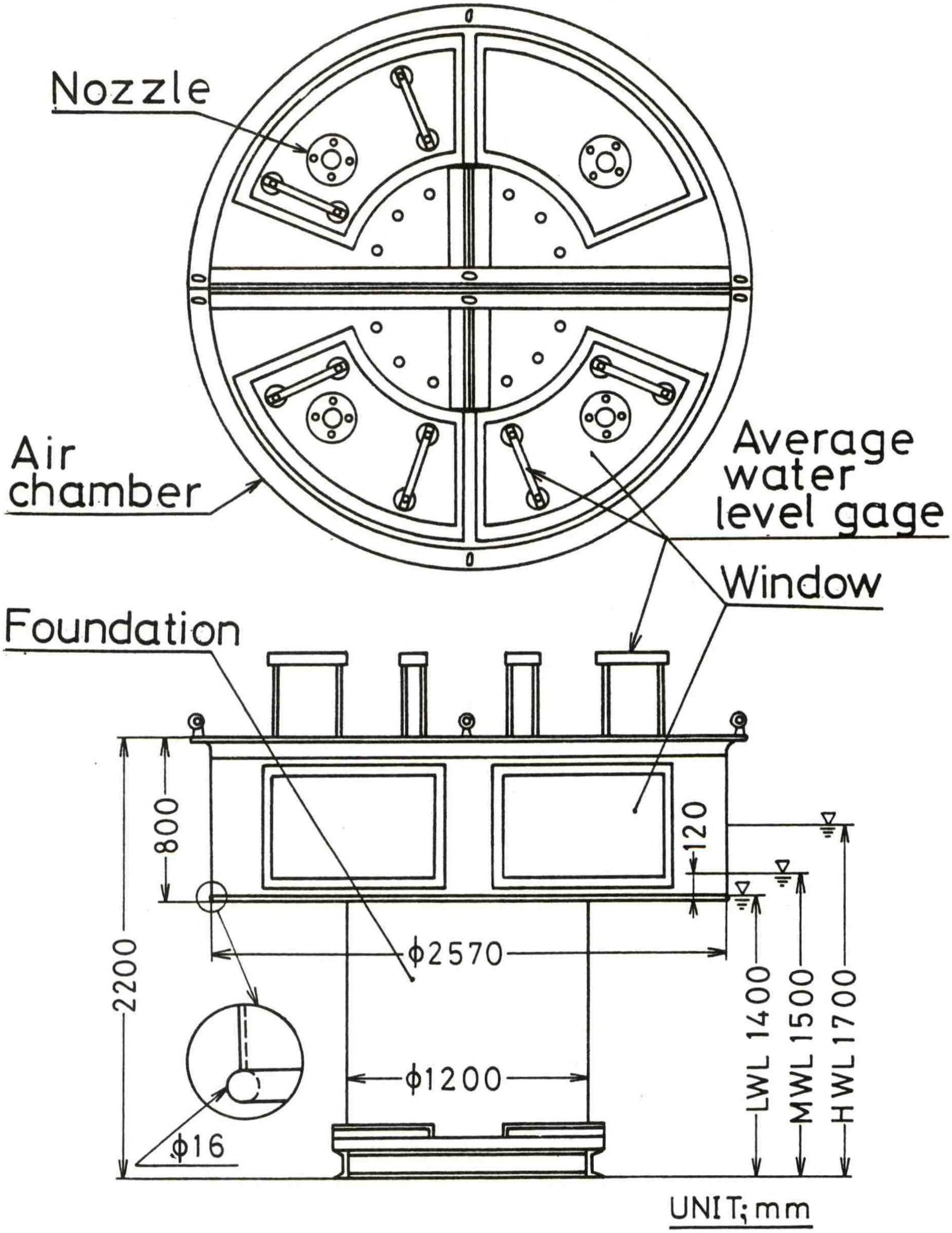

Fig.2 Circular air chamber model

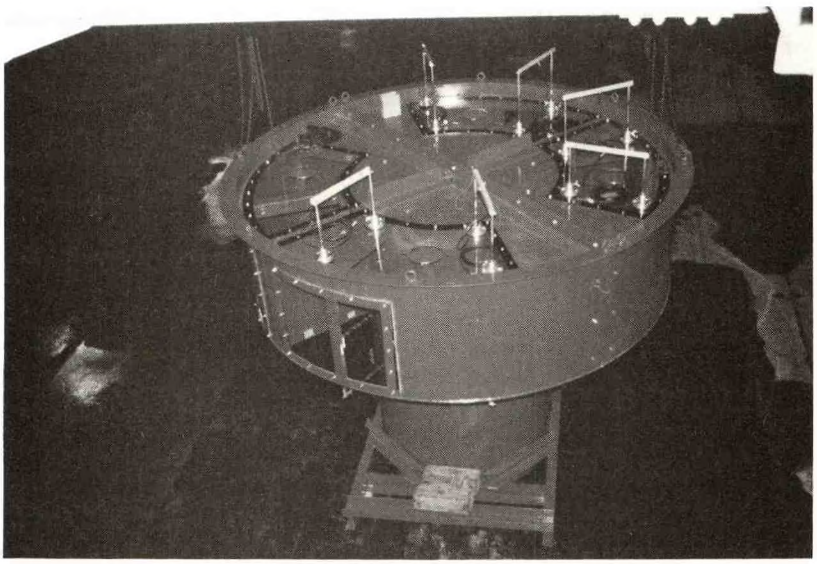

Fig.3 Circular air chamber model

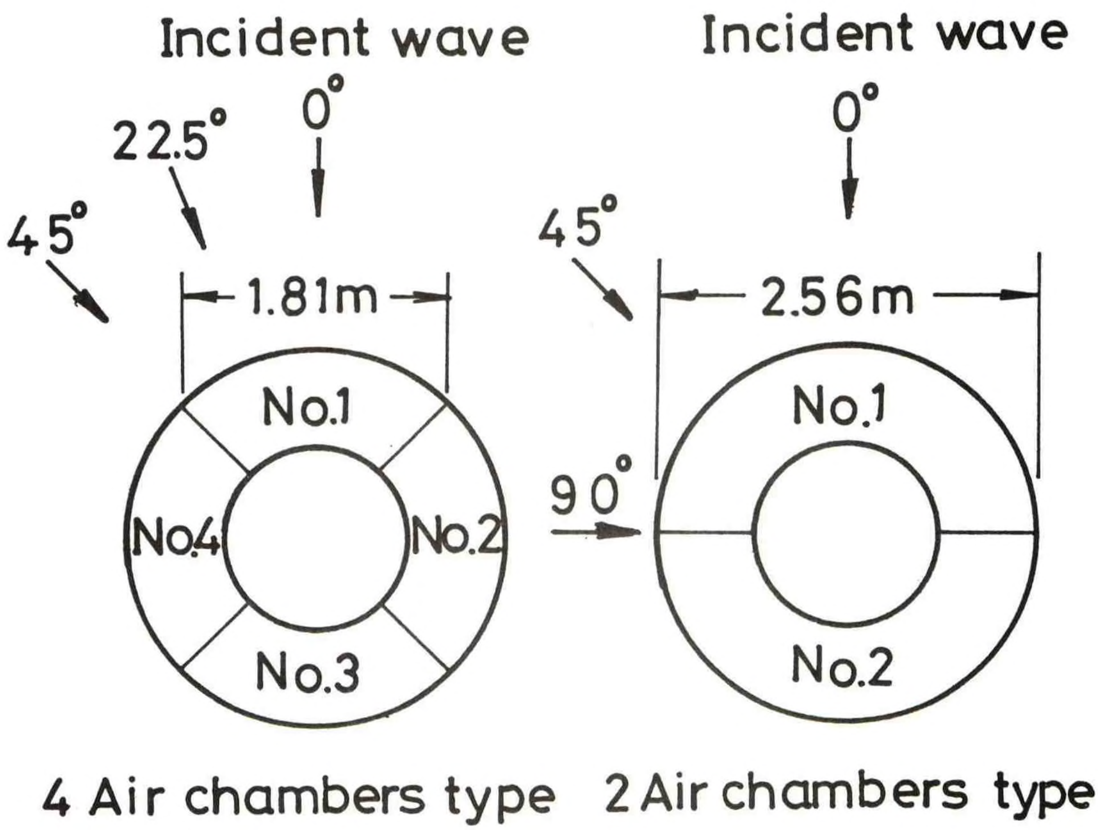

Fig.4 Direction of incident wave

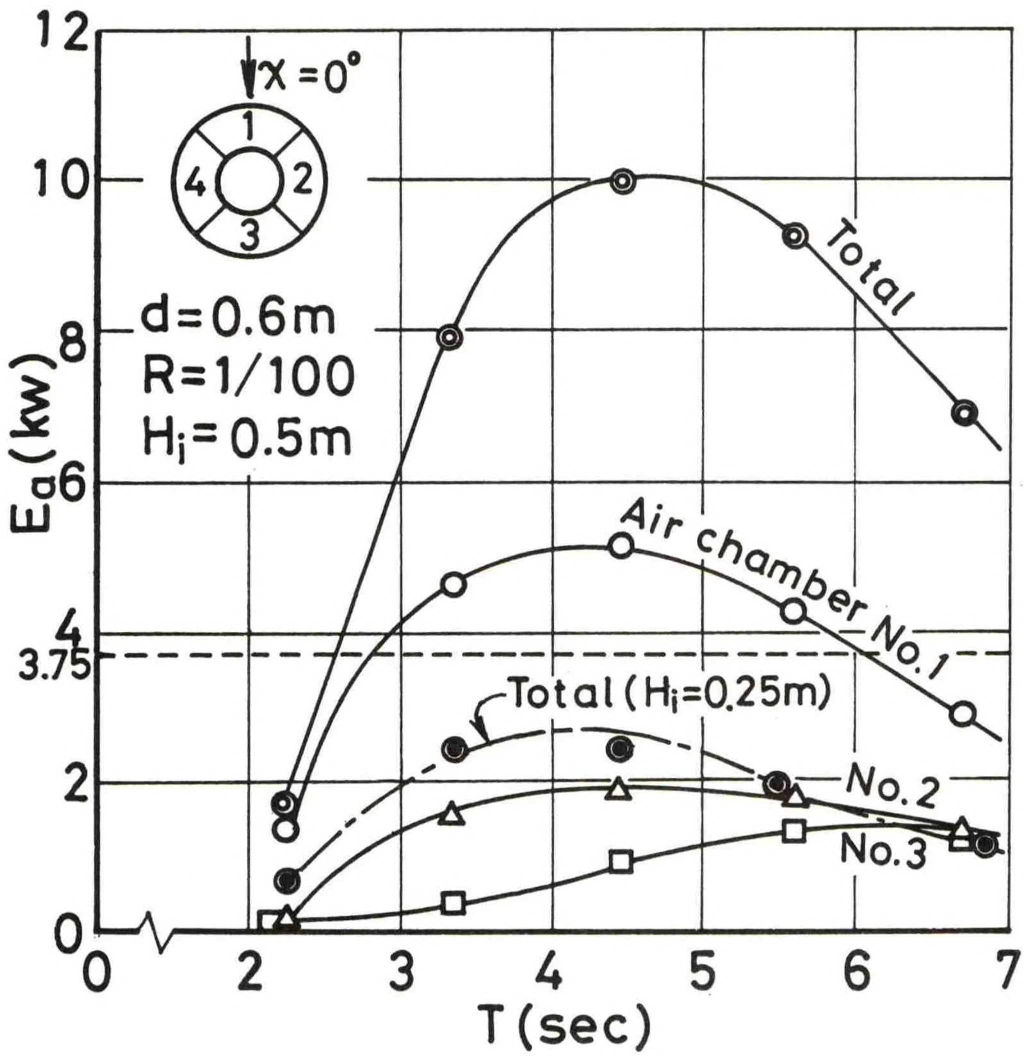

Fig.5 Absorbed wave energy in full scale model

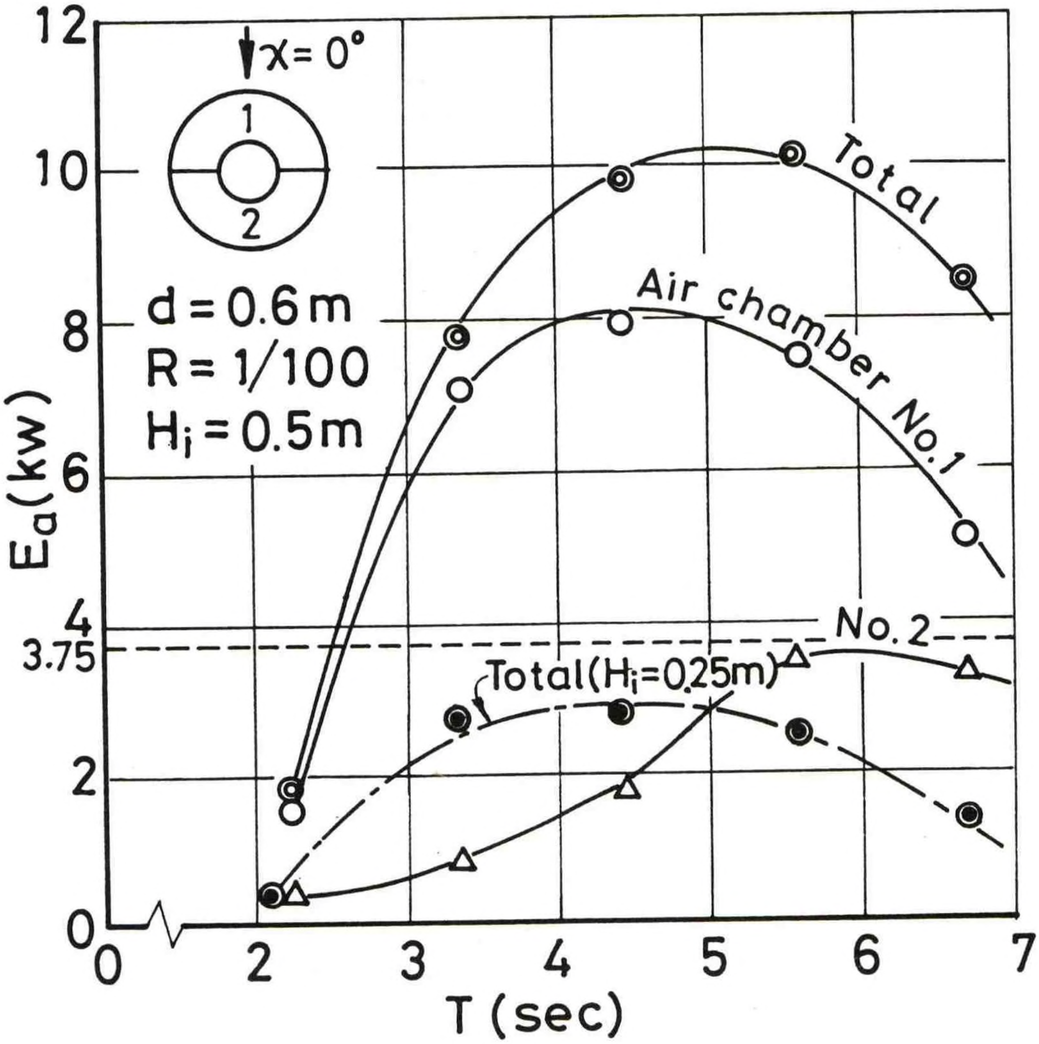

Fig.6 Absorbed wave energy in full scale model

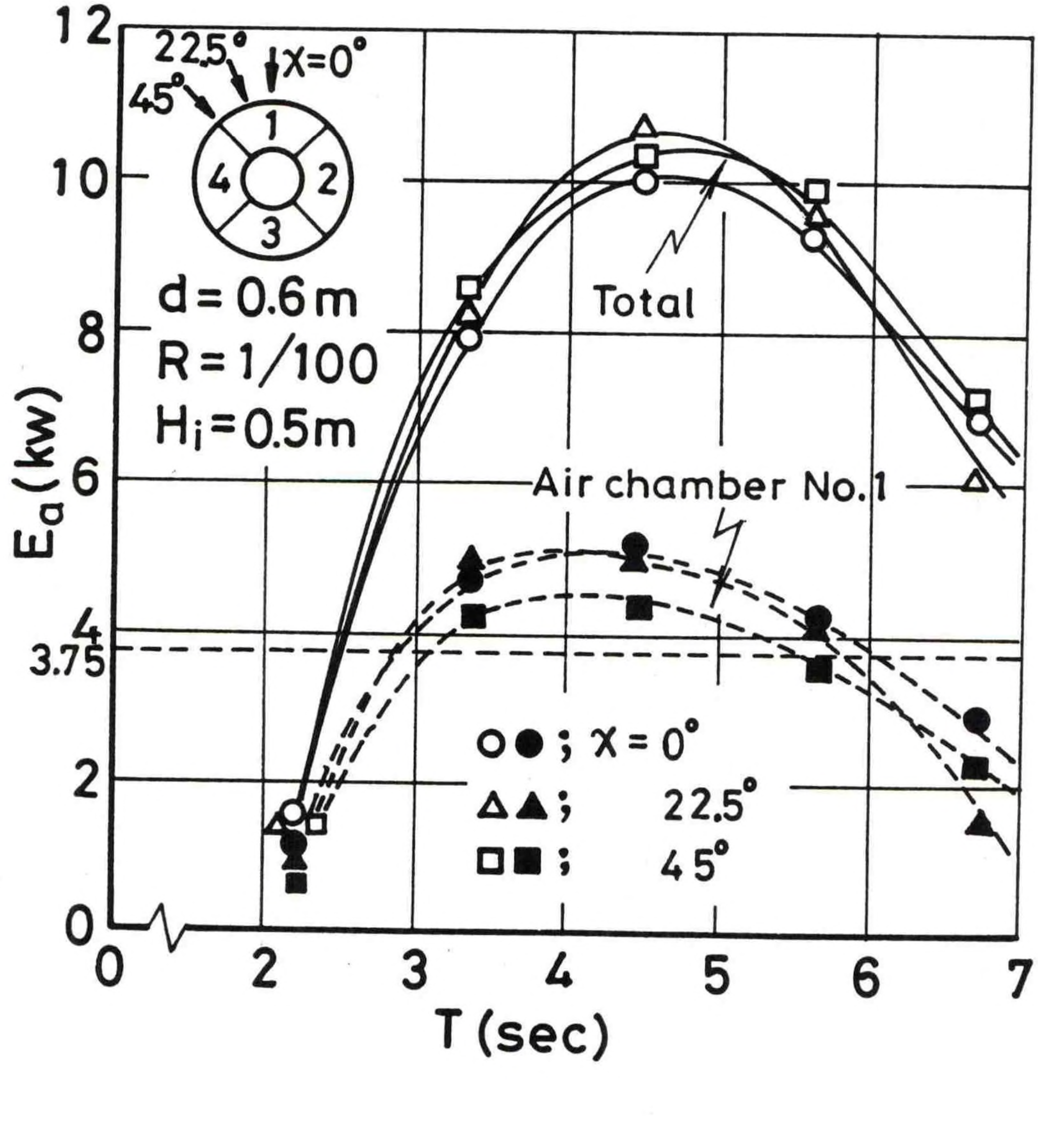

Fig.7 Variation of absorbed wave energy in full scale model owing to direction of incident wave

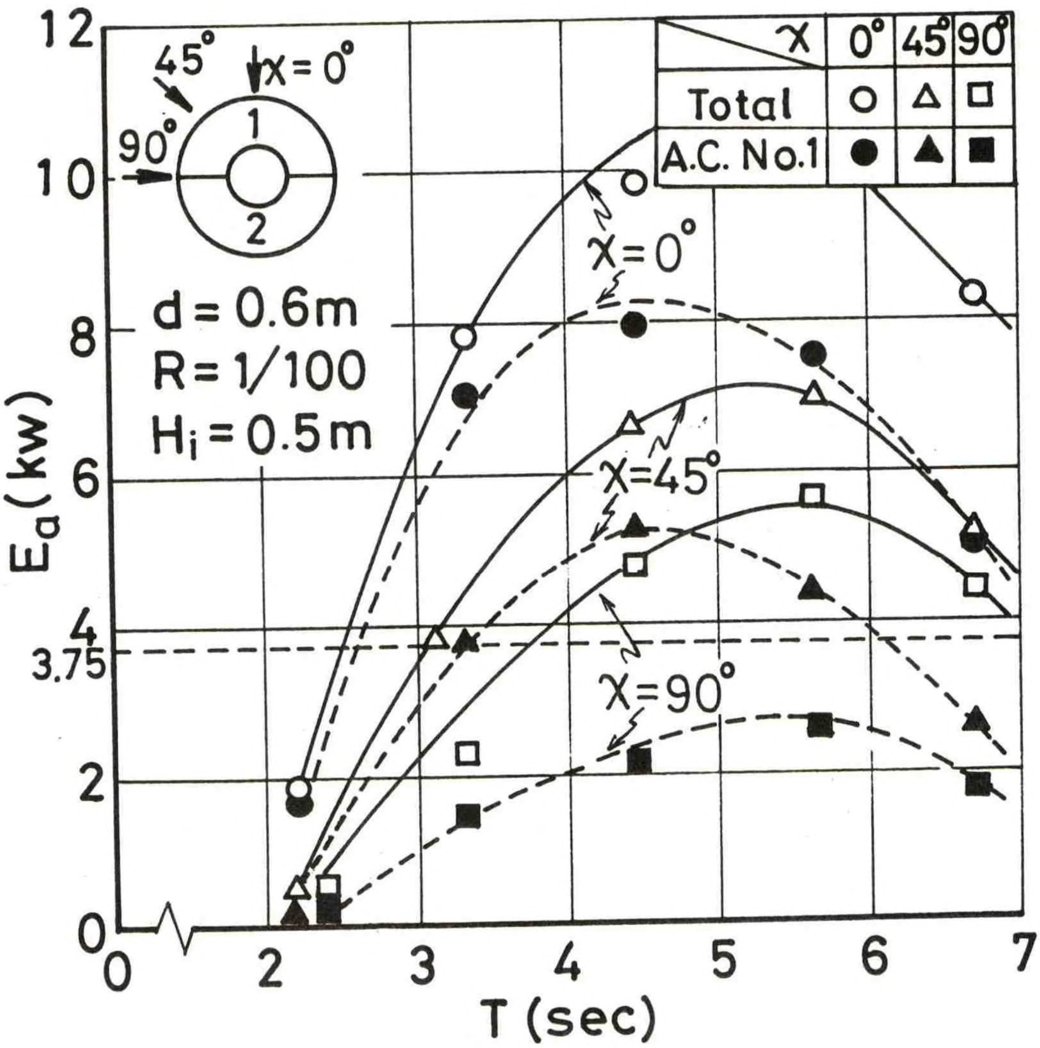

Fig.8 Variation of absorbed wave energy in full scale model owing to direction of incident wave

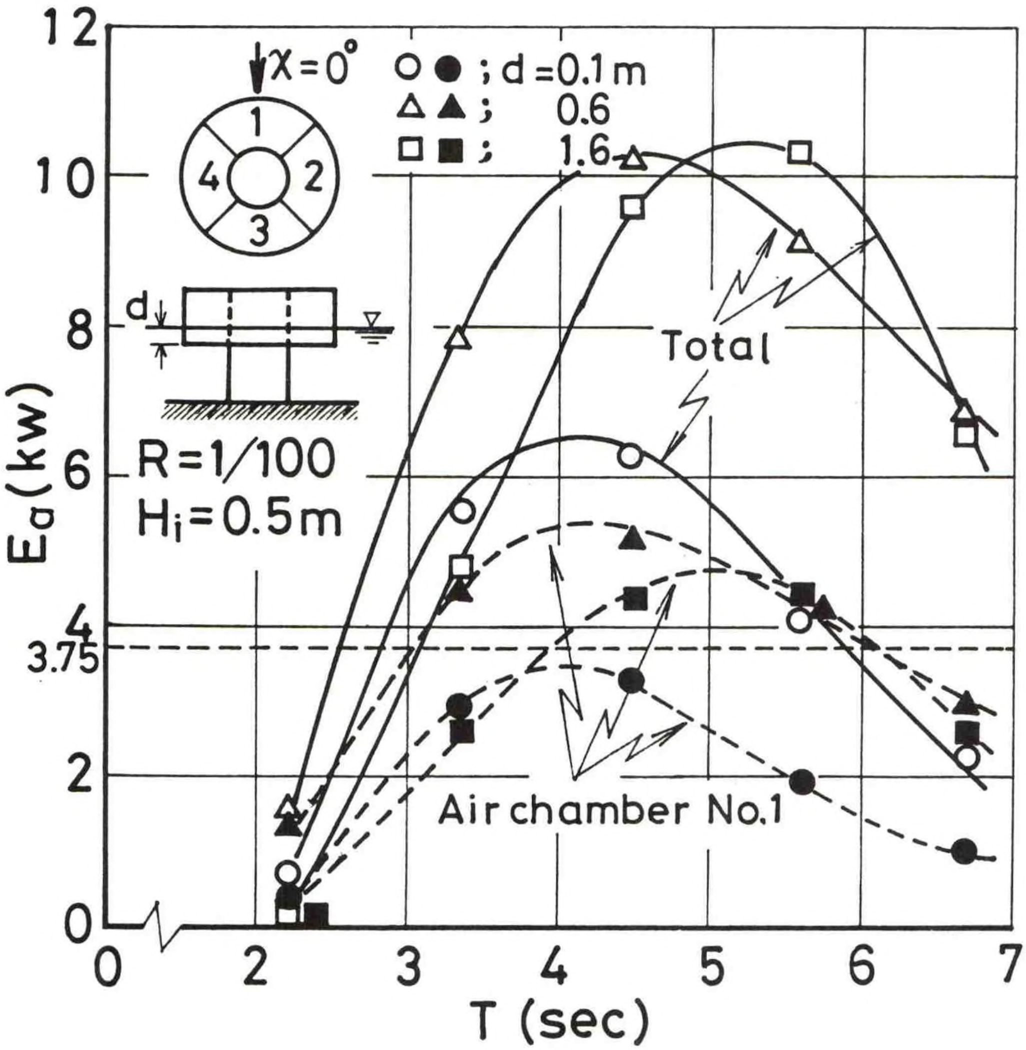

Fig.9 Variation of absorbed wave energy in full scale model owing to depth in front of air chamber

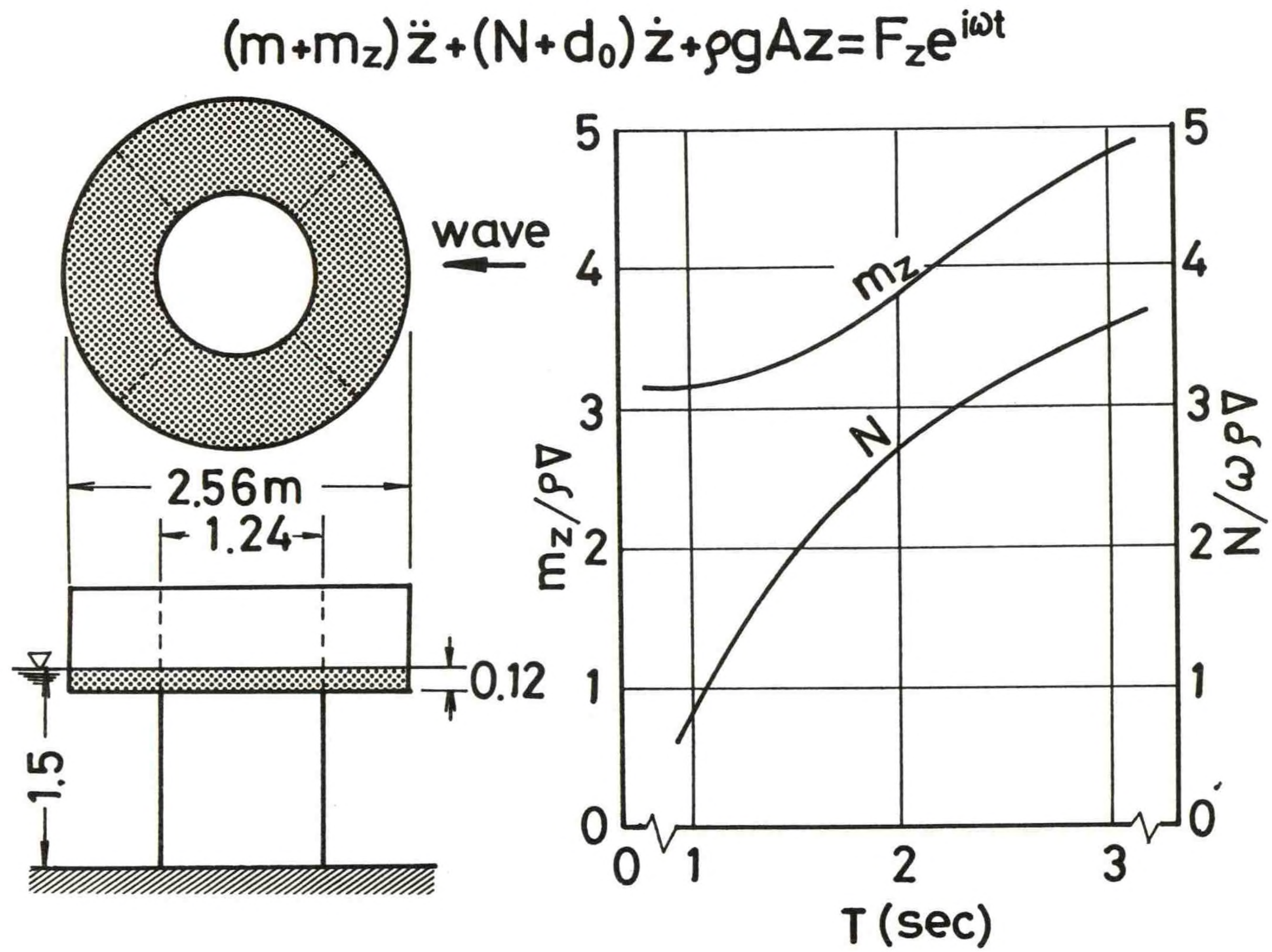

Fig.10 Water column in air chamber and calculated values of added mass and wave damping coefficient

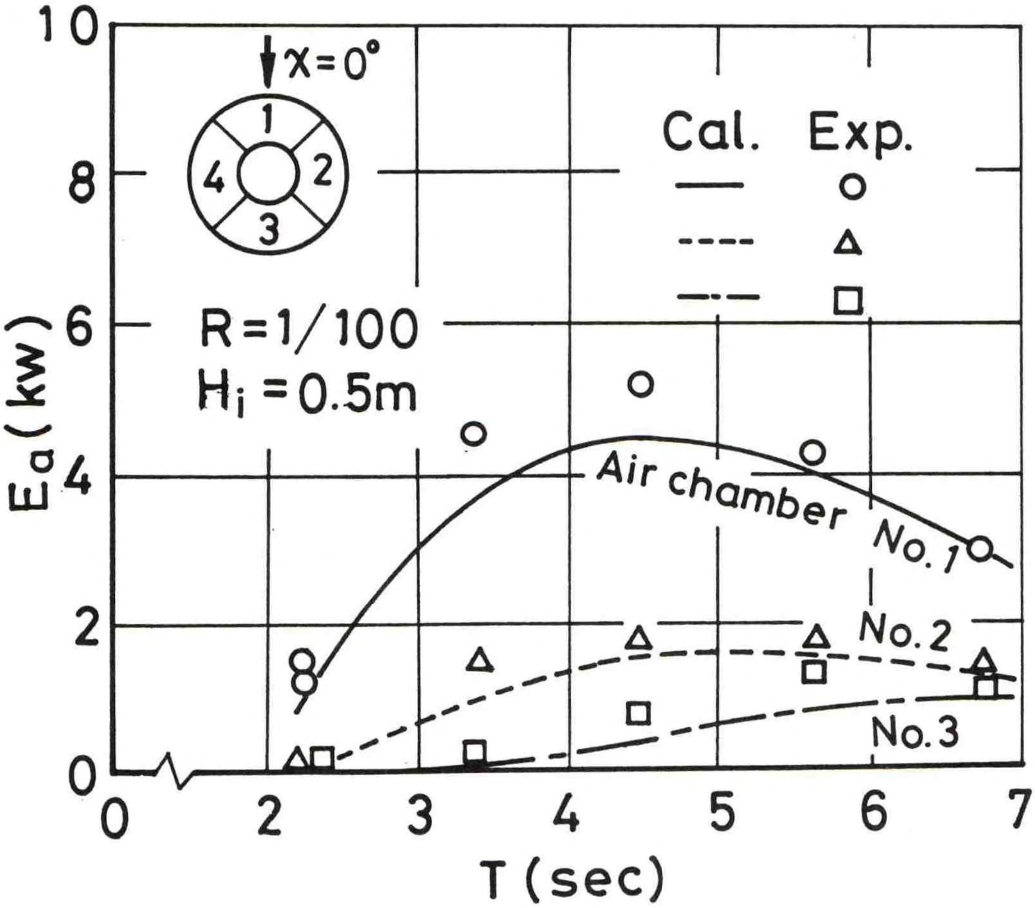

Fig.11 Comparison between experimental and calculated values

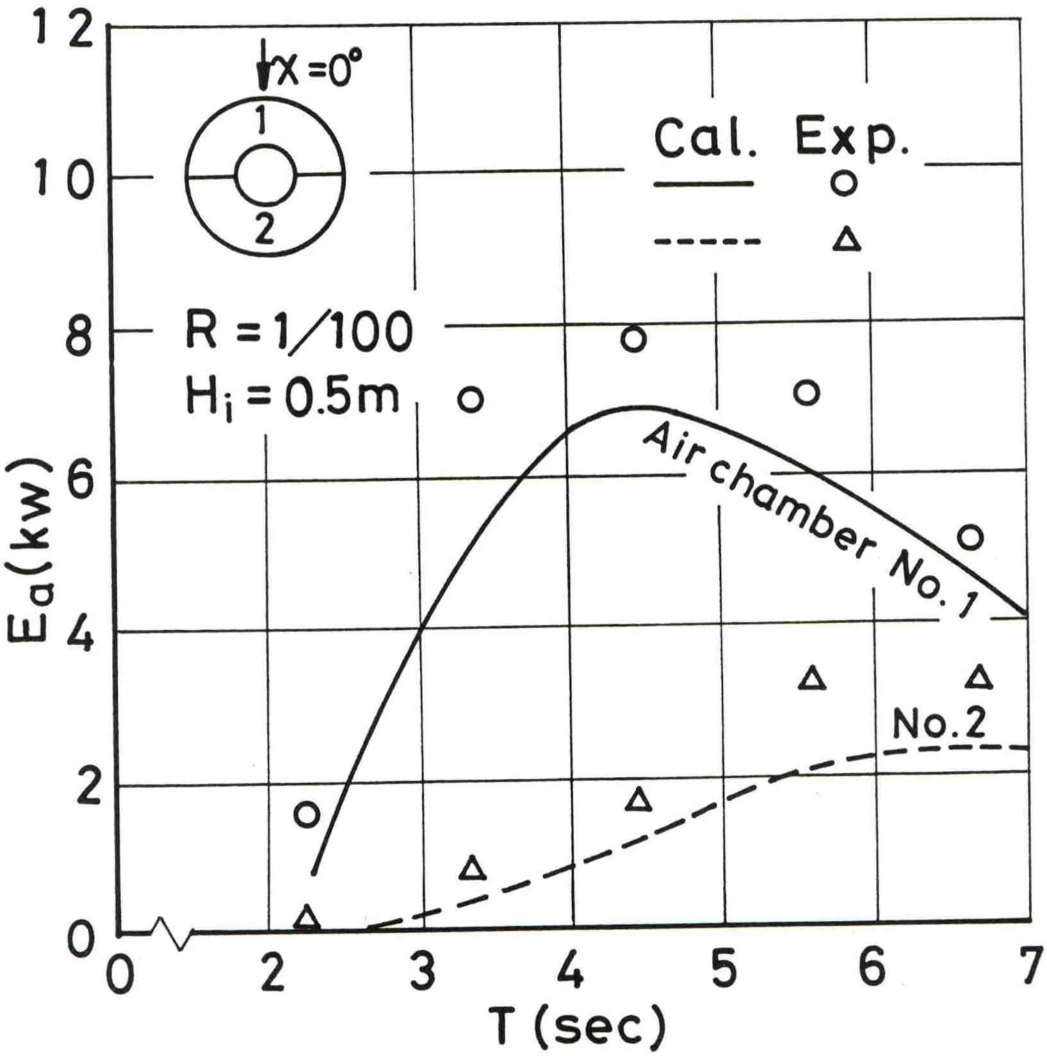

Fig.12 Comparison between experimental and calculated values

FUNCTION OF A STEEL FLOATING FISHING REEF
(ARTIFICIAL SEAWEED FARM PLANT)

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Introduction

The artificial seaweed farm plant, the experimental floating reef made of steel, was anchored by two chains at the depth of fourty-three meters off Tajima in the Japan Sea, from August 1979 to October 1982. Mean component of the plant was a shelf (22 x 22m square) settled at ten meter depth layer and an observation tower rose at the center of the shelf toward the surface.

This was an experimental facility of the artificial continentalshelf project, which had been planned by Hyogo prefectural office and some shipyards in the area [1]. The purpose of the project was to construct the steel continental shelf (200m in width, 20km in length) in the Japan Sea which is known as sandy and flattened bottom, for improving productive algal belt and for gathering fishes especially migrational ones. As the project was paused only to make up one artificial seaweed farm plant, the function of the plant was interested as a special artificial fishing reef.

The behavioral characters and the gathering factors of fishes around the plant were investigated by direct visual observation, some automatic recording instruments and the echosounder.

Method

Investigations were carried out four times from May 1980 to July 1982. Fig.1 shows a view of the complete construction of the plant.

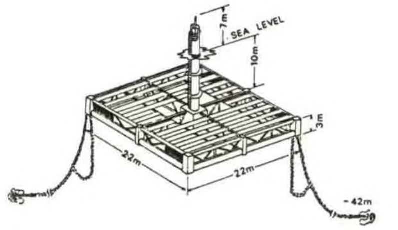

Fig.1 Artificial seaweed farm plant.

The fish fauna and approximate figures of each fish species were observed by divers. Diving observations were carried on day and night mainly around the shelf and the observation tower.

As it was difficult to dive in a rough sea, and the continuous diving was impossible because of the limit of bottom time, automatic recording instruments were used. Fig.3 shows an automatic underwater camera, which could take 250 photographs lit with an electronic flash at every 5, 15, 30 and 60 minutes. Fig.4 shows an automatic fish finder, which records 960 brief echograms of 30 seconds at every 5, 15, 30 and 60 minutes.

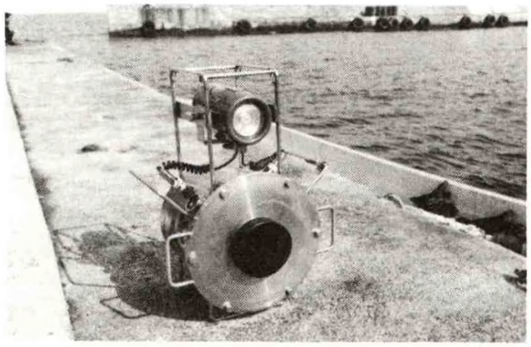

Fig.2 Automatic underwater camera.

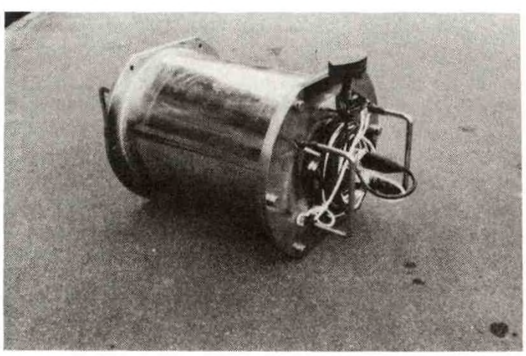

Fig.3 Automatic fish finder.

Result

Diving observarion

By diving observation, twenty-three kinds of fishes were found around the artificial seaweed farm plant (Table 1). Most of them belonged to the young stage, and adult species were not so much. The dominant fishes changed at every observation period.

In the first observation period, young Goldeye Rockfish Sebastes thompsoni were the dominant. In the day, they formed dense inactive schools mainly above the shelf, and in the night, they settled on the shelf to rest or sleep.

In the second observation period, young Yellowfin Horse Mackerel Trachurus japonicus , young Striped Beakperch Oplegnathus fasciatus , young Goldeye Rockfish and young

Black Scraper Navodon modestus were the dominants. Yellowfin Horse Mackerel formed schools and swam rapidly around the plant in the day, but they were not seen in the night. Striped Beakperch acted near the plant close to the surface (Fig. 4) and sometimes moved up and down between the shelf and the bottom along two anchor chains in the day, they settled on the shelf in the night. Black Scraper aggregated near the shelf in the day, and in the night they settled on the shelf.

Table 1. Fishes found near the artificial seaweed farm plant. Total length (T. L.) and number of them were estimated by visual observation.

Species	May 14–16 1980		Sep. 29– Oct. 1 1980		Aug. 11–19 1981		Jul. 5–8 1982	
	T.L. (cm)	No. of fish	T.L. (cm)	No. of fish	T.L. (cm)	No. of fish	T.L. (cm)	No. of fish
Iso flosmaris	10	8–9	—		—		—	
Seriola aureovittata	—		30–35	5–6	50	50–70	15–20	15–20
Trachurus japonicus	—		15–18	1000–2000	—		2–4	200–300
Girella punctata	—		15	3	6–7	10	2–4	25–30
							15	2
Pseudolabrus japonicus	5–10	10	10–15	20–30	7–20	150–200	7–15	100–200
Pteragogus flagellifer	—		—		10	1	7–10	100–200
Oplegnathus fasciatus	15	100	10–15	20–30	5–10	50–100	15–20	200–250
			15–20	20	20	20–30		
Chaetodontoplus septentrionalis	—		—		2–4	1	—	
Abudefduf vaigensis	—		—	1	—	10–20	—	
Pomacentrus coelestes	—		2–3	1	—		—	
Microcanthus strigatus	2–4	2	15–18	10	—		—	
Epinephelus awoara	—		25–30	1	—		—	
Petroscirtes breviceps	—	20–30	—	30–50	—	50–	—	50–
Pictiblennius yatabei	—		—		—	10–	—	10–
Parapercis sp.	—		4–5	1	—		—	
Hexagrammos agrammus	15	10	15	4 5	10–15	10–	10–15	100–200
Hexagrammos otakii	10	10	20–25	2–3	10–15	1	20	1
Sebastes inermis	—		—		15–20	50–100	—	
Sebastes thompsoni	2–4	30000–	6–7	4000–5000	5–7	15–20	3–5	1000–2000
Sebastiscus marmoratus	15	2	8–10	1	15	1	—	
Navodon modestus	20	1	20–25	200–300	10–15	300–400	5–6	30–50
					25	50–	10–15	30–50
							25–30	30–
Rudarius ercodes	—		5–6	1	—	10–20	—	
Stephanolepis cirrhifer	—		10–15	20–30	7–8	30–50	—	

In the third observation period, Goldstriped Amberjack Seriola aureovittata, young Striped Beakperch, young and adult Black Scraper were the dominants. Goldstriped Amberjack formed dense school and swam rapidly in a wide area around the plant in the day (Fig. 5), but they were not seen in the night. Adult Black Scraper aggregated between the shelf and the bottom in the day, and settled on the bottom in the night.

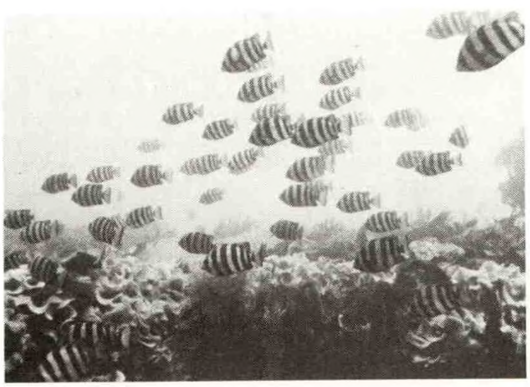

Fig. 4 Young Striped Beakperch Oplegnathus fasciatus.

In the fourth observation period, young Goldeye Rockfish and young Striped Beakperch were the dominants.

As the fish fauna in these three years were almost the same, the constituted fishes of it were not the same. Comparison of the fish fauna and size of them between the first and second observation period, which were conducted in a same year, Bambooleaf Wrasse Pseudolabrus japonicus Striped Beakperch, Spotyellow Greenling Hexagrammos agrammus, Fat Greenling Hexagrammos otakii and Goldeye Rockfish were estimated to stay at least four months, but they were not able to stay there against rough and cold winter. So the longest duration of stay of every fish species were estimated from spring and late autumn or winter.

Fig. 5 Goldstriped Amberjack Seriola aureovittata.

Measurement by automatic instruments

In the third observation period, automatic underwater cameras and automatic fish finder were settled as shown in Fig. 6.

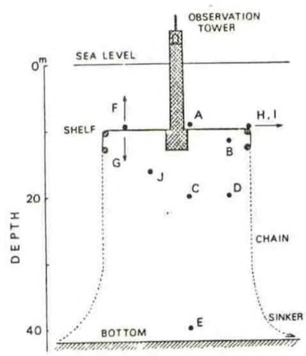

Fig. 6 Observation stations using automatic recording instrument. St. A-E: Automatic underwater camera, St. F-I: Automatic fish finder, St. J: Current and temperature meter.

From the photograph taken by the automatic underwater camera, fishes in species and number were analyzed by every frame and summarised in table 2. Six species of fishes were recognized. Fishes were seen day and night near the shelf (St. A, B), but at midwater layer (St. C, D) and bottom layer (St. E), only Black Scraper were seen in the day.

A transducer of the automatic fish finder was settled upward (St. F), downward (St. G) and sideway (St. H, I). From each brief intermettent echogram, the size of every fish schools were analyzed as "index of fish school by statistic echosounder". Results of them are shown in Fig. 7 to Fig. 9 together with water temperature and current in midwater layer (St. J) obtained by a magnetic tape recording type instrument every five minutres. In every direction around the shelf, distribution and the size of

Table 2. Kind and number of fishes appeared on 35mm film taken by automatic underwater camera by every thirty minutes.

Observation station	Period	Number of frames	Fishes appeared on film: Name	Number of frames	Total number of fish	Fish appeared time
A	15:00 Aug. 11 9:30 Aug. 13	86	*Oplegnathus fasciatus*	10	15	Day & night
			Sebastes inermis	1	1	19:00
			Stephanolepis cirrhifer	1	1	18:30
			Navodon modestus	7	12	8:00–19:00
B	15:00 Aug. 11– 9:30 Aug. 13	86	*Oplegnathus fasciatus*	10	10	Day & night
			Sebastes inermis	3	3	13:00–19:00
			Pseudolabrus japonicus	2	2	14:30–16:30
			Petroscirtes breviceps	1	1	22:30
C	10:30 Aug. 13– 10:30 Aug. 16	145	*Navodon modestus*	17	52	10:00–17:00
D	14:00 Aug. 16– 18:00 Aug. 19	152	*Navodon modestus*	10	17	6:30–15:30
E	10:30 Aug. 13– 8:00 Aug. 14	45	*Navadon modestus*	2	16	6:00– 7:00

fish schools varied between day and night, but the state of distribution was not influenced by change of underwater temperature or current.

Over the shelf (Fig. 7), small fish schools distributed sometimes in the day, large and dense schools distributed constantly in the night.

Under the shelf (Fig. 8), the distribution of fish schools were contrary to the result obtained over the shelf. In the day, large and dense fish schools distributed constantly, but rare in the night. Fishes in the day were estimated as adult Black Scraper. The distributed range of fish schools in the night were limited within ten to twenty meters from the shelf.

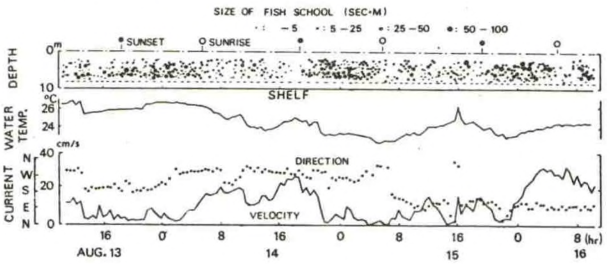

Fig. 7 Fish amount over the shelf obtained by automatic fish finder at St. F, temperature and current at St. J.

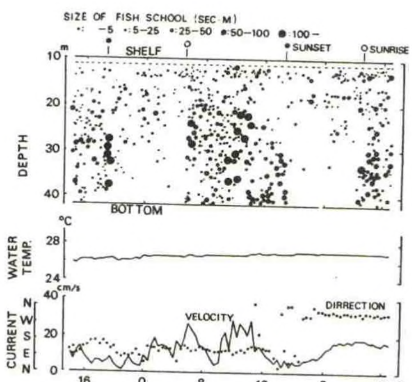

Fig. 8 Fish amount under the shelf at St. G.

Distribution of fish schools in the sideway of the shelf (Fig. 9) were almost the same as over the shelf. Thedistributed range of fish schools were within ten to twenty meters from the shelf, and in two occasions at St. H, big fish schools (estimated as Goldstriped Amberjack) appeared in the day.

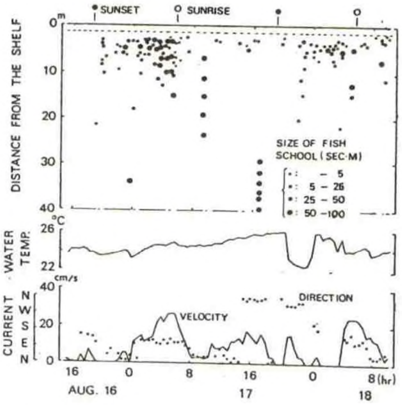

Fig. 9 Fish amount at the shelf layer (10m depth) toward the East from St. H.

Echosounding

Radial echosounding was conducted in the fourth observation period by the scientific echosounder (SIMRAD EY-M) as shown in Fig. 10. As fishes were not so much in this period, fish schools around the plant were rare and little. Under the shelf, big fish schools of adult Black Scraper were recognized.

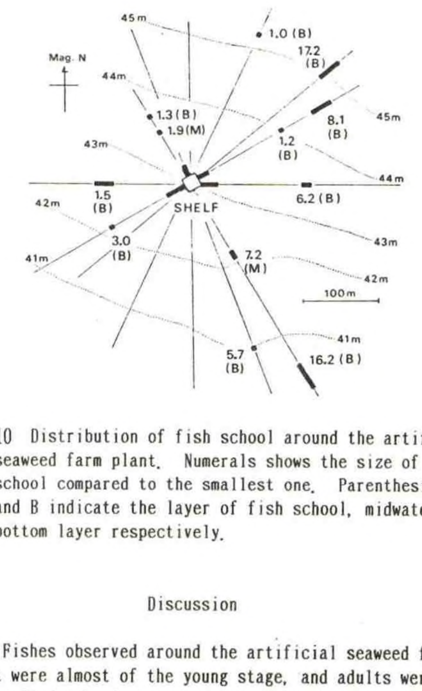

Fig. 10 Distribution of fish school around the artificial seaweed farm plant. Numerals shows the size of fish school compared to the smallest one. Parenthesized M and B indicate the layer of fish school, midwater and bottom layer respectively.

Discussion

Fishes observed around the artificial seaweed farm plant were almost of the young stage, and adults were only Goldstriped Amberjack and a part of Black Scraper. The plant located in the sandy flattened bottom area, at the depth of fourty-three meters, isolated from other reefs or shore more than one kilometer. All fish species except Banded Grouper Epinepherus awoara were known accompanying the drifting algae (Nagaremo in Japanese)[2], and the fish fauna and their popuration changed each year. The drifting algae in the Japan Sea mainly composed of Sargassum appeared much in late spring and early summer. Many young fishes just after post larva stage drift with drifting algae and spend their young stage [2]. So the process of gathering young fishes to the plant as shown in the first observation period is considered to the drifting algae origin or drifting post larva origin. In case of adult or semi-adult fishes, Goldstriped Amberjack , Black Scraper and Yellowfin Horse Mackerel were considered to be the transient to the plant in their migration. Subsequently the function of the plant to fishes are discussed about some dominants fishes more minutely.

Goldeye Rockfish were the most numerous. As the adult of them inhibit at the bottom of seventy-five to two-hundred meters, a large number of the young appeared with the drifting algae [3]. At Noto area in the Japan Sea, the young appeareed between May and July accompanied with drifting algae. Body length of them was 15-25mm in May and 50-60mm in July. As they grew and became active, they change their inhabitant to the bottom layer. They leave from the drifting algae when water temperature rises to about 18℃. At the artificial serweed farm plant, Goldeye Rockfish stayed still around the plant in the second observation period of September, when water temperature was 22.0-22.7 ℃. So they stayed around the plant more extended period of time than at the drifting algae. By night diving in the third observation period, they were seen to settled on the shelf of the plant. From above msntioned facts, it is concluded that the floating shelf of the plant at ten meter depth layer effect as the inhabitation to young Goldeye Rockfish in the same manner as more deeper bottom and extend the duration of their near-surface inhabit up to late autumn or to winter. After all, the floating shelf has both function of the drifting algae and the bottom. This function is considered to be equal to other many young fish species.

On some fishes, different growth stage was seen. They were Goldstriped amberjack, Yellowfin Horse Mackerel and Black Scraper. The distributed area of these fishes varied with the growth stage. Young Goldstriped amberjack (Total Length 15-20cm) distributed near the shelf in the same manner as many other young fishes, but adults (T.L. 50cm) swimmed around the plant in wide areas more than fourty meters. Young Yellowfin Horse Mackerel (T.L. 2-4cm) distributed near the shelf mixed with dense school of young Goldeye Rockfish, but semi-adults (T.L. 15-18cm) swam more wide area. As the behavior in the night of adult Goldstriped amberjack and semi-adult Yellowfin Horse Mackerel were not confirmed, they formed schools above the shelf from the twilight of the morning[4]. So they were considered to distribute not so far from the plant even in the night. Young Black Scraper (T.L. up to 20cm) distributed over the shelf in the day and settled on the shelf in the night, but adults distributed between the shelf and the bottom in the day and settled on the bottom in the night. From these facts, it is concluded that fishes act more wide area as they grow.

The distributed area of young fishes were limited within a range of ten to twenty meters from the shelf all the day. Adult fishes distributed center the plant in the day in more wide area than young fishes, and left the plant in the night. Fig.11 shows the schematic diagram of diurnal-nocturnal actibity of some dominant fishes around the plant in the third observation period [5].

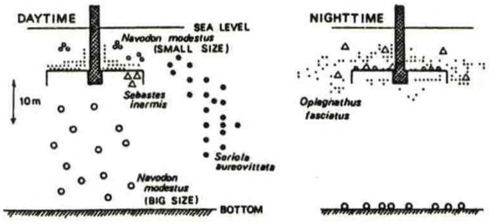

Fig.11 Schematic diagram of diurnal-nocturnal activity of some dominant fishes around the artificial seaweed farm plant.

It is concluded that the artificial seaweed farm plant has three functions to fishes as followes, and the function of 1 and 2 owe much to the presense of the shelf at ten meter depth layer.

1. Gather the larval fishes or drifting young accompanied with the drifting algae.

2. Function as the inhabitation to young fishes like algal belt or natural reefs.

3. Function as the rest place to adult migrational fishes.

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REAL-TIME NAVIGATIONAL INFORMATION SYSTEMS
FOR PORT AND HARBOR OPERATIONS

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ABSTRACT

Based on present day technology in the measurement of tides, currents, and weather and the new techniques for electronic charting and navigational display systems, the integration of tidal and current sensors into a real-time navigation information system is suggested as a logical step toward a complete shipboard display of all pertinent information needed for ship operations. A general concept for the configuration of a multi sensor real-time navigational information system for ports and harbors is described, as well as the details of the first of such systems now in operation or being planned. Information from such systems has proven to be of real value to piloting and dredging operations, and can be installed using "on-the-shelf" technology.

INTRODUCTION

Since 1981, the National Oceanic and Atmospheric Administration (NOAA) has been investigating the development of a real-time navigational system for port and harbor operations as a part of its general program to better understand and apply the dynamic behavior of tide and current in confined waters (bays and estuaries) to the needs of the various users of these waters. A detailed knowledge of actual water depths and currents would be particularly important to the safety and more efficient operation of deep draft vessels in transit to and within ports and also to the control of dredging operations in shipping channels. My company, System Planning Corporation, examined and analyzed a conceptual plan for such a system in 1981. Subsequently, NOAA has sponsored a series of workshops in various U.S. port areas to determine specific needs of shipping and other operations in such areas. These studies, under NOAA's Project PORTS (Port Objectives for Real Time Systems) have culminated in a series of first order operating systems now either operating or being planned for installation in a number of U.S. Port areas.

BACKGROUND AND TECHNICAL CONCEPT

Recent developments in microprocessor technology and computer graphics make possible relattively low-cost systems that can integrate, analyze, and display a wide variety of interrelated navigational data, incorporate models for spatial and temporal extrapolation between data fixes, and combine real-time instrumentation data with basic hydrographic data. Since positional data derived from a global positioning system (GPS) can also be displayed, the capabilities derived from several major technologies can now be combined to develop systems with a computer-stored and automatically updated real-time navigational data system. Such a system is the logical extension of data gathering and analysis systems that are defined by present requirements to provide tide and current data and to develop and test dynamic tide, current, and circulation models.

The technology context for the Real-Time Navigational System is illustrated in Figure 1. The available or rapidly developing technologies for

- o Computer-assisted charting
- o Automated survey
- o Telemetering tide and current gages
- o Tide- and water-level instrumentation
- o Current measurement instrumentation

all place cartographic data in the appropriate computer format for storage and automatic computer graphics display. In addition, the general technologies of

- o Global Positioning Systems (GPS)
- o Microcomputers and storage systems
- o Computer graphics and display

make possible the processing, analysis, and display of such data and the real-time updating of stored data bases by any set of local instrumentation and associated processing system. Thus, in its ultimate conception, such a real-time navigational data system would permit the storage and continuous display of hydrographic information derived from stored data on board ship with provision for the overlay of ship position (and the

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adjustment of chart information centering on the ship position), and local, real-time tide (depth), current, and weather data. Highly accurate, detailed real-time data in critical navigation areas, as well as the more accurate prediction of future conditions (e.g., channel depths under changing tide conditions), should greatly improve navigation in marginal conditions of high traffic, shallow bottoms (or deep draft), restricted waterways and difficult currents and winds.

Benefits of the type of system suggested in Figure 1 may be expected to include

- o Shipping operations, permitting higher traffic density and greater draft operations with safety
- o Improved efficiency of dredging operations
- o Improved navigation aids and traffic control (for example, increased frequency of traffic in the Valdez Arm approach to Valdez Harbor, Alaska, might be possible).

In its fullest configuration, such a real-time system would provide an overlay of high accuracy local dynamic conditions to the electronically stored navigational data aboard, in an integrated shipboard navigation system combining these data with indicated ship position, course, speed, and "collision avoidance" and other navigational checks available from shipboard radar and depth-finding equipment.

Figure 2 suggests some of the data options ultimately available from the Real-Time Navigational Data System and shows how this system might interface with a full shipboard electronic navigational system. Detailed specification and design of each local real-time system will depend on the needs and requirements of the local user community. The real-time system supplements an existing capability (i.e., nautical charts, tide and current tables, and tidal charts) and the need for extending existing capability will vary among port areas. Therefore, the structure and instrumentation of the system may vary, depending on local conditions and requirements.

SYSTEM DESIGN AND EXPERIENCE TO DATE

The proposed Real-Time Navigational Systems would provide mariners with the ability to obtain tide, meteorological, current, and/or nautical chart data in real time, either displayed on a shipboard CRT or transmitted by radio, telephone, or teletype on demand by the user. Figure 3 shows pictorially a possible design configuration for the system. Data from the tide, current, and weather sensors are telemetered to a central site for processing and then merged with digital nautical data. These data may also be used for prediction using a dynamic area model if one has been developed. These data are stored in a file for periodic updating of the shipboard display system; alternately, display information is telemetered or radioed directly to the shipboard operator on demand.

In the actual systems which have been installed or are being planned to date, information from a local network of tide gauges (and, in some instances meteorological and current meter information) is telemetered to a central microcomputer or processor and display. Information is then relayed to users via telephone, radio telephone, or other means. In no case has on-board display yet been used as the operating display method. The primary users are the pilots, who, in some of the first operational areas, have found the real-time information to be very useful. These are the areas where the extension of the mean tide predictions of the national tide network are often at considerable variance from actual water depths.

At this time, local real-time systems, or parts of systems have been installed, on at least a prototype basis, in four localities:

- o Port of New York, under the operation of the Maritime Association of the Port of New York (MAPONY)
- o Delaware Bay, as the instrumentation network required by NOAA for the development of a Delaware Bay dynamic circulation model, operated by NOAA in cooperation with the Delaware Bay Pilots
- o San Francisco Bay, installed by a private company as a system demonstration, in cooperation with the San Francisco Marine Exchange
- o Columbia River, a single tide gauge installed as a cooperative effort between NOAA and the U.S. Army Corps of Engineers

As an indication of specific design requirements, it may be of interest to briefly review these systems, with some mention of other application areas of interest. In all areas, it should be noted, off-the-shelf instrumentation has been found to be generally available which will interface well with standard modems for data transmittal. In all cases, personal computers (PC's) or other low cost micro-processors have been used to combine the instrument data for display. Higher level data processing capability would be required if complete nautical chart data were to be stored, updated, and presented, or to operate dynamic prediction models.

Two specific areas requiring technical improvement -- or at least lower cost options -- are those of current measurement and local dynamic model predictions. Direct current meters have been found unreliable over long times due to fouling (and, of course, direct meters can pose an impediment to navigation). Indirect acoustic current meters have proved to be accurate, but are very expensive. In the Delaware Bay area, NOAA has developed a local dynamic model which can be used for short-term predictions based on data received from the real-time instrument network, but it has been an expensive model to build, and runs on a large mainframe machine under NOAA operation. These shortcomings are in many cases not critical, since the principal users (pilots, tugboat operators, and dredgers) are primarily interested in accurate real-time water depth readings at specific critical locations.

In the New York (MAPONY) and San Francisco installations, the instrument network is of 4-5 tide gauges whose readings are telemetered via telephone line to a central display (MAPONY in N.Y., the Marine Exchange in San Francisco). The layout of the MAPONY system is shown in Figure 4. Data is relayed to pilots and other users via radio, telephone, or other means, on an "on demand" basis. The N.Y. (MAPONY) system uses an electro-mechanical printout. The San Francisco system, using a new tide gauge design by Sea and Meteorology, Inc. (SAM), the cooperating company, uses a CRT display and can also print out the tide history at each gauge site. Neither system directly interfaces with a shipboard electronic display. However, a local shipboard graphic display model, and shipboard display equipment for navigational information has been separately tested by the Staten Island Ferry, and the Sandy Hook Pilots (pilots for New York and New Jersey in the N.Y. harbor area).

The Columbia River installation of a single tide gauge can hardly be called a "system." In conjunction with the U.S. Army Corps of Engineers dynamic model for the river, however, it can provide much improved water depth information for channel dredging, which is the principal interest of the Corps. Columbia River pilots will also find the information useful in keeping track of the actual phase of the tides in making the long (60 miles) river transit from Astoria, at the mouth, to Vancouver and Portland. The principal Columbia River navigational hazard, that of the bar crossing, is not addressed by this measurement, however.

The Delaware Bay system is in a sense a special case, but may be repeated elsewhere. NOAA installed a system of four stations, comprised of two tide gauges and two current meters of different design for each station. The data from these stations have been used by NOAA over the past several months to develop and test a dynamic tide and circulation model for the bay. At the same time, these data were made available through direct telephone line telemeter to the Delaware Bay pilots, who provided a suitable computer, modems, and display units to collect and display the real time data. The data are displayed at the Delaware Bay Pilots Association headquarters in Philadelphia, Pennsylvania (the largest Delaware Bay port) and at the pilot station at Lewes, Delaware at the mouth of the bay. Pilots can receive real-time water level and current meter information from either Philadelphia or Lewes, as well as some local site weather information. Recently, the short-term predictive output of the model, which operates on a NOAA computer in Rockville, Maryland, has also been made available to the pilots, who have found the 4 to 6 hour future predictions of water depth to be useful. This predictive model provides a mesh of future tide and current values tied to the real-time input from the measurement sites, but extended to include all other locations, by specific point calculations or by extrapolation, within the navigating areas of the bay.

It is anticipated that these real-time navigation systems, which, in effect, provide for the accurate extension of the U.S. national tide network data into specific local bays and estuaries will be extended to other port areas. Areas with high tides, difficult current conditions, and restricted waterways are those where the greatest benefits will be realized. In Miami, Florida, the problem is a combination of tidal current problems with the very restricted project geometry and dimensions of the waterway. In the New Orleans area, a major problem is that of marginal bridge clearances for fixed spans. In Alaskan ports, the combined effects of tide, current, and weather are of importance.

In the future, many worldwide ports may find it useful to install such real-time systems for accurate local navigational information. With the growing interest in all electronic navigation data handling and display, and increasing requirements for integrated collision avoidance systems in heavy traffic areas, it seems certain that the advantages of local real-time information systems will soon be combined with these advanced on-board navigational display systems and that the efficiency of port and harbor operations will be significantly improved through their use.

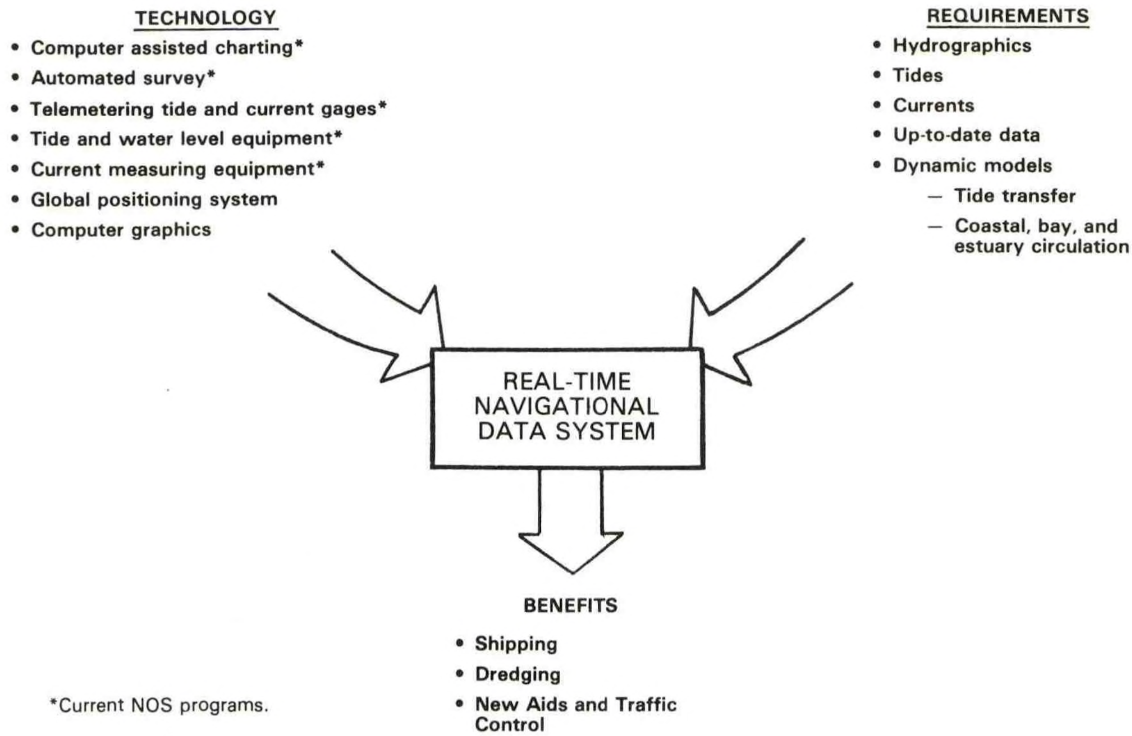

FIGURE 1.
PROGRAM AND TECHNOLOGY CONTEXT FOR REAL-TIME NAVIGATIONAL DATA SYSTEM

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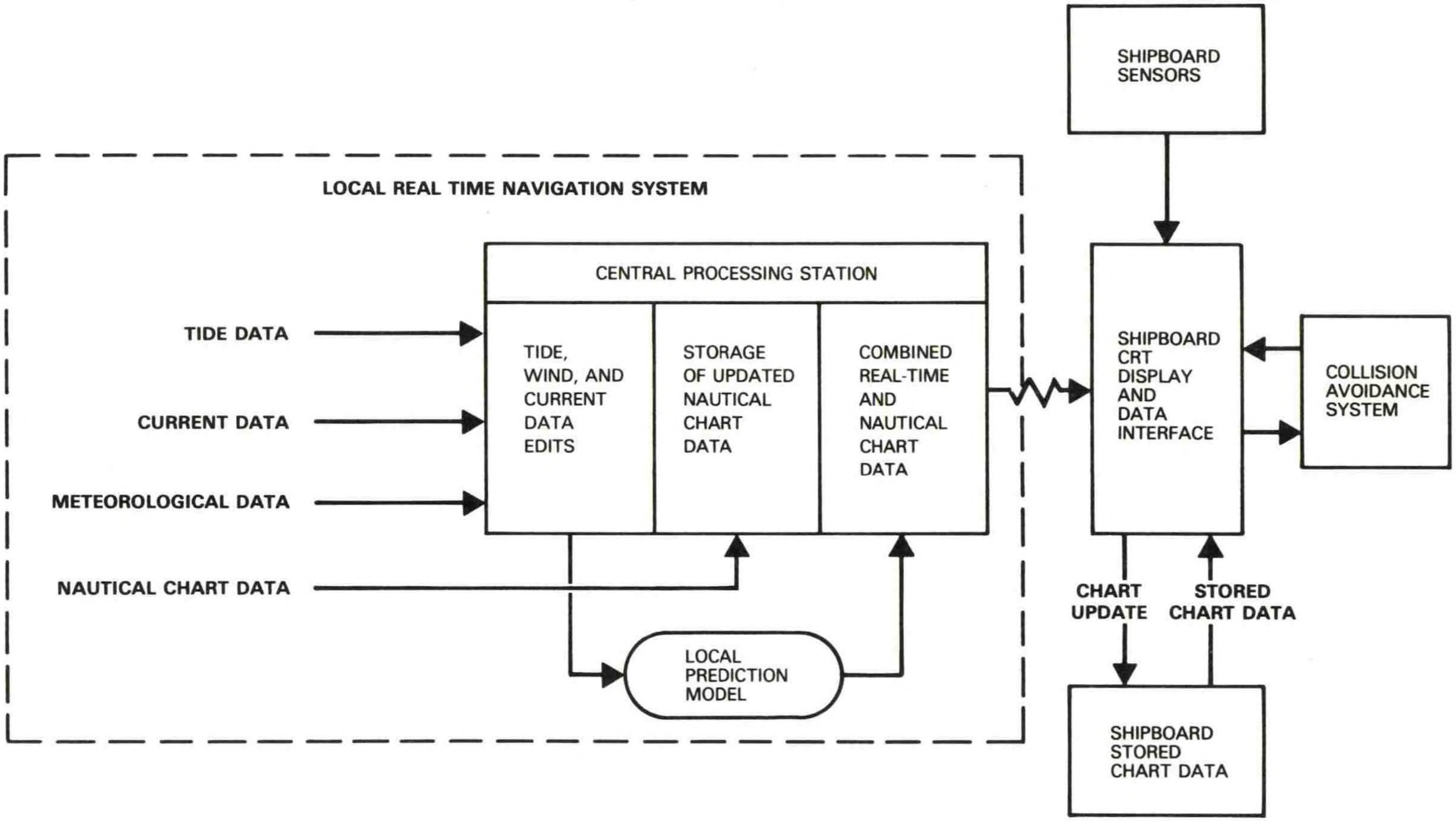

FIGURE 2.
CONCEPTUAL REAL-TIME NAVIGATIONAL DATA SYSTEM

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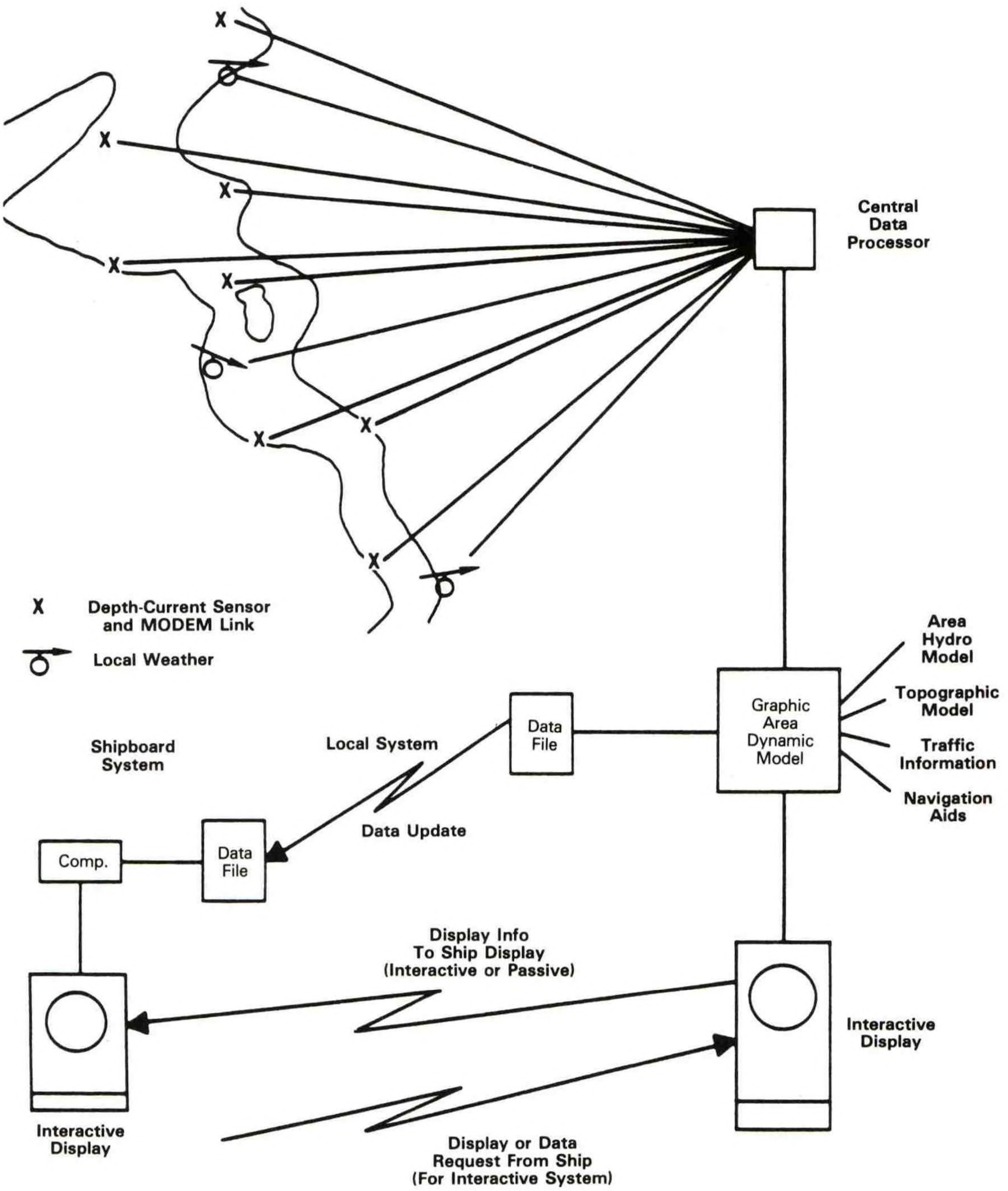

**FIGURE 3.
POSSIBLE CONFIGURATION OF CONCEPTUAL
REAL-TIME NAVIGATIONAL SYSTEM**

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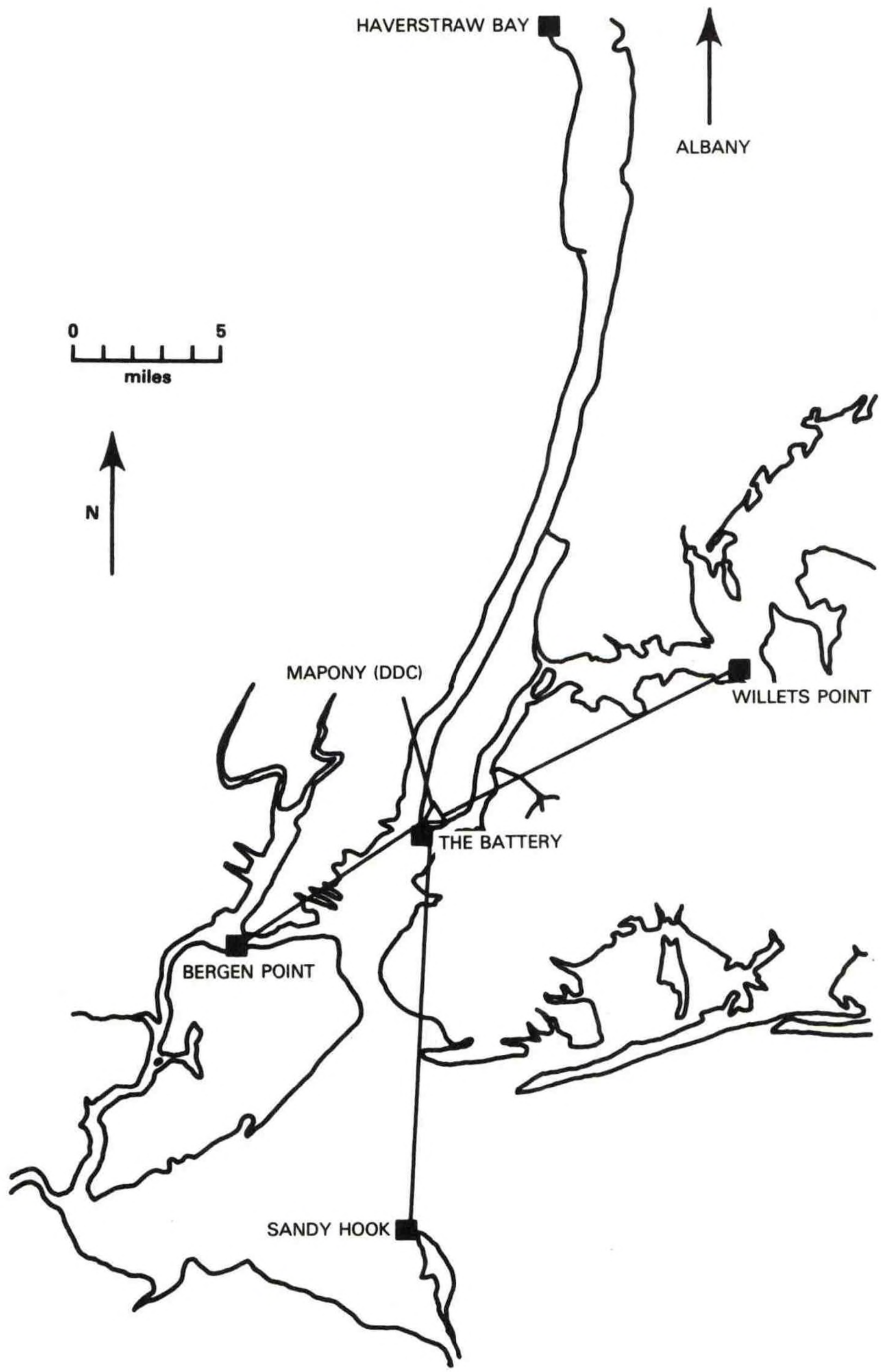

FIGURE 4.
REAL-TIME DATA COLLECTION AND TELEMETRY SYSTEM FOR THE PORT OF NEW YORK

816-2-4-85-11

MACHINERY CONSTRUCTION IN PORT AND HARBOR WORKS

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1. INTRODUCTION

In Japan, there are about 4,000 ports including commercial ports, industrial ports and fishing ports. In association with the port, port facilities, such as breakwater, wharf, and waterway, are constructed top assure the port function to the fullest extent. The construction of these facilities is performed mostly on or in the sea, so it is essential to use construction machinery, i.e., working vessels.

At present, there are about 10,000 working vessels totalling government and private vessels in Japan. The following is the outline of the machinery construction of port and harbour works employing working vessels.

2. BREAKWATER

Breakwaters in Japan are mostly taken the gravity type, typically caisson type breakwaters. The caisson type breakwater construction is consist of construction of the mound (rubble deposition from sand carriers with grab bucket, diver rubble leveling), towing of caissons and placing of caissons. The caissons carried to the place of works are guided to a specified position by tug boats, crane vessels, etc., filled with water, and set on the mound. Then, immediately silling sand is put into the caisson, and a concrete cap is fixed. Construction works demanded a large scale and rapid construction so development of large construction machines and mechanized construction method are required in every part of the works.

Particularly in the leveling of a rubble bed the machinery construction is required to enhance work efficiency and safety in consideration of the depth of the site, therefore the development of leveling machinery of a rubble bed is urgent. The leveling method of a rubble bed currently in R&D stage is largely classified by their mechanism to several types including the method of drawing horizontally and the method of pushing vertically. Of these, the leveling equipment now under development by the Ports and Harbours Construction Bureau, Ministry of Transport will be introduced in the following. This equipment is of the type to move the shoot horizontally while rubble is dumped from the shoot and leveling the crown of mound, i.e., the method of leveling and dumping. The leveling shoot is placed on the rectangular bed set on the crown of mound, and rubble is supplied from rubble-supply-vessel moored just above. Being the bed type, this equipment is hardly affected by the water depth, and is capable of preventing rubble spreading (Fig. 1).

In case the work site is far out at sea, floating mixing plants capable of concrete mixing and handling at the site are used for the concrete works such as coping the caissons. Most of the concrete mixing plants, have been the batching plants hitherto. But interruption of mixing is the disadvantage of this equipment. Lately, the continuous mixing type capable of continuous mixing has started operation. The floating mixing plant of this type can supply the material continuously at a high accuracy and perform a uniform and strong mixing continuously. The continuous mixing plant with its capacity ranging from 90 m^3/h to 120 m^3/h and capable of 1,200 m^3 continuous placing operation without material supply has been cons tructed and in operation.

Production of caisson is either production on land or production on sea. The production on sea using, the floating dock type, is superior of the production on land because a large land site is unnecessary. For this reason, the use of the latter is increasing. As of April 1983, there are around 120 floating docks, and one of the largest class has the lifting capacity of 14,500 tons. It is believed that the floating dock would take its advantage in the caisson production for greater depth breakwaters.

3. GREATER WATER DEPTH BERTHING FACILITIES

One of the typical greater water depth berthing facilities in Japan is the offshore quay utilized for petroleum transport. Around the years of 1965, tanker size grew markedly larger for the reduction of oil transportation cost, and even as large as 200,000 dwt tankers appeared. Accordingly, facilities for berthing such huge tankers became large, and required water depths also became great. As a result, the berthing facility construction point was removed to several kilometers offshore from the existing port.

The structural type of the offshore quay is largely classified to the stationary type and floating type. The former is subdivided to the open piled structure and dolphin piled structure, and the latter the one point mooring system and multi-legged mooring system. At present, there are 35 offshore quays of 200,000 dwt class or greater in Japan, and about half of those are of dolphine piled structure.

The water depths of the dolphine piled structure are generally in the range from 20 m to 30 m. However, there are offshore quays, such as the Okinawa oil offshore terminal for 500,000 dwt oil carriers, which require 40 m water depth. The length of the steel pipe pile, which is a main material, is 60 - 85 m, and its diameter is 1.2 - 2.3 m.

For construction, aiming at the early stabilization during construction and speedy working, the method of jacket is frequently employed, wherein a structure to be obtained by assembling steel pipe sheaths through which piles penetrate is manufactured in advance at the factory, setting it on the sea bed, driving pile into the pipe sheath, and fixing it with the jacket.

As a working vessel, a large pile driving barge and floating crane (a maximum lifing capacity of 3,500 tons) are normally used, however, when the effective working rate markedly decreases with the above working vessels because of the bad marine conditions of the sites, typically due to being located in the open sea, a self-elevating platform is used. There are, at present, 16 self-elevating platforms in Japan, and of them 6 are a large size. The largest self-elevating platform is 5,500 tons in dead weight, 1,500 PS in the main engine MCR, and 55 m in the maximum possible working depth.

For laying pipes, pipe laying vessels were used. For works to dig and burying pipelines, unit dredging machines were used. There are two pipe-lay barges in Japan.

4. FOUNDATION IMPROVEMENT

There are cases when an enough bearing capacity for holding a structure, such as a breakwater, revetment, or mooring facility, cannot be obtained due to soft seabed ground. In such cases, a method to strengthening the seabed ground directly by driving sand piles into the soft clay layer or adding a hardener is employed. Typical of this method are the sand drain method, sand compaction method, and deep layer mixing method.

The sand drain method is such that 40 - 50 cm diameter steel pipes are driven to the subsoil, sand is flown thereinto, and many sand piles almost identical in diameter with the steel pipe are provided. There are 10 sand drain barges currently in Japan, and a large one can make a dozen sand piles at about 45 m under the water level at a time.

The sand compaction method is such that steel pipes are driven similar to the sand drain method, and sand piles (1 - 2 m ϕ) in diameter larger than the steel pipe are produced by inserting sand compulsorily by pressure utilizing the steel pipes and vibrohammer. There are, at present, about 40 sand compaction barges in Japan, whose largest workable depth is 55 m.

The deep-layer mixing method is such that a propeller-shaped mixing apparatus is inserted from a pontoon on the sea into the seabed soft clay layer by pressure while being rotated and improve soft ground into a hard foundation forcedly mixing line or cement stabilizer carried by pressure from the pontoon with soil (Fig. 2).

The deep-layer mixing barges are growing larger and larger in size and greater and greater in working depth, and 6,000 ton class barges can work at a water depth of 70 m at the maximum. There are about 20 such barges.

On the other hand, for the enhancement of the accuracy of construction and the reduction of surveyors, introduction of the auto electric positioning system to these large foundation improving barges is planned. This system is purposed to measure the position and direction of the barge accurately utilizing the auto range finders by light waves, and, in addition, in combination with the electronic computer, to make possible to current position of the barge and the next position of works to be displayed on the display unit at the same time, thus facilitating the guidance of ship.

Typical of foundation improvement works accomplished using these working crafts includes the Daikoku Pier of Yokohama Port and the North Port South District of Osaka Port. In addition, it is expected that many foundation improvement crafts would be used for the reclamation of the New Kansai International Airport due to poor foundation condition there.

5. RECLAMATION

General reclaimed type at sea may be largely classified to the reclaimed type by suction dredger wherein sand is sucked from the seabed by the suction dredger and reclamation is performed by transferring the sand through the discharge pipe by pressure, and the reclamation type by hopper barge wherein soil and sand supplied from the loading equipments at land or dredger are transported by hopper barges and reclamation is performed by direct dumping or using equipments for loading sand.

Typical of works accomplished by the latter type are reclamation for the Port Island and Rokko Island at Port of Kobe.

Transport of sands

In the case of the Port of Kobe, since transportation of sand at land by dump trucks, etc. to be used for reclamation involves such traffic pollutions as noise, vibration, and dust, transport at sea by hopper barges was employed. For the navigation of hopper barges, the pusher type which allows free guidance of hopper barges crossing waterway and is capable of making the fleet of vessels short thus allowing the use of large hopper barges was adopted. This type began to be used in areas of Japan subsequently. The type of hopper of the hopper barge falls into the bottom door type, circular hopper type, non-open door type, etc. The bottom door type is mainly used for the barge which directly dumps sand by opening the hopper door at the reclamation site. It is also used for reclamation under sea level. The circular hopper type is one in which the section of hopper is made semicircular according to the shape of the bucket wheel of unloading machine. The non-open door type is one in which the hopper is a box-form with its bottom closed. Every type is used for reclamation employing the unloading equipment. The volume of the hopper barge is 1,500 - 6,000 m^3.

Unloading

When the place of reclamation is shallow or the outer circumference is bounded by revetment, direct dumping from the hopper barge is impossible. As a result, reclamation by the method of unloading is generally employed. In the reclamation of the Port of Kobe, direct dumping reclamation by the bottom door type is used up to the depth of 2 m, and for the depth less than 2 m, sand unloaded from the circular type hopper barge by the bucket wheel type unloader provided on the reclamation revetment is dumped through the belt conveyor and spreader (Fig. 3).

Unloading equipments are classified the land equipment, and equipment on ship. Typical ones are the reclaimer barge on which unloading equipments of bucket wheel type or grab dredger type is mounted the unloading barge having pump type unloading equipments.

The capacity of these unloading equipments is from 1,500 to 3,000 m^3/h.

6. SURVEY BOAT

For the sounding at sea, water depth is normally checked by the analog type echo-sounder installed on the boat, and the position is measured by the sextant on the boat. The tidal level is found from the data of nearby tide gage. Data thus obtained are manually analyzed, and represented in graphs. As the sounding area is extended, many more analyses are required proportionally, with the resultant large amount of labour and time that must be spent.

To cope with the situation, that which has been developed to perform automatically from every survey to analyses and graphic representation taking advantage of the latest technology of electronics is the automatic survey system. This system is capable of obtaining water depth data of 4 to 6 points at about 2 m intervals, gathering measurements of position and direction of the boat, recording data on the magnetic tape, and generating various graphs, such as depth charts and charts of volume of dredging soil by analyzing the data in a short time using the electronic computer at the land.

The depth chart is generated in such a way that the sea surface is divided to 1.25 to 500 m mesh on an X-Y plotter, mean depth, maximum depth, and minimum depth of that mesh are computed, and the resultant values are typed out

The chart of volume of dredging soil is produced through the computation of the volume of soil to be dredged in the area set similar to above and the typing out of the resultant values by mesh.

At present, about 10 survey boats equipped with such automatic survey system are in operation.

Three of these survey boats can perform water quality and tide flow automatic measurement and sonic prospecting in addition to depth measurement (Fig. 4).

7. FUTURE TREND OF WORKING VESSELS

Regarding the working machinery for port and harbour construction in Japan, performance improvement by the automation of working vessels and efficiency promotion by robotizing underwater works would be attempted.

By automating working vessels to a high degree introducing control technology which shows marked progress lately, performance improvement to a large extent should be attempted.

For example, it involves building an operation system capable of automatically controlling dredger pump flow rate, cutter speed, and dredging speed of the nonpropelling suction dredger to the optimum dredging condition, and realization of unmanned operation of both sides drug heads in the trailing suction dredger.

Robotaization of underwater works is for the promotion of work efficiency and on-the-job safety in underwater rubble leveling, detection of dangerous objects, inspection of completion, etc., which are mainly accomplished manually, by the introduction of underwater robots.

In land works, such as those at automobile factories, robots are used for many jobs. Since underwater works in port and harbour construction involve a variety of works under different conditions and not uniform work such as flow production work, robotization has been delayed.

However, since the trend is such that port and harbour construction in deep water will increase more and more, for the promotion of efficiency and safety of diving work the development of underwater robot is strongly demanded, and a great effort is being made to successful development.

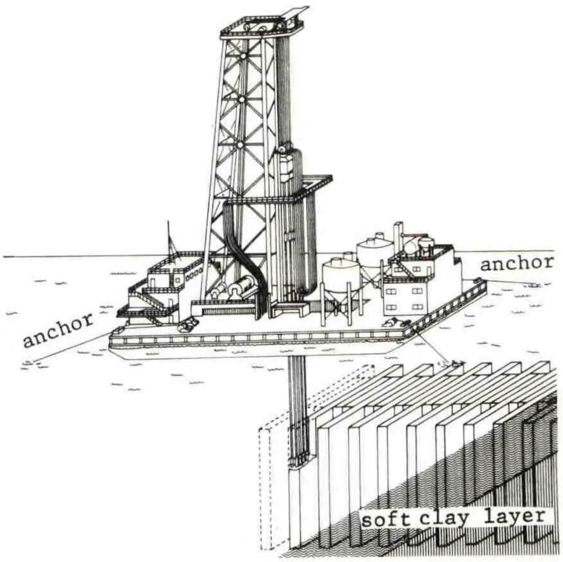

Fig. 2 deep-layer mixing barge

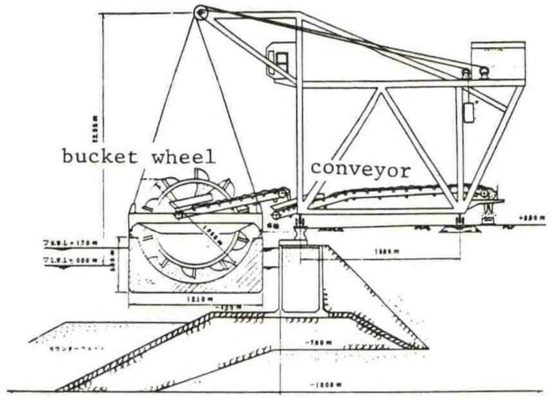

Fig. 3 unloading equipments

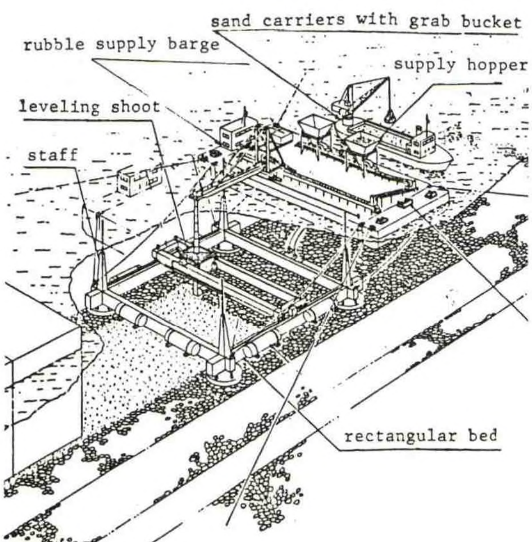

Fig. 1 leveling machinery of a rubble bed

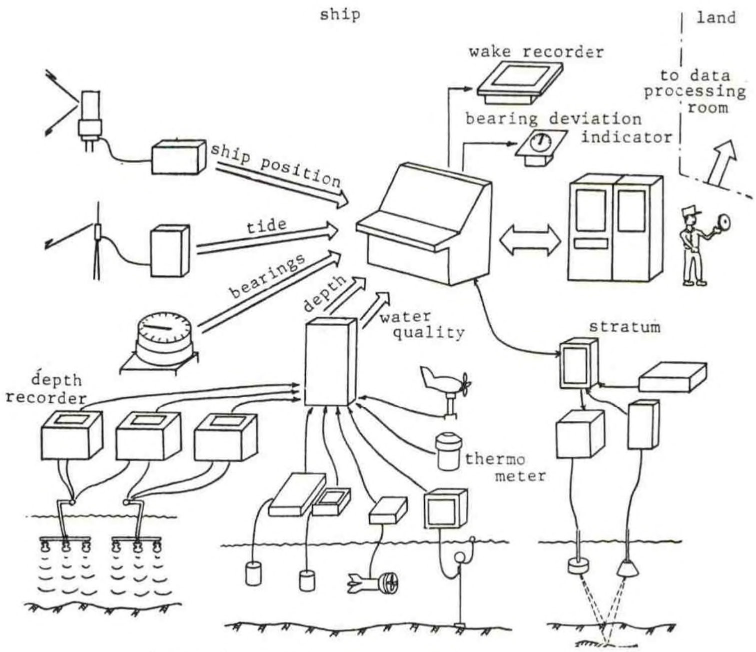

Fig. 4 survey system image

Deep Mixing Method of Soil Improvement for Soft Marine Clays

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ABSTRACT

In order to improve soft clay foundation soil for the construction of the reclamation, port and harbour facilities, Deep Mixing Method (DMM) has been developed in Japan. The method is a kind of in-situ admixture stabilization using lime or cement as a stabilizer. Due to the quick strength increase and due to the extraordinary high shear strength of treated soil, this may be one of the useful technique in the offshore construction. In this article, the outline of the method, its application, current design procedure and scope of the future are described.

Behavior of the improved ground by the method is simulated by centrifuge modeling technique and reported in a companion paper (Terashi and Kitazume, 1985).

INTRODUCTION

Japan is quite mountainous and is consisting of a number of islands and limited plane area has been highly developed for many decades. We have been up to present obliged to reclaim the sea seeking the site for industrial and public usage. For example, the area of approximately 600 km^2 has been reclaimed in 20 years since 1960 to 1980 (Ad hoc Committee of Case Studies of Coastal Reclamation, 1981). Although the rate of the expansion of reclamation has been reduced since the energy crisis in 1973, the needs to reclaim the sea will not be unchanged in the future. However possible site will tend to be in the deeper sea and subsoil condition be more and more difficult than ever. An example for this is the just-started project of a new international airport in Osaka. Feasibility study for the project is suggesting that the site is at water depth around 20 m and the soil condition is thick alluvial clay underlain by layers of clay and sand of diluvial age appearing alternatively up to 400 m from the sea bottom by the available boring data. Geologists suggest that this multiple layers extend up to 1,000 m or more.

In such a sea reclamation or in the construction of port and harbor facilities on alluvial clay deposit, it is absolutely necessary to improve the soft soils in advance to the construction of superstructure. The most common soil improvement techniques employed hitherto have been replacement or vertical drain method. However, for the structure with increasing scale, sufficient improvement is not attained by such techniques in some cases. In some cases, sea bottom sediment in the developed harbor area is so polluted that severe environmental restrictions is to be followed in dredging and dumping of the soft soils. And in some cases, replacement and preloading with the aid of vertical drains will give unfavorable influence on the existing adjacent structures. Therefore, new reinforcement technique of soft soil foundation by manufacturing very stiff treated soil mass in-situ (DMM) have been developed in Japan (Photo 1).

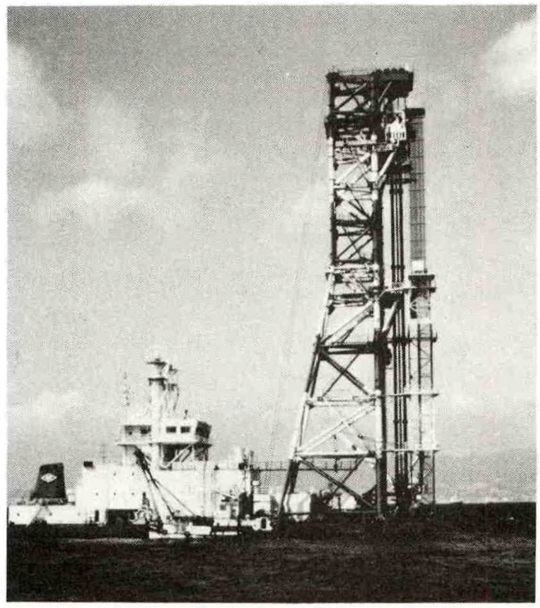

Photo 1 Special DM Barge in Operation

DEEP MIXING METHOD

Deep Mixing Method is a kind of in-situ admixture stabilization technique using quick lime or cement as stabilizing agent. The research work for developing the method started in 1967 at the Port and Harbour Research Institute and the method was brought into practice in 1974 using quick lime and in 1975 using cement milk. In the recent years, the method with cement milk is widely applied to the port construction works.

In practice, special equipment (DM machine) is used to improve the soft soil in-situ. DM machine is basically

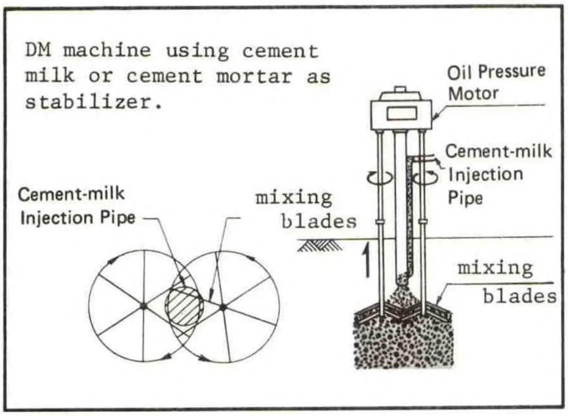

Fig. 1 DM machine with two mixing shafts

consists of several mixing shafts with mixing blades and stabilizer feeding system. Fig. 1 shows the most simple machine with two mixing shafts. The machine is equipped to guide rail of the tower on a crawler type vehicle or on a barge. A column of treated soil is manufactured by the procedure as shown in Fig. 2. During the penetration of the machine to a desired depth of improvement, mixing blades at the bottom end of mixing shafts cut and remold the soft soil and enable the machine to sink by its own weight. In the stage of withdrawal of the machine, stabilizer is forced into the soft soil and thorough mixing of stabilizer with soil is attained by the mixing blades. In order to improve the foundation of relatively low embankment or light weight structure a group of these treated soil columns is manufactured. In the case where a huge treated soil mass is required to support a heavy superstructure, treated soil columns are overlapped one another in the successive operation of DM machine. Actual operation of special DM barge on the sea is already shown in Photo 1.

CURRENT DESIGN PROCEDURE

Treated Japanese marine clays by DMM have high unconfined compressive strength of the order of 1 MN/m^2, small strain at failure of the order of 0.1 %, relatively low tensile strength and low permeability (Terashi et al., 1979 and Kawasaki et al. , 1983). However, strengths of treated soils have a large deviation from its average value even if the manufacturing works were carried out with the best possible care. Furthermore treated soil mass contains weak point at the overlapped surface. Therefore , sufficiently high factor of safety is taken for the strength of in-situ treated soils, which in turn results in extraordinary difference of engineering characteristics between treated and untreated surrounding soft soils. Hence, treated soil mass is considered not to be a part of the ground but to be a rigid structure buried in the ground.

As shown in Fig. 3, current design of the improved ground by DMM is mainly carried out in two stages. The first stage is an "external stability" of a buried rigid structure in which four modes of failures are examined; sliding, overturning, bearing capacity and extrusion. Extrusion is a failure mode considered for untreated soft soil left inbetween treated soil blocks or soil walls which is subjected to the unballance of active and passive earth pressure. In the case of huge treated soil mass as shown in the Fig. 4, it is impossible to manufacture continuous soil mass in the longitudinal direction and untreated soft soil should remain inbetween treated soil blocks. The second stage is an "internal stability" of a structure in which induced stresses should be limited to be lower than the allowable strength of treated soil. Design loads considered both in the external and internal stability analyses are active and passive earth pressures and other external forces exerted onto the boundary of the treated soil structure and mass forces due to gravity and earthquake (Fig. 4).

Above mentioned design concept is derived for simplicity by analogy with the design procedure of a gravity type structure such as concrete retaining structures.

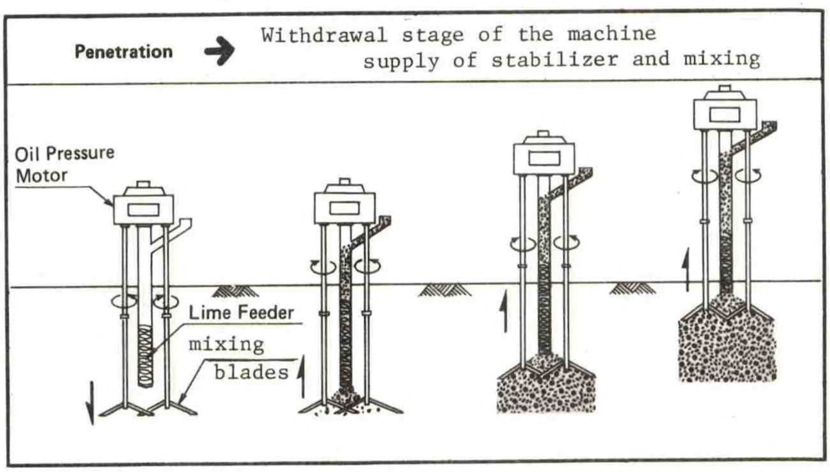

Fig. 2 Procedure of manufacturing a treated soil column in-situ

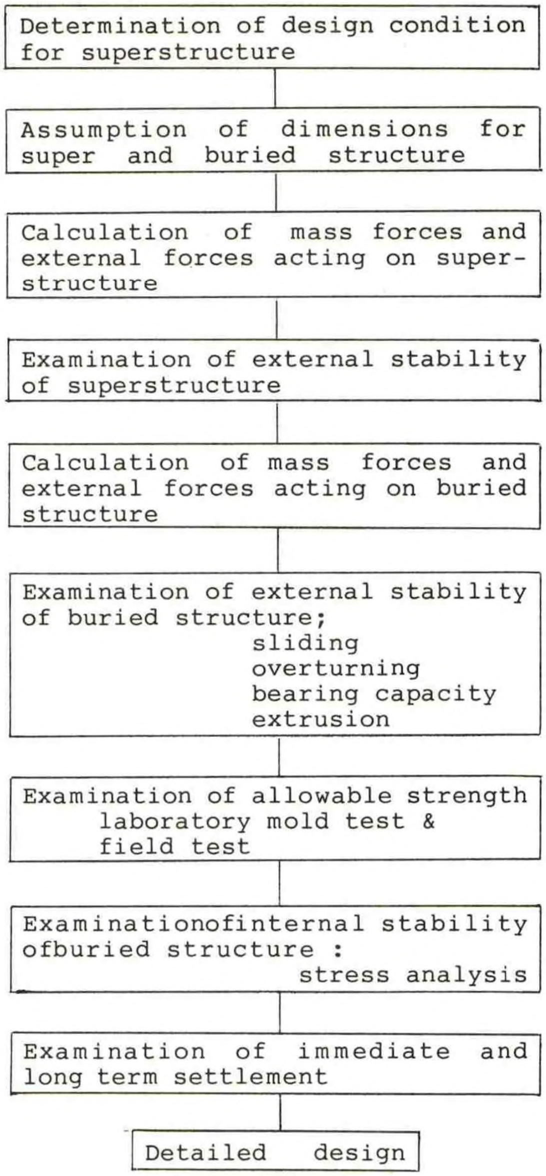

Fig. 3. Flow of the current design procedure

In the current design procedure examining different modes of failure independently, optimum design must be found out by trial and error. An example of these calculation for the most common application of DMM is shown in Fig. 5. In this example, superstructure is a revetment composed of gravel mound and concrete caisson supporting the earth pressure increased by sea reclamation. Superstructure is to be constructed on a soft clay layer underlain by reliable bearing stratum of dense sand as shown in the upper left corner of the figure. First approximation of the shape of treatment in this trial calculation is shown by dotted line. To obtain necessary factor of safety, width B of treated soil mass is increased by changing a distance a and/or b. Three curves in the figure are suggesting the minimum extent of treated soil mass which satisfies the requirement of sliding of the buried

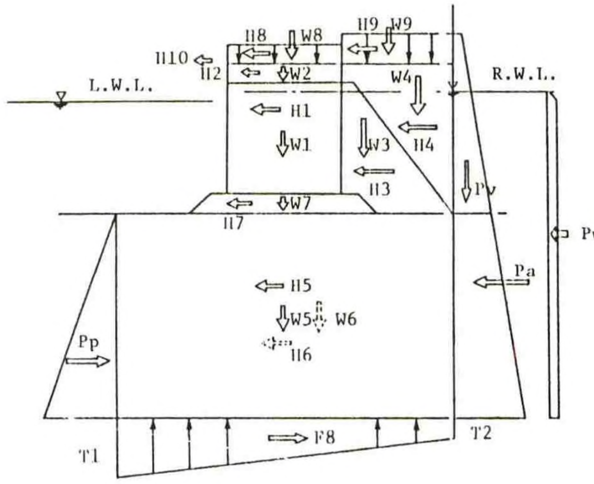

Fig. 4 Schematic Diagram of Design Load

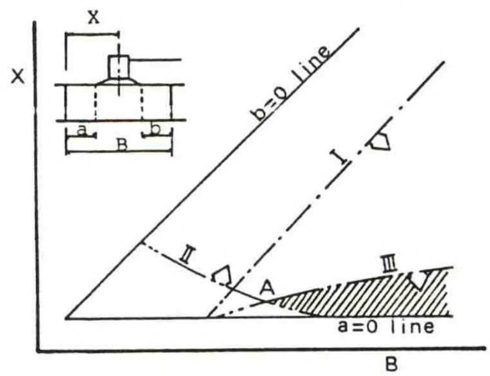

Fig. 5 Determination of Optimum Design

structure (curve I), induced shear stress at the toe of a buried structure (II), and also shear stress in the vertical plane in front of super structure (III). Hatched zone satisfies all the requirements and point A is the optimum. In this particular example, overturning, bearing capacity and extrusion are not the governing factor. As shown, usually, one or two modes become critical factors in determining the shape and extent of treated soil mass. Arrow on each line shows a direction toward the higher factor of safety.

Based on the current design procedure, DMM has already been applied to improve soft clay foundation of several port facilities and a number of light weight or temporary structures. Net volume of improved soil by the method exceeds six million cubic meters.

Problems to be Studied

As is mentioned above, DMM has been applied to a number of practical constructions. However, it is still a new soil improvement technique in which various aspects of problems are left to be studied. For example, boring and sampling technique to obtain undisturbed samples of treated soil is still immature. A variety of DM machine results in the difference in the quality of treated soil. These problems are indirectly but closely related to the design of the improved ground by the method. Regarding the current design concept and procedure, much are left to be studied to increase the accuracy of design and to reduce the cost of improvement. Research efforts by various organizations in Japan are concentrated to the point. At the same moment, complicated three dimensional shape of improved soil mass has been conceived of in order to minimize the volume of treated soil mass as shown in the Fig. 6.

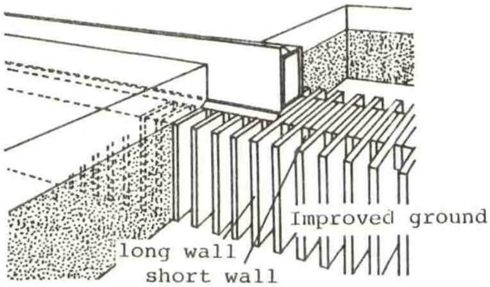

Fig. 6 Wall type of improvement

From the example calculation shown in Fig. 5, it must be easily understood that the optimum design by the current design procedure (point A) is sensitive to the determination of design loads on the boundary and the magnitude of factor of safety. It is natural to take two dimensional active and passive earth pressures as design load for external stability, as long as a buried structure is two dimensional and is resting on a reliable stratum as in the above example. However, it is questionable to apply the same critical earth pressures for the internal stability analysis of a structure whose external stability has been already satisfied. In Fig. 6, earth pressure change during backfilling is schematically shown for rapid and slow rate of filling. When the fill height is increased rapidly to critical height (to failure), earth pressure reach to active and passive state finally. It is the condition of external stability. However, if the fill height is lower than critical which is the case for actual structure, earth pressure is affected by the factor of safety and rate of filling. When the margin of safety is sufficiently large and if the rigid buried structure does not displace during filling, then the earth pressure is dependent only on the rate of filling. In the case of rapid filling, all the fill pressure is carried by the excess pore water pressure. On the other hand, if the rate of filling is sufficiently low as to allow the dissipation of excess pore water pressure, horizontal pressure acting on the buried structure is an at rest pressure under the fill. Real phenomenon will

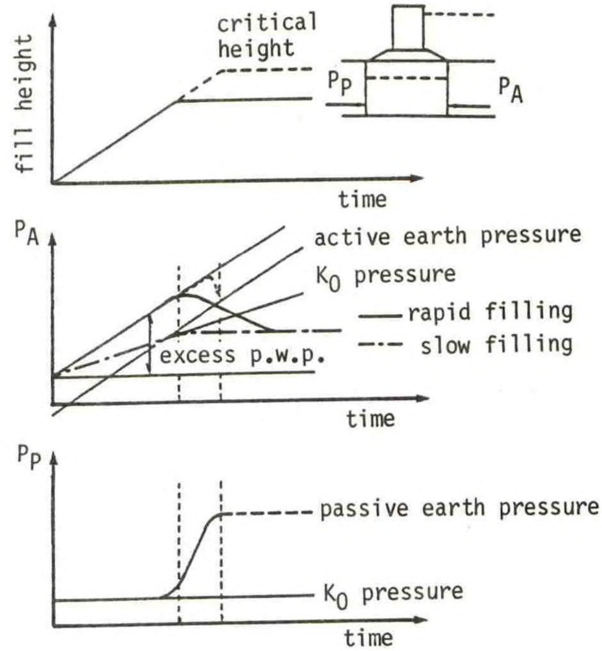

Fig. 7 Concept of Earth pressure change

be inbetween these extremes and this must be the design load for internal stability analysis.

When a rigid buried structure is three dimensional, even for the external stability, further consideration is required for the pattern of failure and for the determination of design loads. Extrusion failure is the typical three dimensional failure (Terashi, et al, 1983). When a rigid buried structure is floating in the soft clay,the magnitude and distribution of contact pressure is highly dependent on the mode of displacement of a rigid structure.

To establish rigorous design method, (i) clear understanding of the design loads acting on boundaries of a buried structure, (ii) improvement of the accuracy of calculation for each mode of failure and (iii) selection of adequate factor of safety for each mode and establishment of appropriate allowable strength for treated soil are required.

Recent Research on DMM

Research group at Port & Harbour Research Institute have started a series of research project to reveal the engineering behavior of the improved ground. In the first step, each mode of failure assumed in the current design procedure (Fig. 3) has been examined by geotechnical centrifuge modeling and elasto-plastic FEM analysis in the soils division, PHRI. Large shaking table test of the model improved ground, dynamic analyses and observation and record of earthquake motion at site are carried out in the structures division. As a part of a feasibility study for the new international airport in Osaka Bay, full scale loading test was carried out by the Third District Port Construction Bureau in collaboration with Port and Harbour Research Institute.

Centrifuge Modeling

Extrusion failure, a typical failure mode for wall type was studied by Terashi et al. (1983). From the test results, evidence of the extrusion failure was observed where soft soil underneath the fill material behind the revetment was squeezed out through the narrow spacing between long walls. Movement of the soft soil inbetween the long walls was almost horizontal and parallel to the underlying sandy layer as shown in the Fig. 8. No large strain was observed to develop within the soft soil, which means that the soft soil mass moves as rigid body under the unballanced earth pressures acting on it. A diagram for estimating the extrusion failure is obtained as a kind of stability number Heq (equivalent fill height) which is a function of density of the fill material, fill height, shear strength of soft soil and spacing of the long walls.

External loading condition for the internal stability analysis is also studied by a series of centrifuge model test. Details of the test results for a rigid buried structure of the wall type resting on a stiff sandy layer is reported in a companion paper (Terashi and Kitazume, 1985).

Full Scale Test

Loading test on the full scale improved ground of wall type was carried out to investigate the validity of the current design procedure of DMM. Loading was applied by gravel mound, concrete caisson and back filling as in the case of centrifugal model test.

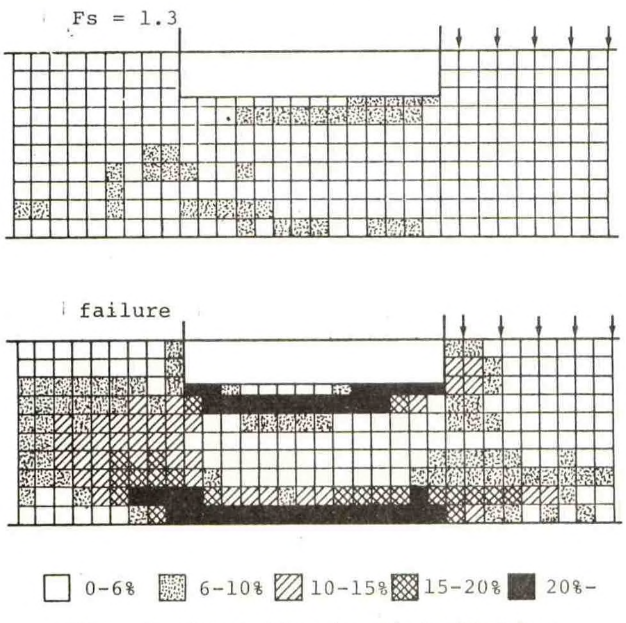

Fig. 8 Shear Strain Distribution

The test was ended by the sliding of super structure. Measurement of displacement of buried structure and superstructure, contact pressures, and strains inside the treated soil mass has been carried out successfully until the end of the test. Obtained data also support the findings by the above mentioned centrifuge study. Yajima and Terashi (1984) have reported the detail.

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CENTRIFUGE MODELING OF IMPROVED GROUND BY D.M.M.

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ABSTRACT

Deep Mixing Method has been applied in Japan to reinforce soft clay by manufacturing an extraordinary stiff treated soil mass in-situ. Interaction of soft alluvial soil and this treated soil walls resting on reliable stratum is investigated to improve current design procedure. It is known from the centrifuge model test that the external forces are carried solely by the treated soil walls, that the magnitude and distribution of contact pressures at the surface of treated soil mass is dependent on the magnitude of factor of safety against external stability, and that the pressures change with time due to consolidation of soft untreated soil.

INTRODUCTION

Deep Mixing Method(DMM), a deep in-situ admixture stabilization using cement slurry, has been developed in Japan to reinforce soft alluvial clays . In practice, huge treated soil mass whose shear strength exceeds 1 MN/m^2 is formed to support superstructure. Due to the large difference in the engineering characteristics between treated soil and untreated soft soils, treated soil mass is assumed to behave as a rigid structure buried in soft ground. Details of DMM, its application and current design procedure are described in a companion paper in the same proceedings (Terashi, 1985). In the present article which is a part of a paper submitted to the coming 11th ICSMFE (Terashi et al, 1985), interaction between soft soil and this rigid buried structure manufactured by DMM is investigated. Special attention is paid to the time dependent change of earth pressure and pore water pressure acting on the surface of rigid structure of wall type resting on a reliable sand layer.

CENTRIFUGE MODELING OF A BURIED RIGID STRUCTURE

test procedure

Model study of a super structure and improved ground is carried out using a large geotechnical centrifuge at Port & Harbour Research Institute (Fig. 1). Details of the centrifuge is described by Terashi et al (1984). Present model tests have no particular prototype and the purpose of the tests is to know the interaction between soft soil and extraordinary stiff treated soil mass of wall type resting on a reliable stratum. Soft clay ground is modeled by kaolinite whose liquid limit, plastic limit, and Gs are 71.5 %, 32.9 % and 2.58 respectively. Bakelite stiff enough to model treated soil whose density is 1.39 g/cm^3 is used to model a rigid buried structure. Toyoura standard sand which is uniform fine sand with Uc = 1.33, D_{10} = 0.12 mm and G_s = 2.64 is used to model underlying sand layer and fill material. Concrete caisson for revetment is modeled by cement mortar with density = 1.71 g/cm^3. Due to the selection of these materials, consolidation of clay ground and instrumentation for contact pressure measurement are carried out with ease.

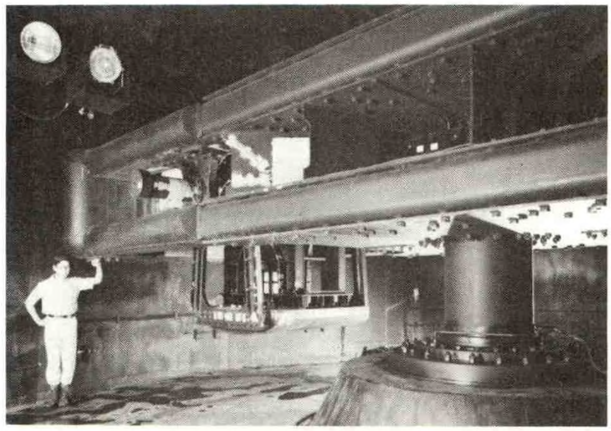


Fig. 1 PHRI Centrifuge

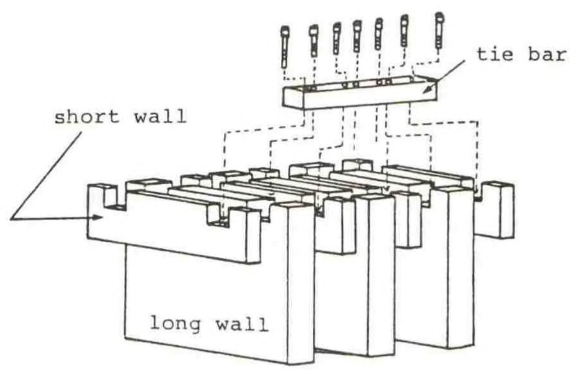


Fig. 2 Model of treated soil walls

Longwallsof amodelrigid buried structure (Fig. 2) is placed on the

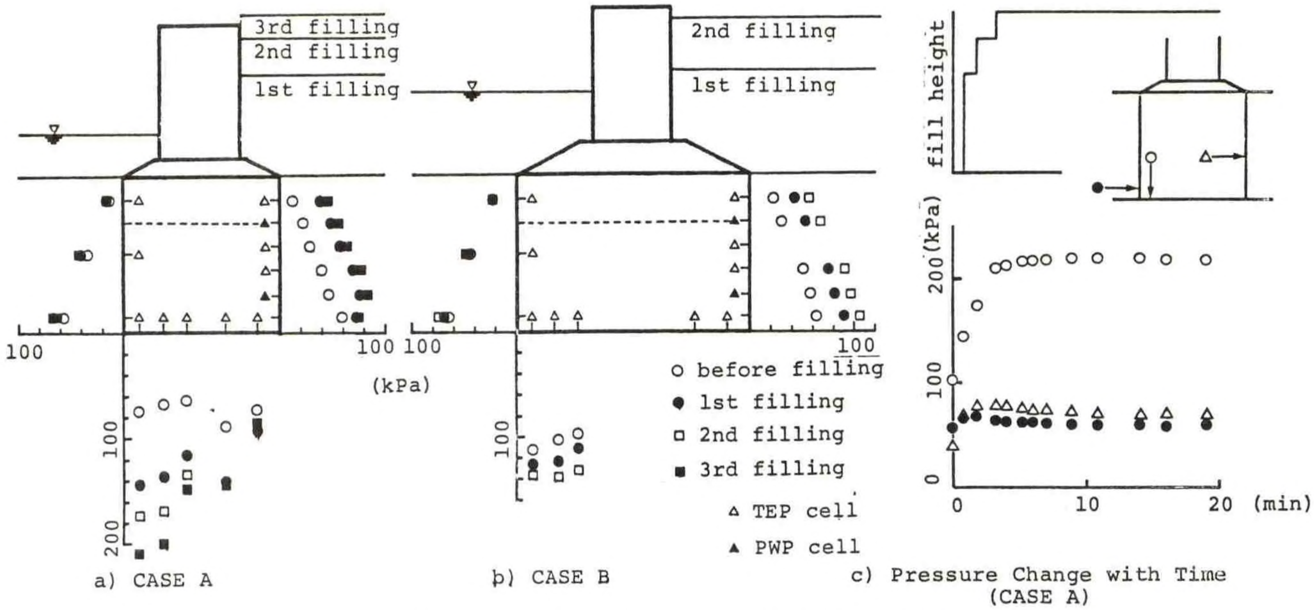


Fig.5 Measured Pressure in the Filling Stage

factor of safety for sliding in case A is around unity. Disagreement between applied vertical stress and measured pressure increment in the case A seems to be due to the horizontal displacement of a buried structure. TEP and PWP on the front of a buried structure shows negligibly small increase with filling in both cases. The pressure increase with filling and decrease with the consolidation of clay is shown in Fig. 5c.

Change of horizontal pressure with time and change of contact pressure distribution at the bottom of long wall is clearly shown in Fig. 6. Increment of resultant vertical force calculated from the measured contact pressure agrees well with the vertical increment of external force.

Fig. 7 shows the TEP and PWP measured in between the long walls and those measured at the vertical surface of treated soil wall at the heel and toe immediately after the filling. The distribution of induced pressure increment in between the long walls is linearly decreasing from heel to toe of the buried structure. Most of this pressure increment disappears with time. It seems that the pressure distribution is dependent solely on the difference of excess pore water pressure between the front and rear of a structure and hence it disappears with dissipation of excess pore water pressure underneath the filling.

These evidences suggest that the external force is carried mostly by the rigid buried structure. From the measured pressures, however, no strong evidence is found of large stress concentration on long walls along the vertical plane at the heel. Therefore, in the external stability analysis of wall type improvement except extrusion, two dimensional earth pressure is applicable as design load along the vertical planes at the heel and toe of a buried structure. Horizontal force acting on soft clay in-between the long walls is considered to be transmitted to long walls by adhesion. The force carried by long walls is finally transmitted to bearing stratum.

Contact pressure at the bottom of long walls is calculated by assuming that the buried structure is rigid and

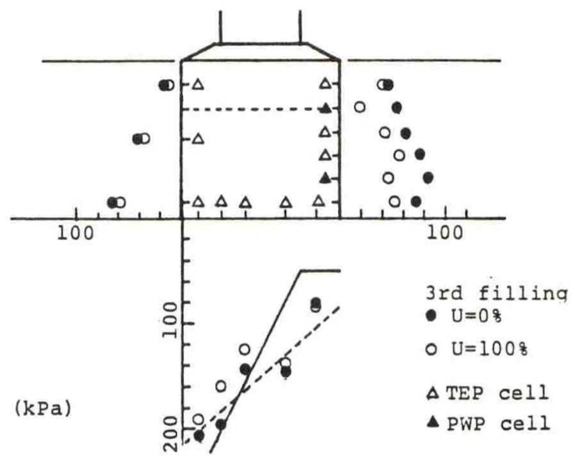


Fig. 6 Pressure Re-distribution due to Consolidation

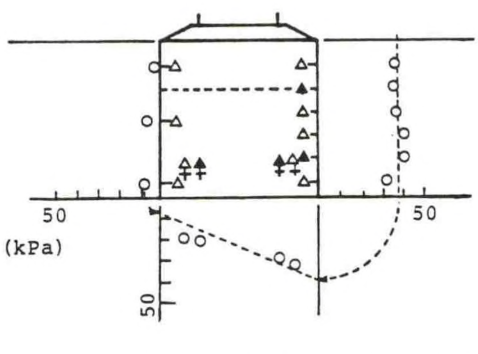
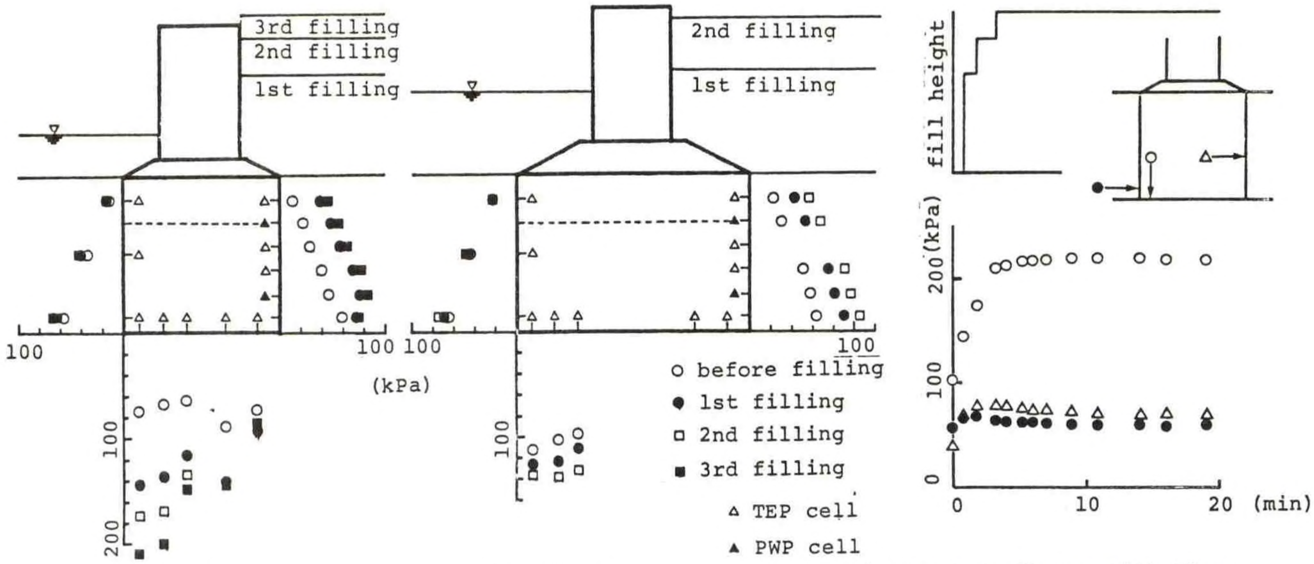


Fig. 7 Pressure Increment between Walls



a) CASE A b) CASE B c) Pressure Change with Time (CASE A)

Fig.5 Measured Pressure in the Filling Stage

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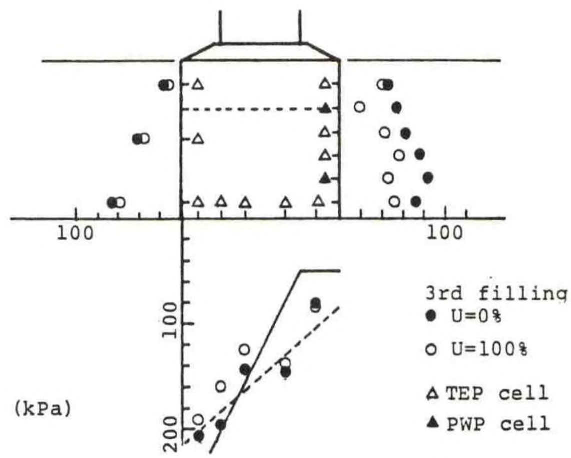

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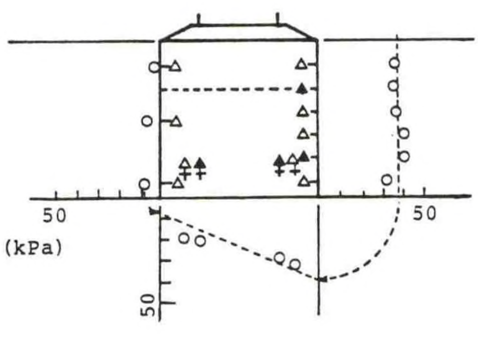
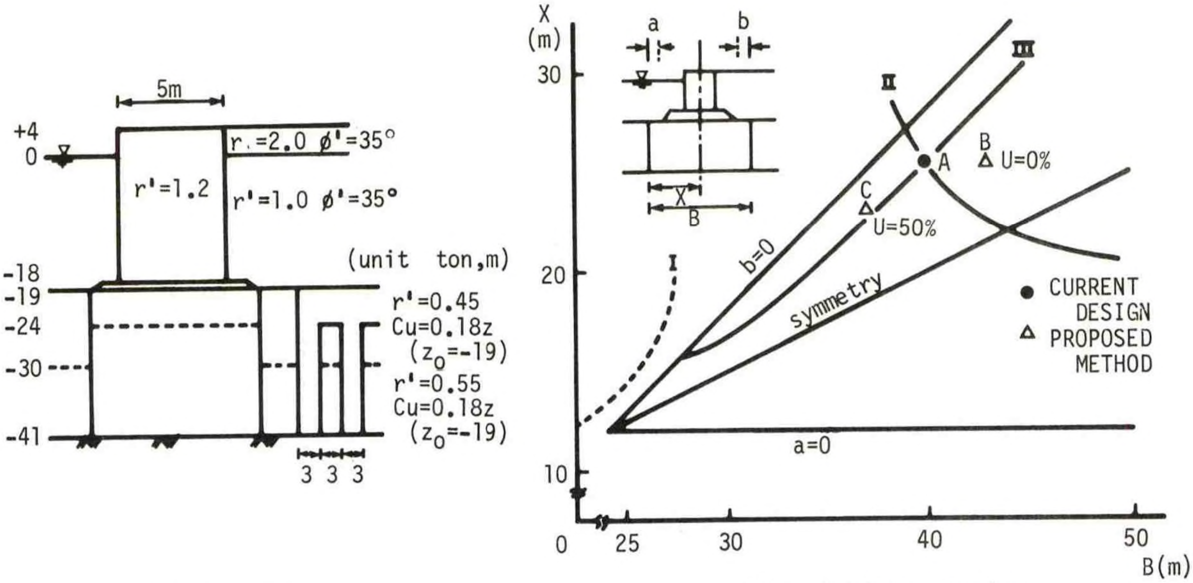


Fig. 7 Pressure Increment between Walls



(a) Cross Section (b) Optimum Design

Fig. 8 Change of Optimum Design with External Loading Conditions

it seats on the elastic springs. As is already described, the resultant vertical stress at the bottom of the long walls agrees well with the vertical external force and mass force. However the calculated contact pressure distribution based on the horizontal component of earth pressure (solid line in Fig. 6 for U = 100 %) is steeper than measured one. This is probably because no account was taken for the vertical component of earth pressure from the fill and shear stress induced in the clay layer on the surface of a buried structure to restrain the rotational movement at the instance of loading and the negative skin friction in the long run. Contact pressure distribution taking account of vertical component of earth pressure of the fill material and the negative skin friction acting on the treated soil walls is shown by dotted line in Fig. 6 for U = 100 % which is the better fit for the test results than solid line. The similar result is obtained from the elasto-plastic FEM simulation of the tests.

Effect of the External Loading Condition on the Optimum Design

In the current design practice, active and passive earth pressures are taken as external load for both internal and external stability analyses. When the rigorous consideration is paid on the rate of filling and the rate of consolidation, both the external and internal stability are influenced tremendously. Fig. 8b shows these effect on the optimum design of revetment under the condition shown in Fig. 8a. Lines I, II, and III represent the critical lines for sliding failure, shear stress at the toe of buried structure and shear stress inside the buried structure. Point A represents the optimum design by the current design procedure and point B and C represent the optimum design for rapid construction and slow construction.

CONCLUSION

Interaction between soft soil and a rigid buried structure sitting on the reliable stratum is studied by means of centrifuge modeling. From the study, it is known that the design load condition is sensitive to relative movement of a rigid buried structure to surrounding soft soils and to the rate of filling.

Conclusions drawn from the present study are as follows.

i) Design load condition in "internal stability" should not be the critical active and passive earth pressures.

ii) When the margin of safety against external stability is sufficiently large, K_0 pressure must be taken at the front of a rigid buried structure.

iii) Underneath the fill, earth pressure must be calculated as a sum of effective horizontal stress and excess pore water pressure. It means that the rate of filling influences the loading condition.

iv) In the analysis of internal stability, it is reasonable to consider that all the external forces are carried by a rigid buried structure.

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STRATEGIES FOR MARINE ENVIRONMENTAL QUALITY ASSESSMENT

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ABSTRACT: The organizational and scientific strategies of the Marine Environmental Quality Assessment Program at the U.S. Naval Ocean Systems Center, San Diego are presented. The scientific effort is directed towards determining stress in individual organisms and in community structure produced by non-lethal but chronic exposure to harmful pollutants.

INTRODUCTION

The National Environmental Policy Act (NEPA) of 1969 made environmental protection and pollution abatement a national mission in the United States. Subsequent Executive Orders called on federal agencies to provide leadership in a nationwide effort to protect and enhance the environment. In April 1971, Chief of Naval Material tasked the Naval Ocean System Center (NOSC) to conduct a research and development program in environmental quality assessment (MEQA). The primary goal was to develop the technology necessary to define, measure and predict the environmental impact of Naval activities on the harbors and coastal areas in which they operate.

The rationale for such a program was clear. In order to maintain compliance with environmental regulations and keep the cost of pollution control within reasonable bounds, the Navy needed to acquire advanced methodology for accurately determining environmental quality. Such technology would enable the Navy to optimize its own pollution abatement programs, identify its own liabilities from those of other potential polluters and to predict the environmental consequences of its activities. The latter would avoid future problems with regulatory agencies, expedite operations and minimize capital investments.

Environmental assessment is not a simple task. One deals with questions which are inherently complex because they are multi-faceted, multi-disciplinary and constantly changing as technology and methods of analysis improve. Environmental criteria are essentially judgements based on direct information, comparisons with information previously collected and consultations with "experts" (Figure 1). The final value judgement is usually based on biological criteria. These criteria arise from two types of environmental alterations: a) those which relate to the aesthetics, economics and well being of the local population and b) the more subtle environmental changes among biological communities caused by chronic, yet sublethal toxicity.

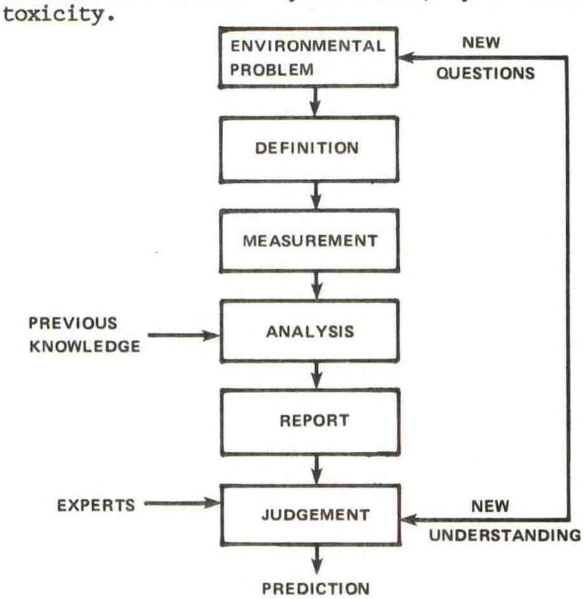


Figure 1. The marine environmental quality process

The first type of environmental insult is of little concern to the research community since it is easily detected and legislated away. On the other hand, long term, chronic effects require much investigation since they often resemble "natural" changes and may be subject to much debate. It is the latter which must be addressed by a comprehensive research program. (At present, a principal Navy concern is the environmental impact of the heavy metal-based antifouling coatings (paints) which cover the hulls of all ships.) A final complication is that environmental insults are not necessarily constant over time and space. Estuaries are notoriously dynamic in both of these variables. Thus, a satisfactory environmental research program must both supply information on subtle biological phenomena and a comprehensive field measurement capability.

This paper presents an overview of the NOSC marine environmental program and discusses three of the research strategies in some detail.

STRATEGY

In order to adequately serve present and future Navy requirements, the MEQA R&D program must be able to obtain accurate and timely information and to pass on this information, in a usable form, to the Navy field activity which has need of it. For this purpose, the NOSC environmental R&D effort is organized into four distinct work areas wherein information is collected by the first three and disseminated by the fourth. The four work units are:

1) Development of analytical methods and instrumentation. This work unit is tasked with developing cost-effective technology for measuring, defining and predicting marine environmental quality when commercial technology is not available or adequate.

2) Biological Effects. This work unit provides methodology for biological testing. Efforts are directed towards identifying molecular products in marine organisms subjected to chronic, but sublethal toxicity. Other work is directed towards developing standardized testing procedures.

3) Field Survey Methodology. The emphasis of this work unit has been the development of protocols for rapid biological field surveys and for real-time chemical and physical measurements. This effort has resulted in the development of an instrumented houseboat known as the Marine Environmental Survey Craft (MESC) [1].

4) Information and Technology Transfer. This work unit collects environmental information and makes it available to the Fleet and Facilities. Simultaneously, it keeps abreast of Navy environmental problems and provides guidelines for future research.

The relationship between the four work units, the Fleet and Facilities and the scientific and regulatory communities are shown in Figure 2.

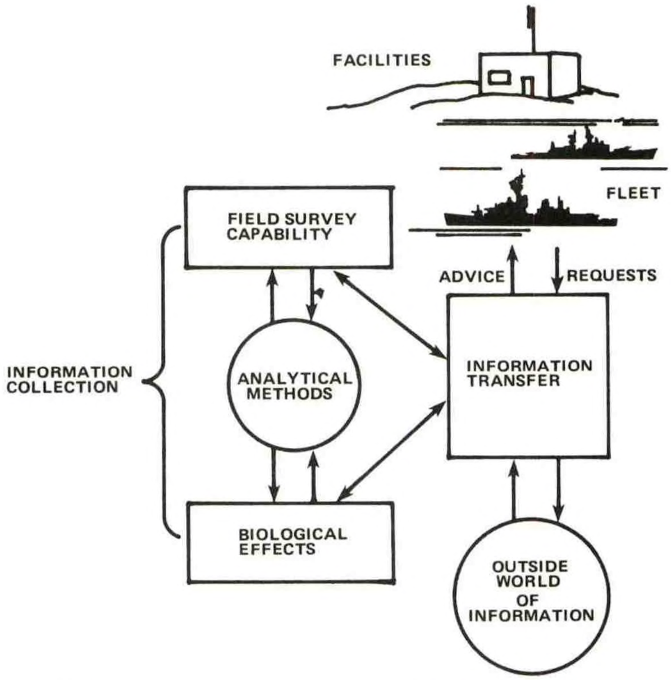


Figure 2. Organization of the MEQA program

MARINE ENVIRONMENT SUPPORT OFFICE

The full value of each of the work areas above can only be realized if the relevant environmental information can be transferred readily, in a useable form, to the ultimate user. In the U.S. Navy, the users are primarily the Environmental Field Divisions (EFD's) of the Naval Facility Command which deal directly with the local, state and national regulatory agencies. The EFD's are charged with obtaining permits for dredging, construction, waste disposal and any other alteration to existing marine facilities. Similarly, Officers In Charge of Construction (OICC's) are charged with obtaining permits for the construction of new Naval facilities. Since environmental issues are often complex and guidelines are either unclear or subject to change, both EFD's and OICC's often need expert opinion from the research community. On the other hand, the research program can be responsive to the Navy's needs only if it has an ear to the Navy's problems. For this reason the MEQA program instituted the Information and Technology Transfer unit. The primary "product" of this unit is the Marine Environmental Support Office (MESO). Via a telecommunications network, MESO will be the interface between EFD's, OICC's and planning units and the body of environmental information available in the public, private, academic and military sectors. MESO is intended to be the "in-house" consultant on the technical aspects of marine environmemntal quality and the regulatory aspects of environmental compliance. Additionally, MESO is expected to provide imputs into the Navy's Environmental Protection R&D Program. Figure 3 shows how MESO is intended to interface between the users and suppliers of environmental information.

BIOLOGICAL EFFECTS

I. Individual Organisms

Our previous article, "Real Time Environmental Survey Techniques" [2] stressed the MEQA program's emphasis on field methodology and described some of the field survey techniques and instrumentation developed at the Naval Ocean System Center, San Diego. It dealt primarily with the development of an instrumented houseboat

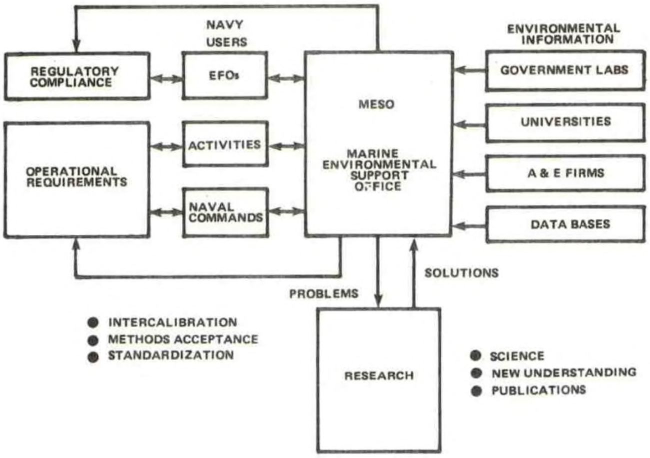


Figure 3. Relationships between MESO, the Navy and other environmental activities

(Marine Environmental Survey Craft or MESC) and with some electrochemical instrumentation capable of measuring trace levels of Cu and other heavy metals in seawater in or near real-time. This paper presents some exploratory methodology for determining the biological effects of chronic, low-level environmental insults.

It is important to assess the environment before permanent damage occurs to its inhabitants. Present technology for environmental assessment depends primarily on estimating numbers of surviving organisms, after the damage has been done. For this reason, the MEQA program has carried out research on biochemical methods for determining stress in marine organism. At this point, it should be emphasized that the problem is complex because most animals have some ability to cope with toxins. Thus, simple tissue burdens of toxicants may not indicate stress. For instance, at non-lethal concentrations, mussels may sequester toxic metals with metal binding proteins, thereby mitigating or avoiding the toxic properties of the metals.

The MEQA project intends to develop rapid, sensitive and quantifiable methods of assessing the health status of impacted marine organisms at sites of Naval relevance. The present approach is to develop quantititative assays for "stress proteins" which may appear in the "blood" (hemolymph) of mussels and oysters [3]. The latter organisms were chosen because they are virtually ubiquitous, sessile, and easy to sample and monitor. Figure 4 shows diagrams of the scientific approach.

Three types of "stress" proteins are being considered as indicators of environmental insult: (1) hydrolytic enzymes, such as lysozyme, which appears in the hemolymph at the onset of irreversible cell breakdown and tissue death; (2)metallothioneins which act to bind and thus detoxify heavy metals; and (3) components of the mixed function oxygenase (MFO) system which detoxify organic pollutants by making the invading toxic organic molecule more susceptible to cleavage and final breakdown by other enzyme systems. The first type of response is termed "passive" because it does not constitute a defense by the organism but rather is a sign of internal damage. The other two responses are termed "active" because they represent actual defense mechanisms which (when activated) can enable the organism to pursue its normal functions despite exposure to toxins.

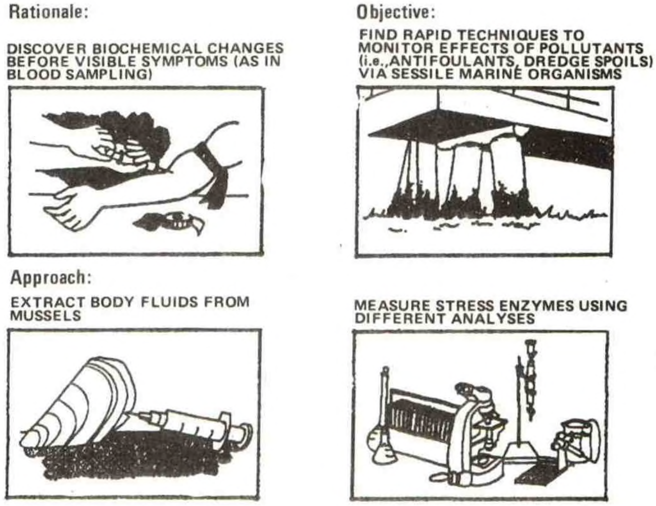


Figure 4. Biochemical environmental impact assessment

As mentioned earlier, present research efforts are intended to determine the environmental effects of Cu and organotin-based antifouling paints. Thus, sensitive immuno-assays are being developed to study these agents. Figure 5 shows a diagram of the expected mussel response and of the "stress" proteins under investigation. The approach is three pronged: (1) mussels are stressed in the laboratory with known toxicants, such as Cu. The "stress" protein, lysozyme in this case, is then isolated from the hemolymph, purified and (2), injected into New Zealand white rabbits. The rabbits develop antibodies specific to the mussel hemolymph which are then extracted from their serum. (3) The purified antibodies are then used to quantify the amount of lysozyme in mussels collected in the field.

The method currently employed for this is known as Enzyme-Linked Immunosorbent Assay (ELISA). The ELISA technique works as follows: A suitable "test" enzyme that will bind with the antibody is chosen. Alkaline phosphatase was chosen in this case. This "test" enzyme will produce a color when added to a neutral substrate (a 1mg/ml solution pf p-nitrophenylphosphate in pH 9.6 buffer). When the antibody, alkaline phosphatase and substrate are combined and the excess antibody is washed away, no color is produced because the alkaline phosphatase has been tied up by the antibody and rendered inactive. On the other hand, when the lysozyme from the mussel hemolymph is added, the antibody preferentially binds to it, thereby freeing an equivalent amount of alkaline phosphatase. The "freed" alkaline phosphatase can now produce a color with the substrate. The intensity of the color is then proportional to the concentration of mussel lysozyme. The advantage of the ELISA method is that it can be performed in the field, since the antibody-alkaline phosphatase substrate mixture can be immobilized and preserved on a small plate and the color read by eye or with a portable spectrophotometer.

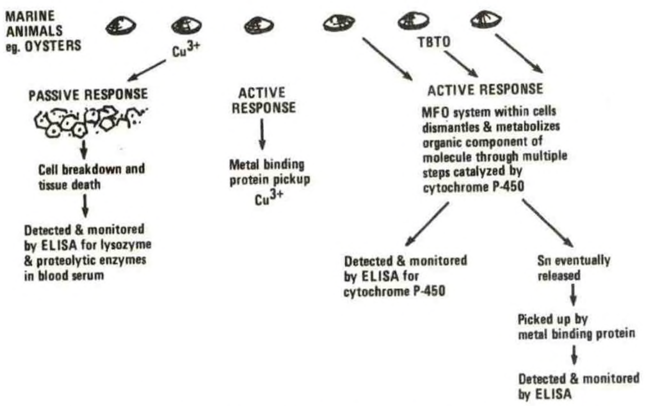


Figure 5. Biochemical responses of organisms to toxins

The details of this work have been given by Pickwell and Steinert [4] and Steinert and Pickwell [5]. Figure 6 shows a plot of lysosome released into mussel hemolymph in response to cupric ion challenge. The lysozyme activity was measured using conventional laboratory methods. Figure 7 shows ELISA-determined hemolymph 0ysozyme concentrations in Cu exposed mussels. The occurrence of lysozyme activity several days after Cu was removed suggests that latent tissue damage occurred following the first exposure.

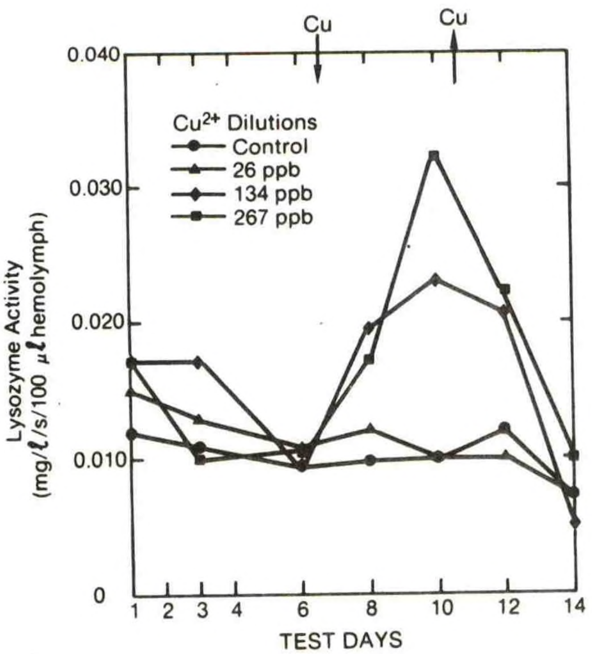


Figure 6. Lysozyme released into mussel hemolymph in response to cupric ion challenge

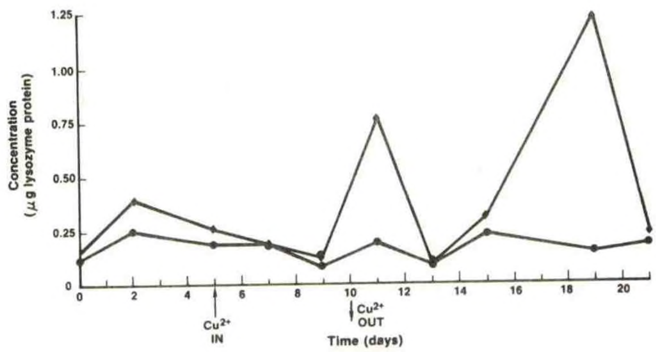


Figure 7. ELISA-determined hemolymph lysozyme concentrations in mussels. (upper line, 160 ppb copper-exposed mussels; lower line, controls

II. Community Effects

While the biochemical determination of stress in individual organisms is important for forecasting of environmental damage, it is virtually impossible to project precisely the results of this stress beyond the population of organisms immediately affected. That is to say, ecological communities can be thought of as a network of organisms in constant competition, fighting for food and shelter. Over time, the community, which consists of plants and animals, reaches a "steady state", a dynamic condition in which the requirements of each member of the community are balanced against those of the others. The removal of a single population of organisms will produce a "domino effect" within the community, leading to complicated rearrangements, and, if given enough time, to a new "steady state". Because ecosystems are very complex, and most of the components and interactions are not known, it is very difficult to predict analytically the new "steady state" from individual perturbations.

A way of obtaining community information is to construct analogue models of specific ecosystems. These are known as microcosms [6]. The NOSC microcosms are located on the Mokapu Peninsula, on the island of Oahu, Hawaii. It consists of twelve, approximately 1 m square, 0.5 m deep fiber-glassed tanks placed on the roof of NOSC's Ulupau, waterfront laboratory (Fig. 8). The tanks are flow-through, that is, fresh seawater is pumped from an inter-tidal reef adjacent to the laboratory into the tanks and allowed to overflow. The system maintains a constant head, thus constant flow rates can be maintained. Since the tanks, by necessity, have higher surface area to volume ratios than the natural environment, this difference can be compensated for by choosing the appropriate flow rate. Figure 9 shows a schematic diagram of a tank with its inlet and outlet plumbing and metabolic monitoring apparatus.

Microcosms are useful for studying the effects of pollutants on naturally recruited or

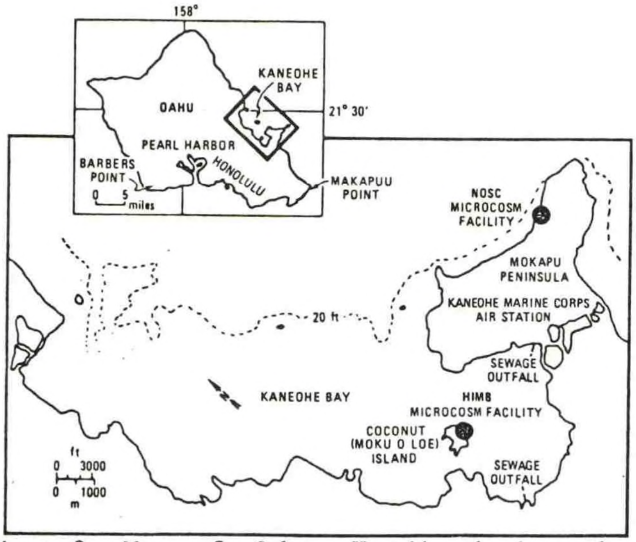


Figure 8. Map of Oahu, Hawaii showing the location of the NOSC microcosm facilities

transplanted shallow water communities. The organisms of a typical soft-bottomed microcosm community are shown in Figure 10. For an experiment to study the effect of pollutants on the natural recruitment of organisms, the tanks are prepared by placing the appropriate substrate on the bottom (mud, sand, crushed coral and individual testing panels), and allowing the water to flow. Ambient light can also be reduced if desired by placing screens over the tanks. Over time, natural populations of animals and plants carried by the inflowing water will settle in the tanks. The predominant species, however, will be determined by the condition of the water.

Thus, for a typical experiment, several tanks will be designated as controls and no pollutant will be added to them. The others, designated as "test tanks" will have some foreign substance added to the inflowing water, in such a manner that the concentration of pollutant will be constant over time. Three types of pollutants have been tested at the NOSC facilities: the nutrient elements ammonia and phosphate common in sewage and waste waters, ionic copper and copper-based antifouling paints and organotin antifouling paints. The results of an elevated nutrient experiment have been published [7] and will be summarized here. Six tanks were used in the experiment: two were kept as controls, two were enriched by about 8 micromoles of phosphorus as phosphate and the last two by an equal amount of nitrogen as ammonia. The tanks were first "aged" for 126 days and were then nutrient enriched for 66 more days. Dissolved oxygen was measured as an indicator of community production and metabolism.

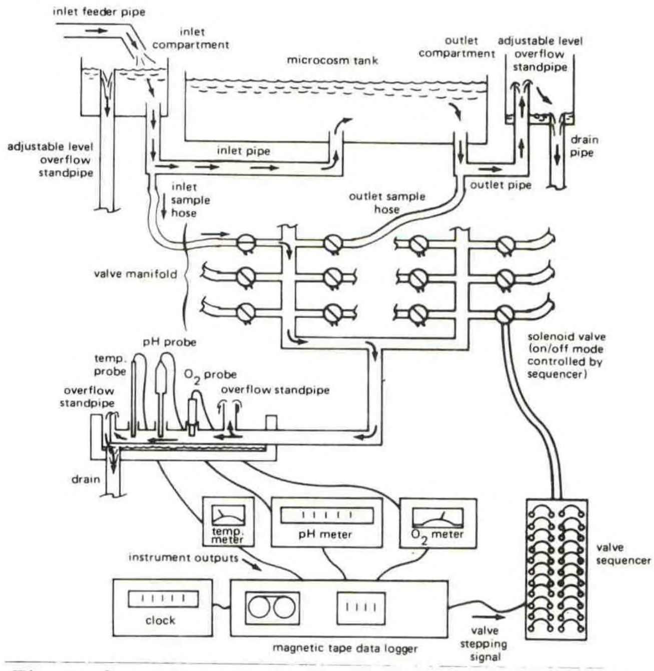


Figure 9. Schematic of plumbing and metabolic monitoring apparatus for a microcosm tank

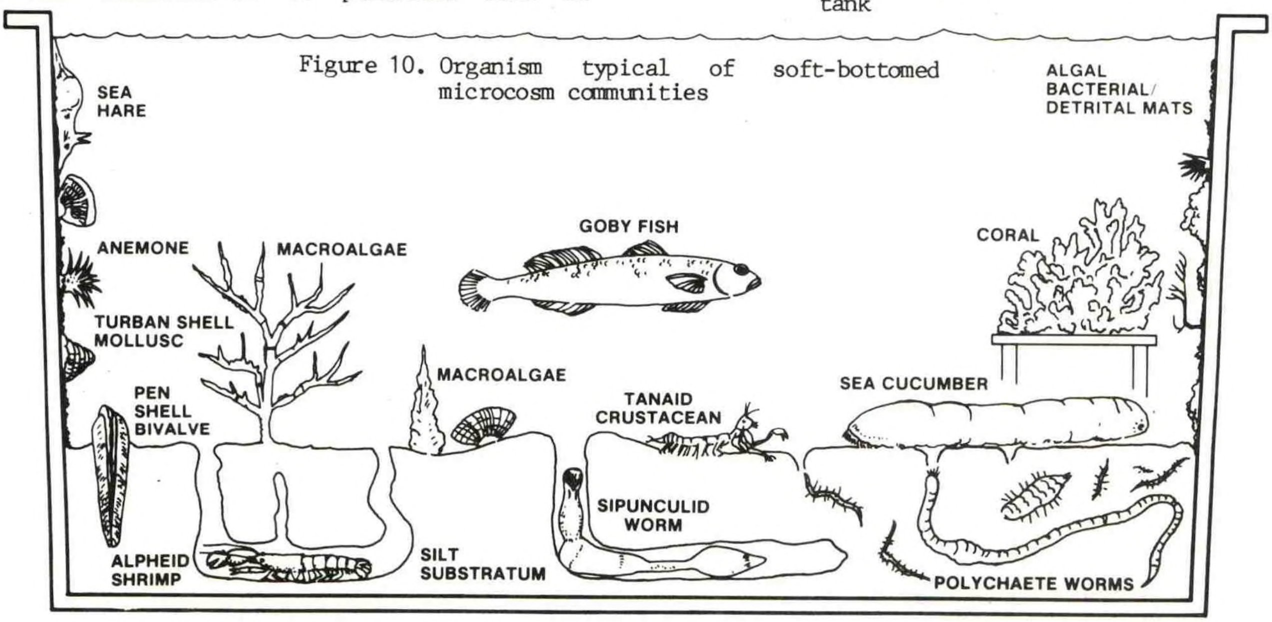


Figure 10. Organism typical of soft-bottomed microcosm communities

After nutrient enrichment, algal populations in the treatment tanks were markedly different (Table I). The control tanks contained approximately equal amounts of unicellular blue-green algae and diatoms. On the other hand, the ammonia treated tanks were dominated by a multi-cellular green alga, Ulva sp., commonly known as sea lettuce. Similarly, the phosphate treated tanks contained a much higher percentage of blue-green algae than the control tanks. Proliferation of cyanophytes in the phosphate enriched tanks is probably due to their ability to fix nitrogen (they are marine legumes) and thus achieve the proper N/P ratios required for production. Both phosphate and ammonia enrichment significantly increased productivity. However, the effect of phosphate enrichment persisted even after the phosphate additions were terminated. Presumably, phosphorus is retained in the sediments and recycled efficiently within the reef community. The nutrient enriched microcosm also developed more abundant and diverse infaunal (living in the sediment) communities than did the control. "This suggests that the largely detrivore-based food webs that developed were about equally favored by any appropriate food addition" [7]. The infauna was dominated by several species of segmented worms which were two to three times more abundant in the treatment tanks. Within those groups, Nereis acuminata was 3 and 5 times more abundant in the ammonia and phosphate treatments respectively, as compared with the control population. Also 20 individuals of Dorvillea sp. A were found in both (test) tanks, whereas only one individal was found in the control tanks" [7]. These two organisms have been used as indicators of moderate levels of sewage in metropolitan harbors [8].

Similar experiments on the toxic effects of Cu and organotin-based antifouling formulations on tropical communities have also been conducted [9]. While organotin compounds were found to be appreciably more toxic than Cu-based toxins, both produced marked ecological effects even when the tanks were maintained at low-level,(initially) non-lethal concentrations.

III. Underway Determinations of Biological Populations.

Community effects must also be determined in the field. The organisms which 1) are very sensitive to environmental changes and 2) are amenable to an instrumental assessment in the field include the microalgae [10], microcrustaceans and the larval forms of larger organisms. For this reason the MEQA program has made some efforts to analyze for phytoplankton by in situ fluorescence analysis [2]. This effort is also being carried out independently by Oldham and colleagues who have recently field tested just such an analyzer [11]. Unfortunately, fluorescence analysis measures only chlorophyll in phytoplankton.

Thus, NOSC scientists have developed techniques for the in situ analysis of mechanically stimulated bioluminescence. Of all of the organism in the deep sea, approximately 90% of them bear light-emitting cells or photophores. When stimulated, nearly all of these organisms will emit light principally in the blue-green. However, the high time resolution spectra are often characteristic of the type of organism [12]. While mear-surface bioluminescent organisms are not as numerous, many bays and harbors contain bioluminescent dinoflagellates as well as zooplankters.

Details of the instrumentation used to measure bioluminescence have been described [13]. Briefly, seawater is pumped through a narrow viewing chamber equipped with two oppositely mounted RCA 8575 photomultiplier tubes (PMT's). The narrowness of the chamber induces the organisms to "flash" and the light is detected by the photomultiplier tubes. One of the tubes measures the polychromatic (broadband) radiation while the other can be shielded with filters for spectral work (Figure 11). Signal pulses are then handled in two ways: high time resolution data is obtained by binning the pulses into time bins on two multichannel analyzers or output from the PMT's is converted to a DC signal and recorded continuously on a data logger along with signals from other oceanographic sensors.

TABLE I

Coverage and Dominance of the Five Most Common Algal Taxa on Tank Walls

Treatment and algae	Percent Coverage	Percent Dominance
CONTROL		
Blue-green algae	25.7	50
Green Algae	0.5	<1
Diatoms	22.8	45
Calcareous	1.9	5
Total Coverage*	50.9	
NH_3 ADDITION		
Blue-green algae	23.4	27
Green algae	39.3	45
Diatoms	23.8	28
Calcareous	trace	<1
Total Coverage*	86.5	
PO_4 ADDITION		
Blue-green algae	58.5	75
Green algae	6.1	8
Diatoms	13.4	17
Calcareous	0.3	<1
Total Coverage*	78.3	

*Balance is bare wall

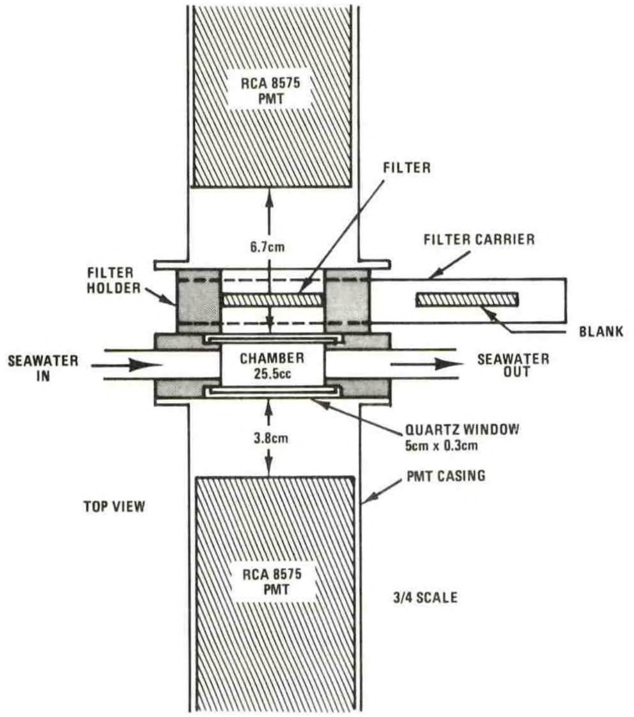


Figure 11. Schematic of chamber for measuring mechanically stimulated bioluminescence

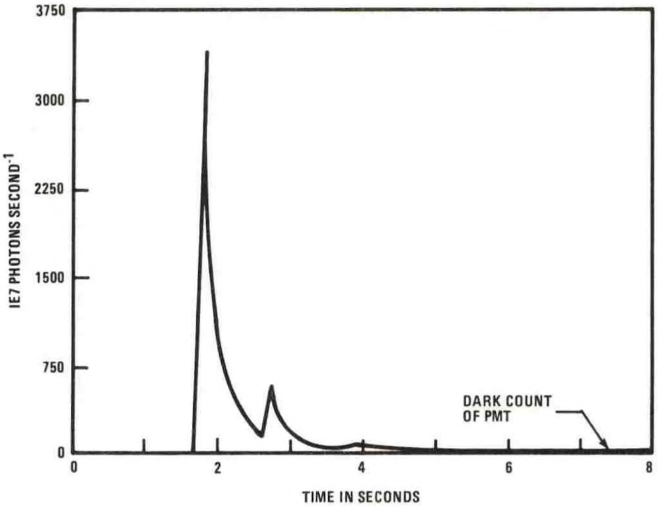
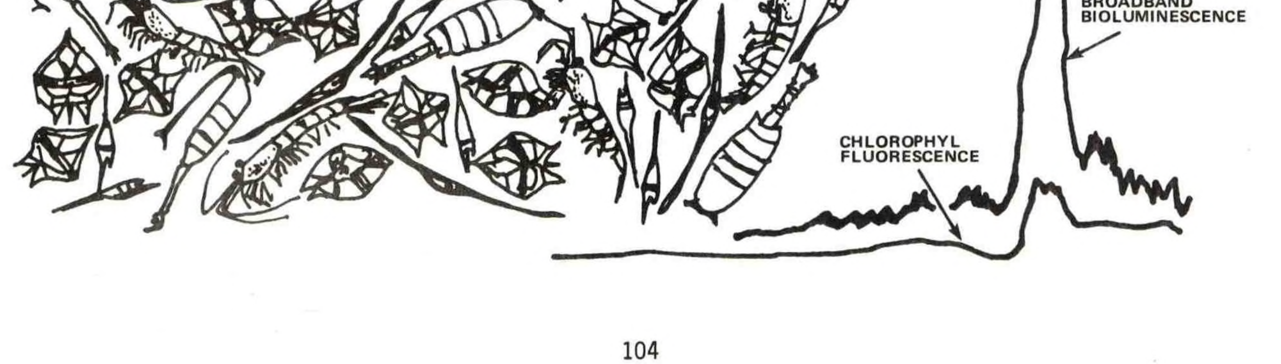


Figure 12. High time resolution spectrum of larval crustacean

Figure 12 shows some high time resolution spectra recorded from the "flash" of the larva of a small crustacean Metridia longa Lubbock. It can be seen that the flash has a very steep rise, then an exponential decay which is followed two smaller rises occurring one and two seconds after the initial burst. The "flash" patterns of many other crustaceans and dinoflagellates have been found to vary [13]. Also, assemblages of organisms give high time resolution patterns which are characteristic of the mixed population. Additionally, the DC signal which is the time integral of the intensities of the combined flashes has been found to vary with the physical characteristics of the marine waters studied. Figure 13 gives an artist's rendition of the MESC determining the composition of micro-organism by fluorescence and bioluminescence while underway at sea. The figure presents actual data from the Gulf of California which show that both bioluminescence and chlorophyll (measured from fluorescence) are high on the cold side of a 1 degree celsius temperature front. The fact that the peaks in fluorescence and bioluminescence coincide suggests that dinoflagellates (chlorophyll-bearing bioluminescent organisms) are responsible for the signal.

Figure 13. Artist's rendition of MESC sampling the microbiological realm while underway



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TECHNIQUES FOR HIGH RESOLUTION WAVE DIRECTIONAL SPECTRA IN DEEP WATER

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ABSTRACT

High resolution directional spectra in deep water are valuable to establish wave climates for broad areas and to verify modelling techniques. No means exist today to provide these estimates. Several possible techniques are discussed, including upward-looking sonar in fixed and steerable arrays, side-looking Doppler sonar, and buoy arrays. A form of remote sensing is described in which a large shallow water array is used along a coastline with straight, smooth contours. This latter method is found to be the only one not requiring substantial development.

THE MEASUREMENT PROBLEM

Measurement of wave direction in deep water (>100 m) is desirable because the directional spectrum has not been significantly modified by refraction. Therefore, the direction estimate can be assumed to have generality and can be employed to derive waves at many shallow water locations. Further, since it is uncontaminated by refraction and shoaling, the deepwater measurement is much more valuable for verifying predictive models of wave generation.

In either case, the wave directional spectrum must be measured with good resolution to be useful. The effects of refraction over complicated topography are very sensitive to even small changes in incident wave energy. In the case where offshore islands provide a shadowing effect, studies have shown that a one degree change in approach direction for swell can cause an order of magnitude change in the wave energy at the shoreline 100 km from the islands. It is also clear that the measurement system must have significantly better resolution than the model to provide reasonable testing of its capabilities.

The present state of the art in measuring direction in deep water is to use the measurement of sea surface slope as first suggested in Longuet-Higgins et al. (1963). This is accomplished with a pitch-roll buoy that measures two components of slope and may also contain a vertically stabilized accelerometer to derive energy. This approach is inherently very poor at resolving direction. It is barely capable of separating two wave trains of the same frequency which arrive from directions as much as 90 degrees apart. While it is theoretically possible to improve this resolution by measuring higher moments (i.e., curvature) of the slope [see, for example the cloverleaf buoy, Mitsuyasu et al. (1975).], these approaches have been uniformly unsuccessful. This appears to be caused by the great sensitivity of these higher order terms to the contributions of high frequency components which have poor signal-to-noise characteristics. In short, there are, at present, no techniques for achieving wave directional spectra routinely in deep water. Although synthetic aperature radar (SAR) looks very promising, it provides a wave number spectrum at best, with no estimate of the energy distribution.

A variety of methods are available in shallow water for measuring wave direction, including surface-piercing staffs and bottom-mounted pressure sensors in various array configurations. Two-axis current meters, in conjunction with a pressure sensor to yield energy, have also been used. Compact arrays, with lengths of a few meters, [see, for example, Seymour and Higgins (1978)] and the current meter system, provide very low resolution measurements. They are the equivalent of the pitch-roll buoys used in deep water. High resolution measurements have been accomplished in shallow water only by using very large arrays with many sensors and lengths of hundreds of meters [see Pawka et al. (1976).] Neither the surface-piercing staffs nor the pressure sensors are useful in deep water, however. Therefore, obtaining high resolution directional measurements in deep water will require new technology.

POSSIBLE SOLUTIONS

In the following sections, several potential direct measurement techniques will be discussed:

A. Upward-looking Sonar.

Bottom-mounted sonars for measuring wave energy spectra have been used extensively in Japan. It is possible that five or six such instruments could be installed in a carefully surveyed array of about 400 m length to provide directional capability. As in all multi-element arrays, signals must be recorded with strict attention to time phasing to extract meaningful directional data. There is a question of the ability to resolve high frequency components because of beam width problems. Also, speed of sound variations caused by sharp thermoclines and bubbles from breaking waves will

This work was supported in part by a grant from the Foundation for Ocean Research.

degrade accuracy. This scheme offers the advantage of fixed locations but is difficult to install.

A multiple-beam steerable acoustical array could, in theory, provide resolution equivalent to a very large number of individual sonar beams. However,the distortion caused by the thermocline will be aggravated because of the non-normal intersection as the beam is steered. The installation is somewhat simpler than the sonar array, but the power and data rate requirements will be more severe.

B. Side-looking Doppler Sonar. In this technique, two beams at right angles to each other are projected horizontally near the surface from a buoy. Use of a stable configuration, like a spar buoy, reduces error and data analysis complexity. In the Doppler mode, the sonars could (in theory) detect the horizontal components of wave orbital motion. Linear theory allows a simple transformation to the directional spectrum in frequency space. The heading of the beams would be derived from a compass on the buoy. By range-gating over intervals as short as a few meters, it is theoretically possible to construct the equivalent of a very large and dense array. However, the data rate is enormous. It would probably require an on-board computer to condense the data.

C. Array of Wave Measurement Buoys. A number of commercially available buoys are capable of reliably measuring wave height at a point, through sensing vertical acceleration. If several of these buoys were moored in the approximate position required for an array, and their outputs recorded simultaneously, directional data could be derived. The equipment is state of the art and can be installed entirely from the surface. Two problems arise. First, the position of the array elements relative to each other and their compass heading is only known approximately because of the slack moored arrangement. Second, the elements of the array are not always at the same location, which complicates the analysis. The position uncertainty can be removed by using two navigation systems. The first is short range and consists of mutual rangefinding between buoys using either acoustics or radio signals. The second is a shorebased electronic system which determines the position of the two furthest apart elements relative to a baseline on shore. These two systems then provide both relative position and azimuthal heading of the array at all times. The "flexible" array problem is resolved by an iterative scheme that assumes first the mean position for all elements and then makes successive corrections to the wave field for the actual positions. This scheme employs easy-to-use instruments and commercially available, but complicated, navigational equipment. The analysis is slightly more complicated than a fixed array, but removes uncertainty of the type encountered with acoustical systems.

D. Shore-based Array. Recognizing the technical difficulties associated with the methods discussed above, a form of remote sensing was developed by the author and Professor Robert Guza of Scripps Institution of Oceanography. In this scheme, a large linear array of pressure sensors is built in shallow water. The location is carefully selected to provide straight and parallel bottom contours from shallow water to the edge of the shelf. One such location was found along the California coast, north of Point Sal, as shown in Figure 1. This location is subject to very energetic waves and is adjacent to an important area for petroleum exploration. High resolution directional spectra would be calculated for the shallow water location. These would be then mapped into deepwater spectra using conversion functions developed from linear refraction. Preliminary analyses show that wave trains of the same frequency and separated in direction by as little as 10 degrees in deep water can be resolved by such an array.

CONCLUSION

Determination of high resolution directional spectra in deep water by direct measurement will require considerable development and evaluation of specialized equipment. If the proper bathymetry exists, "remote sensing" is possible through a state of the art shore-based array.

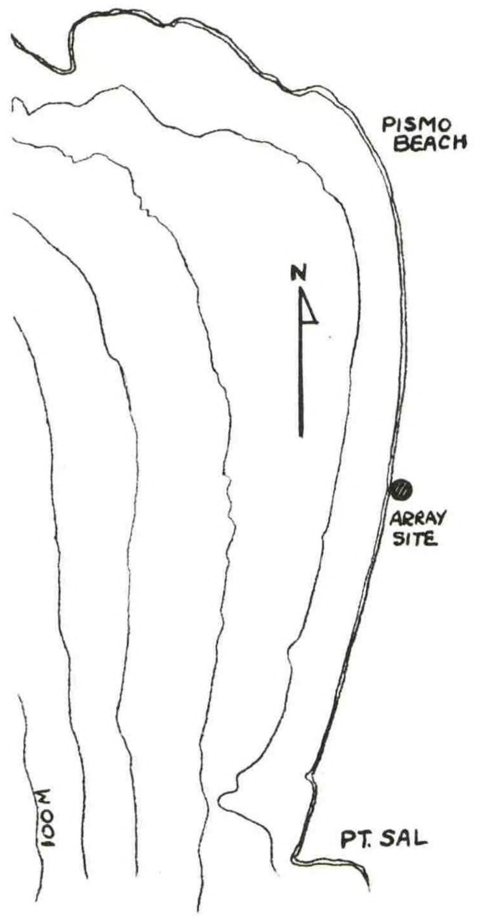

Figure 1

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Ocean-waves observation buoy

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and

Kiyoshi Katagiri
Japan Meteorological Agency

1. Introduction

In 1982, the Ministry of Transport of the Japanese Government initiated a comprehensive study entitled "Research and development for a system to prevent unusual shipwrecks under violent waves condition". This five-year project aims to clear up causes of frequent shipwrecks involving ocean-going vessels in the western North Pacific Ocean (see Fig. 1), and to develop a total system for safety navigation.

In the study one of the important and essential themes is to obtain detailed ocean-waves data with their directional characteristics for long periods in winter seasons when unusual high waves are suspected. For this purpose an ocean-waves observation buoy was fabricated in 1982, and deployed at a site south-east of Honshu Island for eight months in 1983 to 1984.

2. Configuration and functions of the buoy

The buoy in discus shape weighs 48 tons with overall diameter of 10 meters. The configuration of the buoy and mooring, similar to those of the operational ocean data buoys of the Japan Meteorological Agency (JMA), is given in Fig. 2.

The buoy has functions to measure a number of parameters of marine environment including ocean-waves as given in Table 1 every 3 hours and to transmit the obtained data to the ground station via the Geostationary Meteorological Satellite (GMS) on real time basis. Beside the radio link, all of the obtained data are stored on magnetic tapes installed onboard the hull. (Fig. 3)

Regarding the ocean-waves measurements, three kind of sensors are equipped, namely, (1) a vertical accelerator to measure heaving of the hull,

(2) a compass to measure heading of the hull, and

(3) a 3-axis wave directional sensor to obtain pitching rolling and heaving.

The accelerator and 3-axis wave directional sensor make measurements every 200 ms and 1000 ms, respectively, for 20 minutes each 3 hours. The analog data from the wave sensors are converted into digital form to fed to the wave data analyzer.

They are processed to have the following characteristic values;

(1) time series of the elevation of the sea surface from the data obtained with the accelerator,

(2) those of directional data (the latitudinal/longitudinal components of the sea surface slope and the elevation of sea surface) from the data obtained with 3-axis wave directional sensor,

(3) those of height and duration between the successive two peaks,

(4) significant, mean and maximum wave height and period, and

(5) maximum and mean inclination, mean wave direction and spreading angle, skewness, kurtosis, principal direction, long crestedness, cross-spectrum, and wave direction at each frequency.

The processed values of (1) and (2) are stored on magnetic tapes for more detailed analysis in laboratories after recovering the buoy.

The processed ocean-waves data from (2) to (5) as well as meteorological and oceanographical data are put into a UHF (402.1046 MHz, 20 W RF output power) for real time data collection. The transmitter makes radio message in the format given in Fig. 4 to the ground station in the suburbs of Tokyo via the GMS.

3. Operation at sea and preliminary results

The buoy was operated from October 18, 1983 to June 22, 1984 at 32°00'N 147°00'E in water approximately 6000 meters deep. The data received at the Meteorological Satellite Center, JMA are distributed to the Meteorological Research Institute, Ship Research Institute, Port Harbour Research Institute and others concerned to the project in the Ministry. Comprehensive studies of the ocean-waves data are now being carried out. A few examples of the received data are given in Table 2 and Fig. 5.

4. Summary

The first attempt in Japan to obtain detailed ocean-waves data in high sea for long period was successfully made, and it is expected that the buoy will play important role in our comprehensive project.

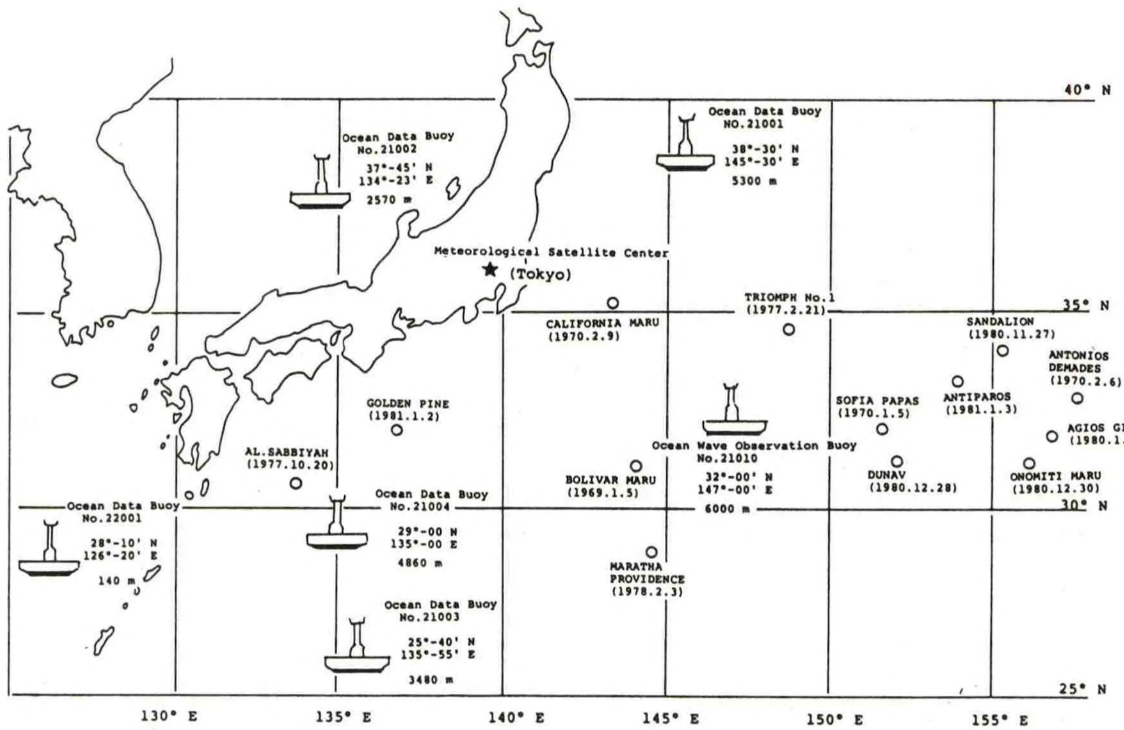


Fig.1 Locations of Ocean-data buoys and occurences of shipwrecks(1969-1981)

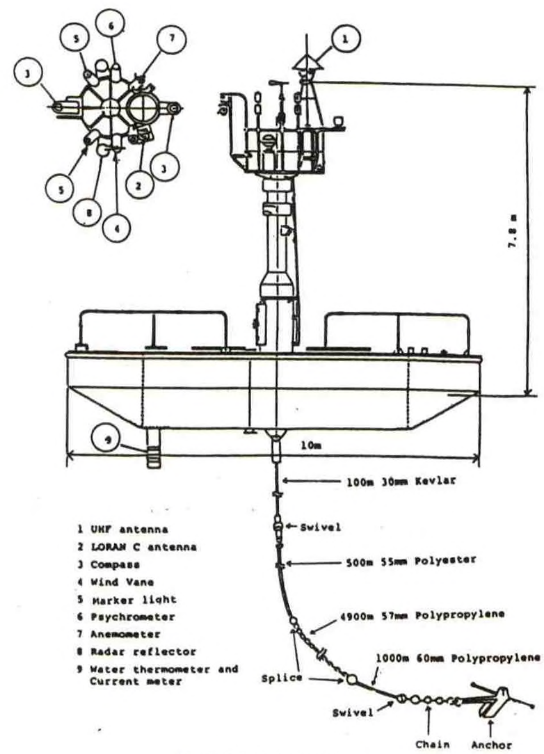


Fig.2 External Appearrance

Table 1 List of Measurment

Item	Range
Wave data	
Vertical amplitude	-15 - +15m
Wave direction	
pitching	-90° - +90°
rolling	-90° - +90°
heaving	-10 - +10m
heading	0 - 360°
Meteorological data	
wind direction	0 - 360°
Wind velocity	0 - 120KT
Air temperature	-10 - +40°c
Wet-bulb temperature	-10 - +40°c
Atmospheric pressure	920 - 1040mb
Compass	0 - 360°
Oceanographic data	
Water temperature	-10 - +40°c
Current direction	0 - 360°
Current velocity	0 - 10KT

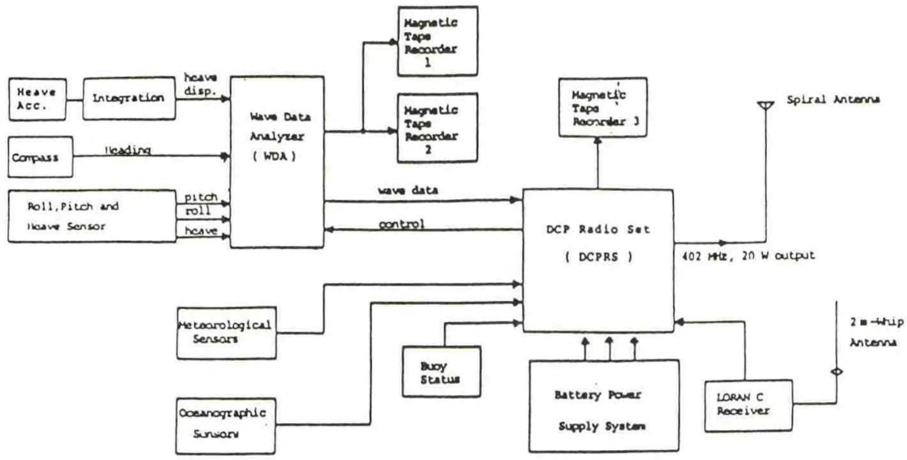


Fig.3 System Block Diagram

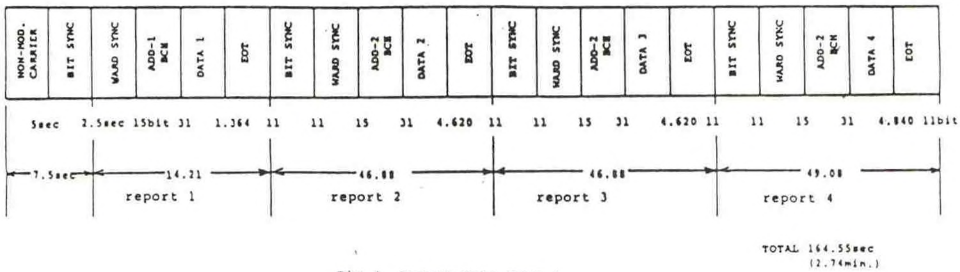


Fig.4 Report Data Format

Table 2 Highest 10 of the Maximam Wave Height
(Oct.18,1983--June 22,1984)

No	Date/Time (M.D.H.)	Wind Dir.	Wind Speed	Max. Wave H.	Max. Wave P.	H 1/3	Mean Wave H.	Mean Wave P.	Air temp.	Air press.	SST	Mean of wave dir.
1	3,11,03	W	38	13.7	12	7.8	4.5	9	14.1	1000.4	16.9	W
2	1, 6,18	WSW	33	12.8	8	6.6	3.9	8	11.0	996.3	17.6	WSW
3	1, 4,03	W	41	12.6	10	8.2	5.4	10	16.8	1001.1	18.0	WSW
4	2,18,03	WNW	29	11.9	11	8.4	5.1	10	15.6	997.3	19.0	SW
5	2, 7,03	W	37	11.8	10	6.4	3.8	8	11.1	995.5	17.6	WSW
6	1, 4,06	WNW	32	11.8	12	7.6	4.7	10	15.3	1003.9	18.9	W
7	2,27,18	W	43	11.6	12	8.9	4.8	10	12.0	999.7	17.2	W
8	12,31,18	WNW	24	11.4	10	6.4	3.9	9	13.1	1006.4	18.3	WNW
9	3,11,18	WNW	18	11.0	12	6.2	3.7	9	8.9	1010.4	17.1	W
10	1,26,18	W	36	10.7	13	6.8	4.1	9	10.3	1005.3	17.6	WSW

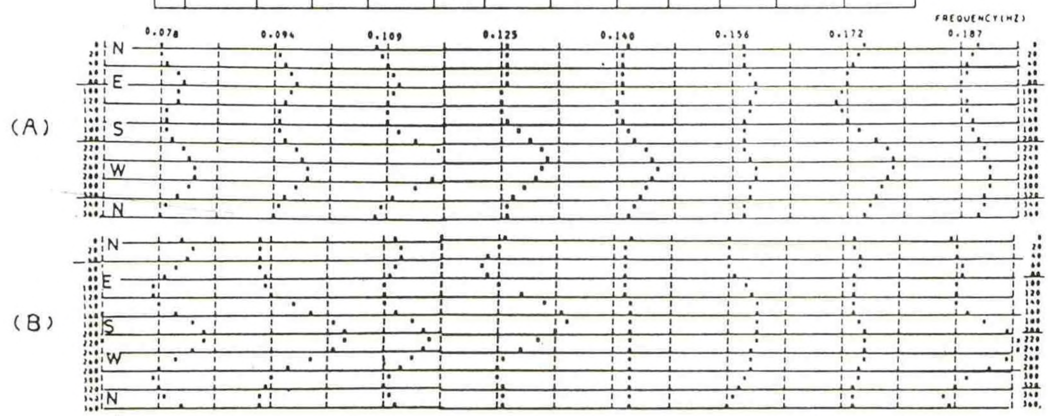
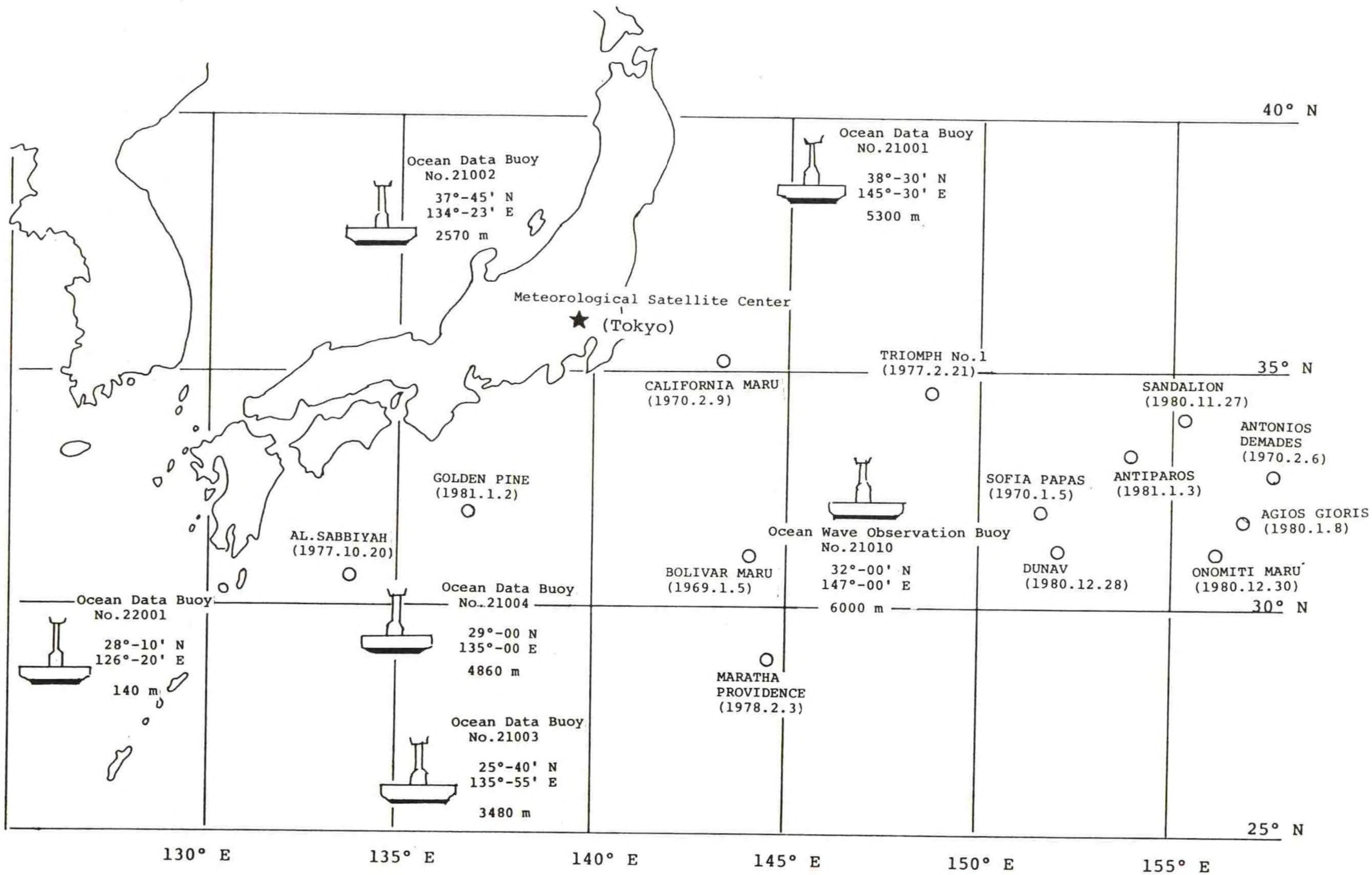


Fig.5 Directinal Spectra (A) 0300Z, March 11,1984
(B) 0300Z, Feb. 18,1984



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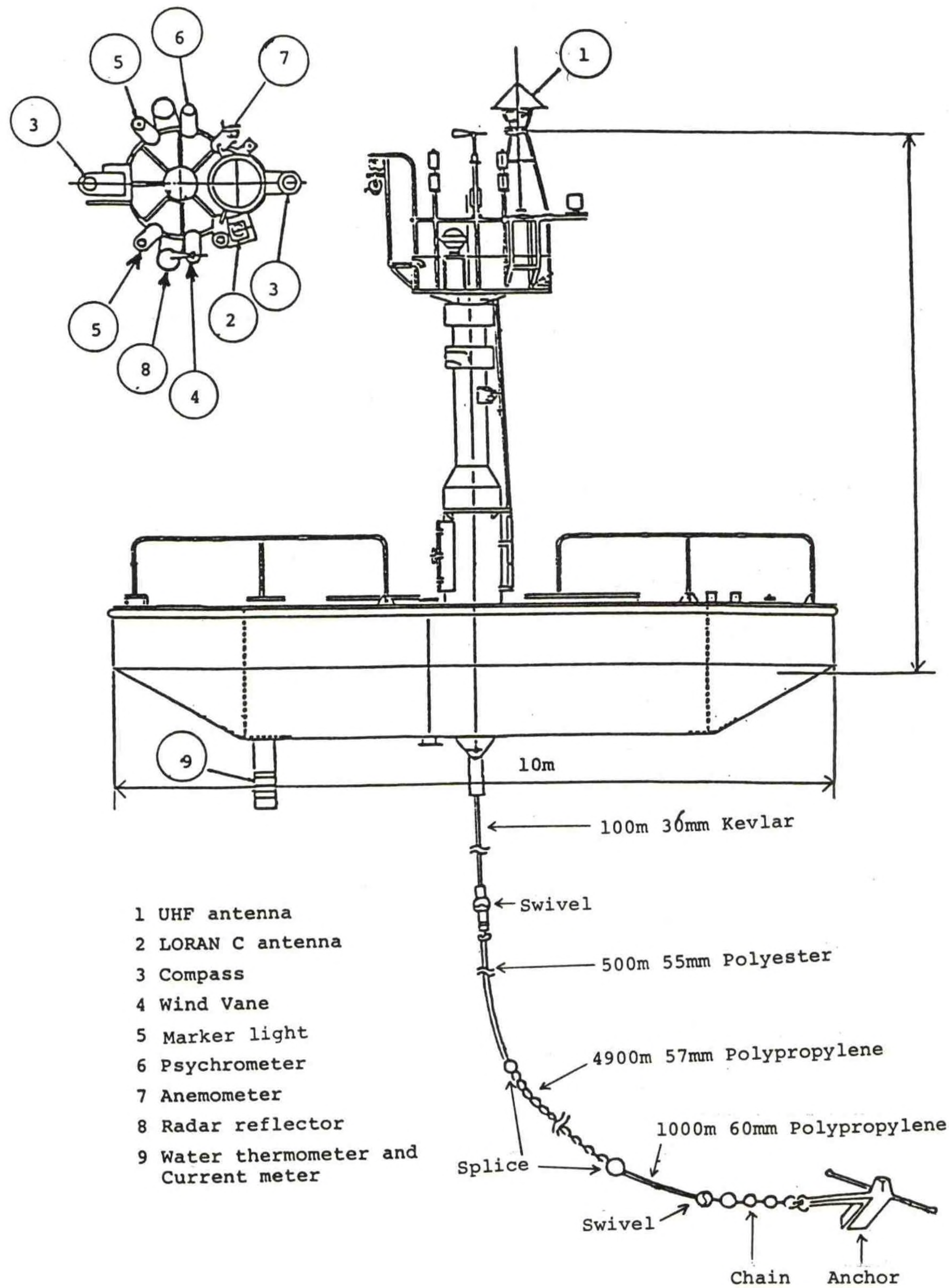
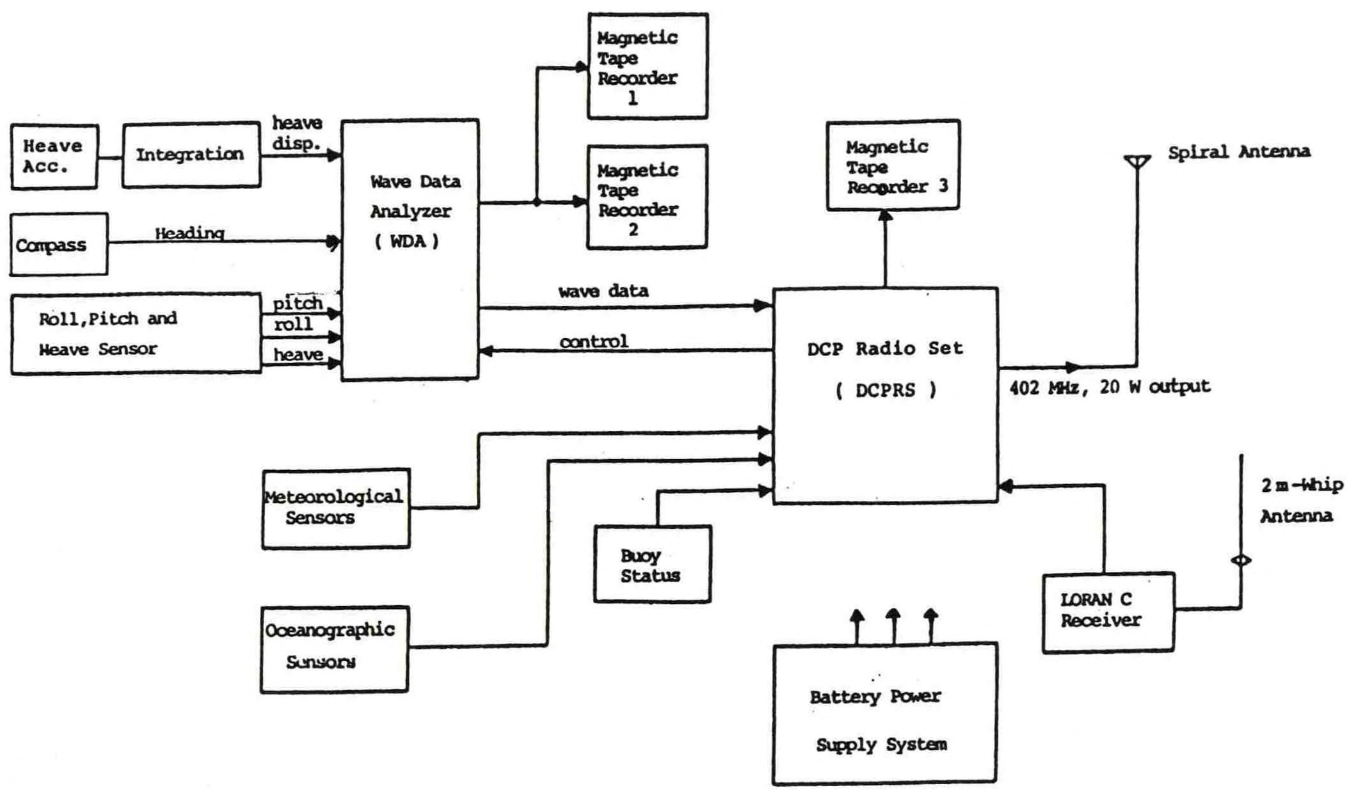


Fig.2 External Appearrance



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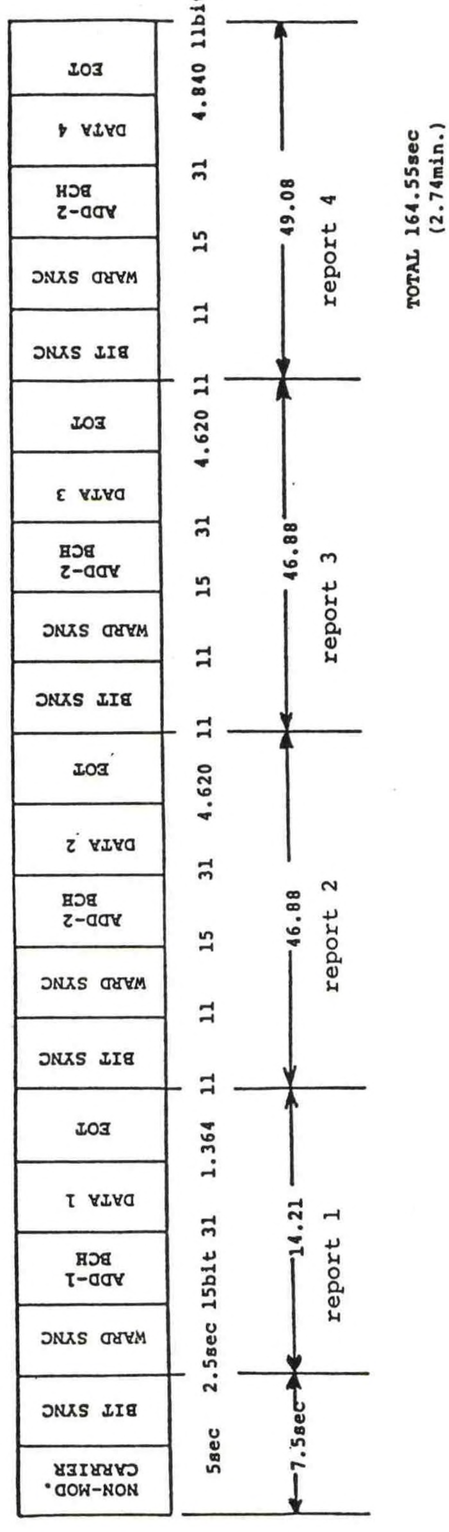
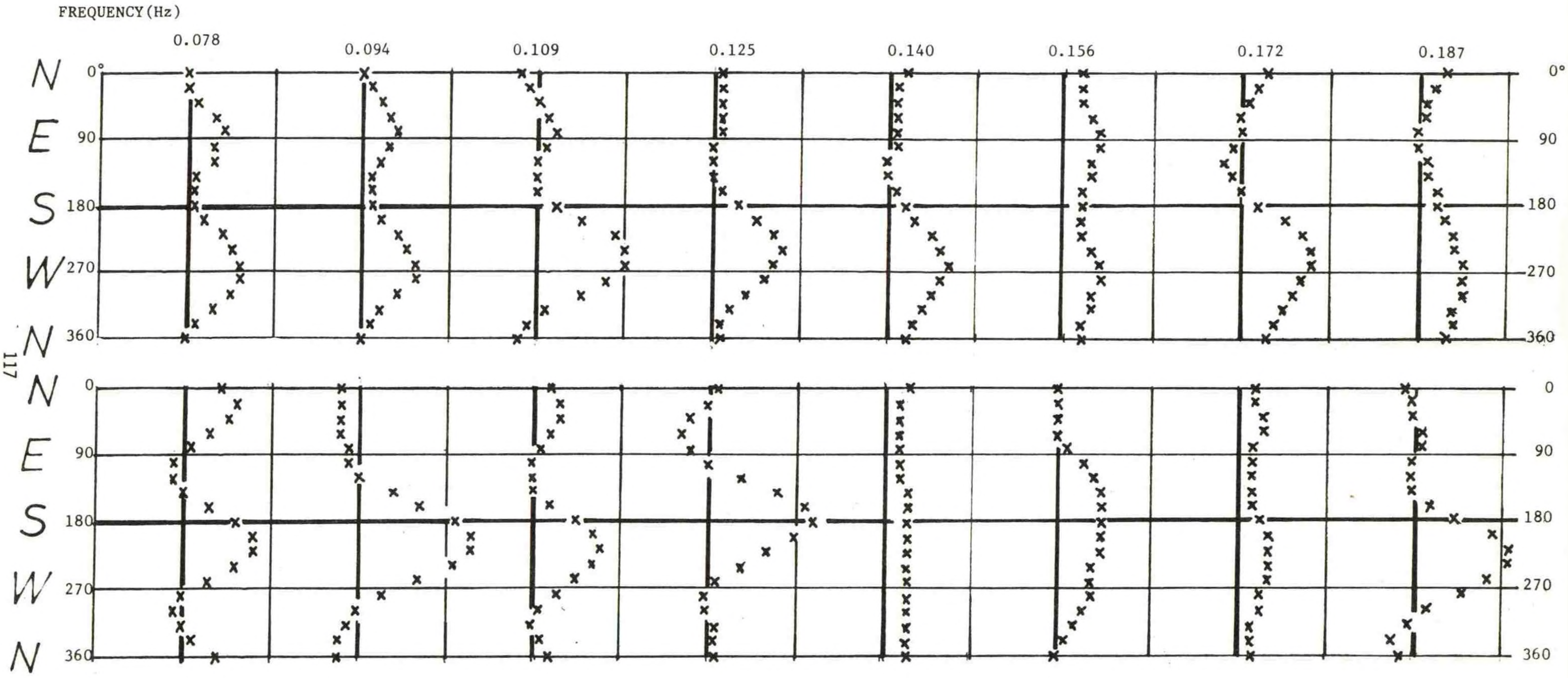


Fig.4 Report Data Format



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Atmospheric pressure	920 - 1040mb
Compass	0 - 360°
Oceanographic data	
Water temperature	-10 - +40°c
Current direction	0 - 360°
Current velocity	0 - 10KT

Table 2 Highest 10 of the Maximum Wave Height

(Oct.18,1983--June 22,1984)

No.	Date/Time	Wind		Max. Wave		$H_{1/3}$	Mean Wave		Air	Air	SST	Mean
	(M.D.H.)	Dir.	Speed	Height	Per.		Height	Per.	Temp.	Press.		Wave Dir.
1	3,11,03 z	W	38 kt.	13.7 m	12 s	7.8 m	4.5 m	9 s	14.1 °C	1000.4 mb	16.9 °C	W
2	2, 6,18	WSW	33	12.8	9	6.6	3.9	8	11.0	996.3	17.6	WSW
3	1, 4,03	W	41	12.6	10	8.2	5.4	10	16.9	1001.1	19.0	WSW
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5	2, 7,03	W	37	11.9	10	6.4	3.8	8	11.1	995.5	17.6	WSW
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9	3,11,18	WNW	18	11.0	12	6.2	3.7	9	9.9	1010.4	17.1	W
10	1,26,18	W	36	10.7	13	6.8	4.1	9	10.3	1005.3	17.6	WSW

APPLICATIONS OF OPTICAL FIBERS AT SEA

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INTRODUCTION

An earlier paper [1] discussed the nature of optical fibers and associated devices that could be used for data transmission or sensing at sea. This paper describes both actual and potential applications of such systems for civilian and military purposes. Also discussed in OTDR, "Optical Time-Domain Reflectometry," now used routinely to measure attenuation in fibers, connectors, etc., but which also has promise as a sensing system.

Among the reasons for interest in using optical systems at sea are the following:

1. Optical cables with glass fibers are smaller and lighter than cables with metallic wires.
2. Optical fibers are totally dielectric. Thus data can be transmitted free of interference in electrically congested regions. Furthermore, optical fibers cannot spark or short circuit.
3. Optical fibers have very large information-carrying capacity that allow simultaneous transmission of video, data, facsimile, imagery, etc.
4. Optical fibers can transmit high-quality signals that emit no detectable radiation. Signals can be transmitted long distances with few repeater stations.
5. In many applications, optical-fiber systems can be installed, operated, and maintained at relatively low cost.

TRANSOCEANIC COMMUNICATIONS

Pan [2] reported that international telecommunications traffic via undersea coaxial cables has been increasing at a rate of about 10 times per decade and shows the status of plans for new undersea installations as of November 1983. Other plans have been formulated in recent months.

The next generation undersea transatlantic cables will be TAT-8 single-mode fiber-optic cable scheduled for operational use in 1988, and a transpacific optical link will be in operation shortly thereafter. The transatlantic system is expected to connect Tuckerton, New Jersey with Widemouth, England and Penmarch, France, and may include ports in Canada, Spain, and Portugal [3]. This AT&T system would operate at 1300 nm wave length and transmit at 280 Mbps. The system has been designed for a "mean time before failure" of eight years with repeater stations at 25 to 50 km. The system must withstand ocean-bottom temperatures of about 3°C and pressures of 5×10^5 Torr. Undersea tests to date have been highly successful.

Japan also plans an undersea fiber-optic cable to be in operation in 1988 connecting Japan and Hawaii [4]. It anticipates operating at a 1300 nm wave length with a 400 Mbps data rate with repeater spacing of 50 to 100 km.

UNDERSEA LINK TO OFFSHORE PLATFORM

In April 1985, a 150-kilometer repeaterless undersea link will run from shore to a semi-submersible offshore platform [5]. The link, built by AT&T Technologies Federal Systems group, is part of a military "Air Combat Maneuvering Instrumentation Range" used to train aircraft crews in battle simulation. Lasers & Applications report data transmission at 3.088 Mbps with attenuation under 0.25 dB/km and dispersion of 14 ps/nm/km at 1550 nm. Metal strength members in the four-fiber cable will carry over 500 watts of electrical power to the platform.

VIEWING UNDER THE SEA

Lyons [6] described a coherent fiber-optic viewing system that allows a surface operator to view weld preparation, the welding arc, and the weld pool in the so-called OTTO process. The fiber-optic conductor has eight 50-micron glass fibers. The entire system has been tested extensively at pressures in excess of the design working depth.

TETHERED WEAPONS

Research and development is underway to develop fiber-optic tethered guided missiles and naval torpedos that are improved versions of standard wire-guided weapons. The fibers allow video targeting signals to be fed back to the launch site so that operators can use a joy-stick and video screen to direct the weapon onto the target. The system is intended to direct torpedos 10 to 15 kilometers from the launch platform [7].

SUBMARINE ADVANCED COMBAT SYSTEM

The prime contract for engineering development of SubACS was awarded to IBM's Federal System Division for $683 million while the production phase has been estimated to cost at least $2 billion [8].

SubACS is considered a part of the Defense Departments "technology insertion effort" directed to improve significantly the performance of weapons systems. If the system works as well as anticipated, it could be included in future surface ships. aircraft, missiles, land combat vehicles, and spacecraft [8].

The four technologies to be evaluated in SubACS are: (1) light-wave data bussing, (2) Ada computer language, (3) very large scale integration of electronics, and (4) distributed processing computer architecture.

ARIADNE

In Greek mythology Ariadne, the daughter of King Minos and Pasiphae, gave her lover Theseus a thread which allowed him to escape the Labyrinth after he battled the monster Minotaur. Today, the United States Defense Advanced Research Projects Agency and the Naval Research Laboratory, with the assistance of industrial concerns, are endeavoring to supply the glass threads and associated facilities to warn of the presence of hostile underwater "monsters". Ariadne is the code name given to a top-secret project to develop a system that can be deployed from either small vessels or aircraft [9]. It is expected to consist of conventional sensors on the ocean floor connected by fiber-optic cables to land-based computers for analysis and interpretation.

It has been estimated that the project, if fully funded, will need about 2,000 kilometers of single-mode fiber per year in 25 kilometer lengths from 1987 to at least 1990 [9]. The maximum attenuation is to be 0.5 decibels per kilometer at 1300 nm and 0.35 at 1550 nm. A life expectancy of at least one year is required.

OPTICAL TIME DOMAIN REFLECTOMETRY

OTDR has been described as a "one-dimensional closed-circuit optical radar [10]." As shown in Figure 1, a high-intensity short-duration light pulse is launched into a fiber, and a photodetector records the backscattered light. Backscattering results from Fresnel reflections at fiber ends, breaks, and connectors, and from Rayleigh scattering due primarily to inhomogeneity in the fibers, see Figure 2. OTDR has been used primarily as a method for measuring optical-fiber attenuation and locating defects. See the pioneering paper of Bonarski [11].

Photodyne Incorporated [10] described a commercially available OTDR unit with a range of 5 to 20,000 meters with a resolution of one meter and a repetition rate of 3 kHz at 850 nm ± 10 nm.

Rogers [12] described a new optical-fiber technique for spatial distribution of physical fields such as magnetic field, electrical field, temperature, and mechanical stress using polarization optical time domain reflectometry, POTDR. In POTDR a plane-polarized pulse of light is launched into a polarization-preserving single-mode fiber. The backscattered light is resolved into two orthogonal polarizations and the outputs recorded on two photodetectors. The fibers chosen are such that the parameter being measured will cause significant rotation of polarization of the backscattered energy with minimum change due to the other factors. Rogers gives a number of possible applications such as detecting signatures of large structures.

Kingsley [13] described several distributed fiber-optic sensor systems in which a number of sensors are positioned along a single-mode fiber. He described how such systems might be used to monitor oil and gas lines for local stresses, for intruder detection, corrosion inside the frame of an airplane, determine the state of a bridge structure, and as a nuclear radiation dosimeter.

The distributed OTDR system seems well suited for determining the state of offshore structures and vessels. A single-mode fiber could be laid adjacent to structural members and be able to sense unusual stress, vibration, pressure, temperature, etc. The very small size of the coated fiber would permit installations in regions of limited access.

SHIPBOARD SIGNAL DISTRIBUTION

Slemon and Abbott [14] have described a "Fiber-Optic Cabling and Switching" (FOCAS) network to provide a vessel with a truly universal signal distribution network. They claim that a FOCAS network can handle all present or future shipboard signal distribution architectures such as point-to-point or data bus. They state that although the technique is far from optimized, conversion to a FOCAS network is straightforward and would result in substantial savings in cable weight and cost.

Paton [15] described several demonstration projects that involve the installation of fiber-optic telephone systems on shipboard, the installation of an engine control system between the bridge and engine room of the cargo vessel America Maru, and tethers to undersea divers and vehicles.

Paton stated that "one estimate of an aircraft carrier radar cable was $1 million for a copper installation vs $30,000 for a fiber-optic cable."

SHIPBOARD CHEMICAL SENSORS

The establishment of the Exclusive Economic Zones around national shores gives added incentive to determining the extent of available resources in coastal waters and developing economical methods of obtaining them. It would obviously be false economy to sacrifice extensive renewable resources in the recovery process. An ocean monitoring program is thus required to provide early warning of the possibility of undesirable and potentially dangerous trends in localized ocean areas. Because of the vastness of the bodies of water involved and the relative slowness of movement of dissolved substances, it would be unwise to depend solely on results from fixed stations and the analyses of organs from marine life brought to market. There is need for accurate and sensitive analytical methods that can be conducted on shipboard by relatively inexperienced personnel for determining the level of trace substances in seawater in real-time and preferably in situ. Several potential methods for doing so involve the use of optical fibers. Most of these methods involve sending a laser beam down one fiber and collecting a return beam from one or more other fibers.

FIBER SWELLING

Butler [16] has developed a simple technique to detect the presence of various substances based on the swelling of an optical fiber and the resulting change in an interference pattern. He has detected the presence of hydrogen using a fiber coated with palladium, a metal that readily forms a hydride. It seems feasible to develop coatings for fibers that would change size in the presence of specific substances in seawater.

BIOMEDICAL SENSORS

Peterson [17] and others have developed a wide variety of fiber-optic sensors useful in various biomedical applications such as oximetry, dye-dilution measurements, laser-Doppler velocimetry, and fluorometry and as physical sensors of pH, partial pressure of blood gases, and glucose. These sensors involve a reactive tip of an optical fiber that causes a change in the returned signal. Saari and Seitz [18] have developed sensors based on immobilized reagents whose fluorescence characteristics change with pH and/or metal-ion concentration.

OPTRODES

Herschfeld and associates have popularized the term optrodes, from optical electrodes, and developed several types of sensors using optical fibers for remote fiber fluorescence measurements [19]. These may or may not involve a reactive tip.

MONITORING HYDROCARBONS

Kawahara and Fiutem [20] described a novel method of monitoring hydrocarbons in water using an unclad optical fiber coated with octadecyltrichlorosilane. In its present form, the monitor can detect diesel oil in water at 17 mg/liter and crude oil at 3 mg/liter.

RAMAN SAMPLING AND ANALYSIS

Schwab and McCreery [21] have obtained extremely high-quality Raman spectra using one optical fiber to conduct the exciting light and 18 similar fibers to carry the backscattered light. The entire array diameter is 1.0 mm.

Brown et al [22] and Van Haverbeke et al [23] demonstrated in the laboratory that it was possible to detect the presence of various organic molecules in water at very low concentrations by use of the Raman technique using a flow-through system.

Asher [24] has demonstrated that it is possible to detect trace levels of polycyclic aromatic hydrocarbons (PAH) at levels of 20 ppb in acetonitrile by Raman spectroscopy. PAH are a potential health hazard because some species are know carcinogens.

Vickers et al [25] have shown that it is possible to detect the presence of several trace organics in simulated seawater at levels below parts per million.

Previous work thus indicates that it will be possible to employ optical fibers with lasers to make real-time in-situ measurements at sea of various substances at trace concentrations.

SHIPBOARD SENSING OF PHYSICAL PROPERTIES OF SEAWATER

The "Fiber Optic Sensing Systems" (FOSS) program of the Naval Research Laboratory has developed a large number of different sensors that can measure acoustic waves, magnetic fields, rates of rotation, and numerous physical properties [26].

The Applied Physics Laboratory has used a fiber-optic tether to bring back temperature profile data from a free-fall sensor package to the ship's laboratory [15].

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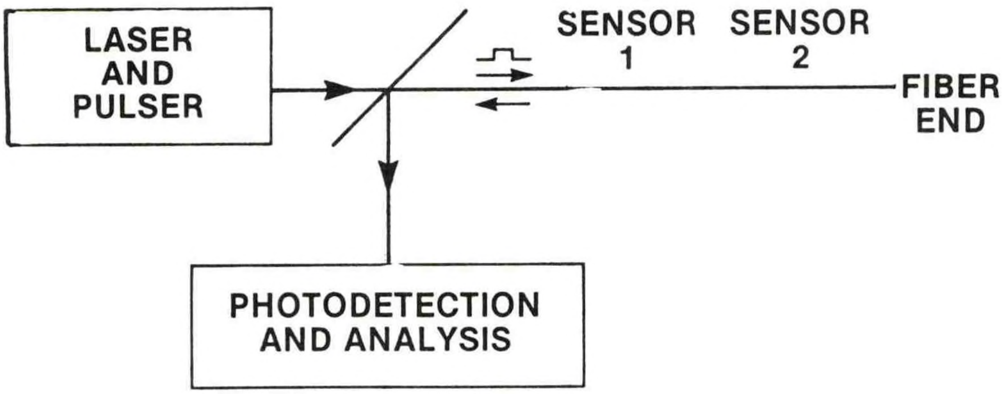

Figure 1. Schematic of Optical Time Domain Reflectometer

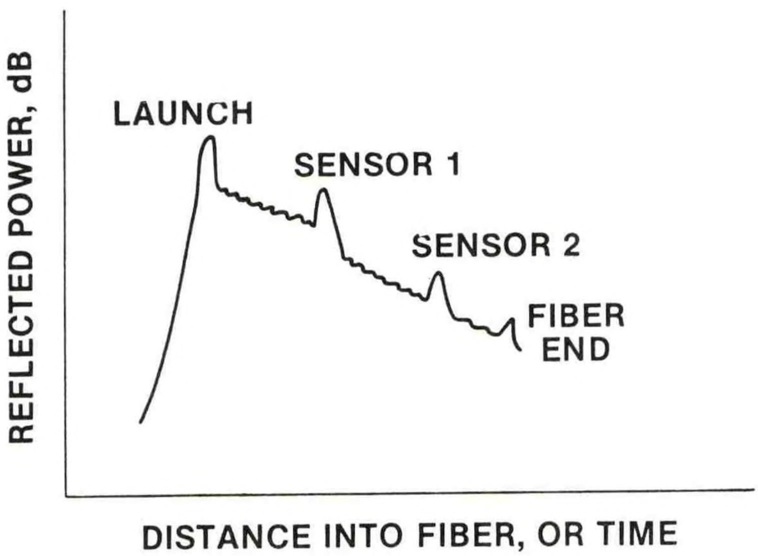

Figure 2. Schematic Response of Optical Time Domain Reflectometer

NOAA COASTAL STORM SURGE PROGRAM

Joseph R. Vadus

NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION (NOAA)

The NOAA National Weather Service (NWS) has developed a computer model for making real-time forecasts of storm surge due to an impending hurricane. The model has been applied to 22 basins covering most of the Gulf of Mexico and Atlantic coastal areas of the U.S. The model has been successfully used for providing warnings and assisting coastal planners in evacuation planning, emergency preparedness and land-use control. Evacuation maps and plans are based on computer simulation using previously recorded hurricane tracks as well as simulated tracks.

Situation

Over the last 33 years there have been 19 major hurricanes (category 3 or greater), averaging about one every one and a half years. A major hurricane greater than category 3 has not occurred in the U.S. over the last 25 years. Over this period, there has been considerable coastal development. The shore population is now increasing at a rate of 3 to 4 times faster than average. There are over 60 million people and over 55 percent of the Atlantic and Gulf of Mexico coastlines. People have not been adequately conditioned and educated on the impact of a major hurricane. Many high-rise buildings have been erected at a fast pace in the major coastal cities and resorts, and few of these new communities have experienced the winds and wurge forces of a major hurricane.

Storm surge which is primarily generated by hurricane wind-driven coastal waters has been a major threat to life. Figure 1 illustrates the tracks of major hurricanes (category 3 or greater) experienced on the U.S. east coast and Gulf of Mexico over the past 30 years. Hurricanes are categorized using the SAFFIR/SIMPSON scale as noted in Table 1. The deadliest U.S. hurricanes in the Atlantic and Gulf of Mexico are given in Table 2. One of the deadliest hurricanes occurred in Galveston, Texas in 1900 which resulted in from 5,000 to 6,000 deaths.

Tide gage observations made during a hurricane's passage shows that storm surge lasts typically about six hours. The surge from hurricane Camille in 1969 reached 24 feet.

NOAA Program

NOAA's storm surge technique is a numerical dynamical computer model called SLOSH which stands for Sea, Lake Overland Surge from Hurricanes. In 1980, NOAA began a five year program to adapt the SLOSH model to 22 basins as shown in Figure 2. There are about 20 additional basins or gaps in coverage proposed for future adaptation of the model.

This modeling technique was developed by the NWS, principally by Mr. G. W. Platzman and Mr. C. P. Jelesnianski. Their early research is described in references 1 and 2. More recent information on the SLOSH model, cited herein, is the subject of reference 3.

The SLOSH model is two-dimensional, covering part of the continental shelf, inland water bodies, and terrain. The equations of fluid motion are solved numerically incorporating finite amplitude effects but not the advective terms from the equations of motion. At any given point, the computed surge is designed to follow a time-history of a long-period gravity wave, as shown in a tide gage graph of water level versus time. The SLOSH basin models use a polar grid to provide the highest resolution near the greatest area of interest.

At each of the model's grid points the amplitude of terrain height and water depth is provided. The model considers overtopping barriers and impediments to water for e.g. dunes, levees, spoil areas, natural ridges, reefs, and man-made structures. In addition, the model takes into account the flow between cuts and barriers, channel flow, and constructions and expansions along rivers.

The SLOSH model incorporates a hurricane wind model. In order to run the model, the user must provide time-dependent meteorological parameters viz., position (latitude and longitude), storm size, and central pressure. Note that wind is not an input parameter. These inputs are entered at 6-hour intervals, beginning 48 hours before landfall and ending 24 hours after landfall. The wind model incorporated in the program produces a vector wind field throughout the basin balancing forces based on the meteorological input parameters.

The accuracy of the SLOSH model, based on nine storms, eight basins, 542 tide gage readings, and high mark observations is ± 20 per cent for significant surge heights.

The next phase of the NOAA Program is directed toward preparation of atlases for the basins for which SLOSH models have been adapted. In order to determine a region's potential for storm surge a large number of hypothetical storms, around 250 to 300, are simulated to impact the region. The storms are varied in intensity, size, and landfall points along likely tracks. This number of simulated tracks is sufficient to highlight the critical hurricane paths and associated storm surge levels and areas flooded. An example of the type of information compiled in the atlas is illustrated for Southwest Florida (Charlotte Harbor/Ft. Myers). Figure 3 shows the major highways, principal towns in an area roughly 120 miles by 120 miles. Figure 4 shows the contour levels of the terrain in feet. It also lists 12 locations for which specific graphs are generated. Figure 5, which shows plots of storm surge versus time, and wind speed versus time for a category 4 storm from the NNE with landfall 60 miles to the left of Charlotte Harbor. Such graphs can be generated to forecast storms from any direction for a given landfall. This time series forecast presentation is an invaluable tool for emergency and evacuation planners. Figure 6 shows the predicted maximum envelope of overland waters (MEOW), which is an integration of simulated runs for categories 1 and 5 landfalling hurricanes simulated from all directions. Note that the surge level from the category 5 hurricane can reach terrain levels greater than 30 miles inland.

Conclusions

The NWS uses the atlases for each region, based on up to 300 simulated runs, to assist in forecasting the possible storm surge levels which can be expected. The Federal Emergency Management Agency (FEMA), the U.S. Army Corps of Engineers, and state coastal planners can use the MEOWS for evacuation planning, locating emergency facilities, and determining evacuation routes. The SLOSH model has been effective in forecasting storm surge heights with an accuracy of about ± 20 percent.

Based on the rapid level of development of coastal cities and resort areas, the limited experience of new inhabitants, an accelerated education program is needed as well as a combined Federal and State planning and preparedness to deal with the problems and emergencies of a major hurricane. It is inevitable that the Atlantic and Gulf Coasts will be exposed to a major hurricane greater than category 3 in the future, and the highly developed character of this region will experience these destructive forces of storm surge and flooding. Preparedness is essential.

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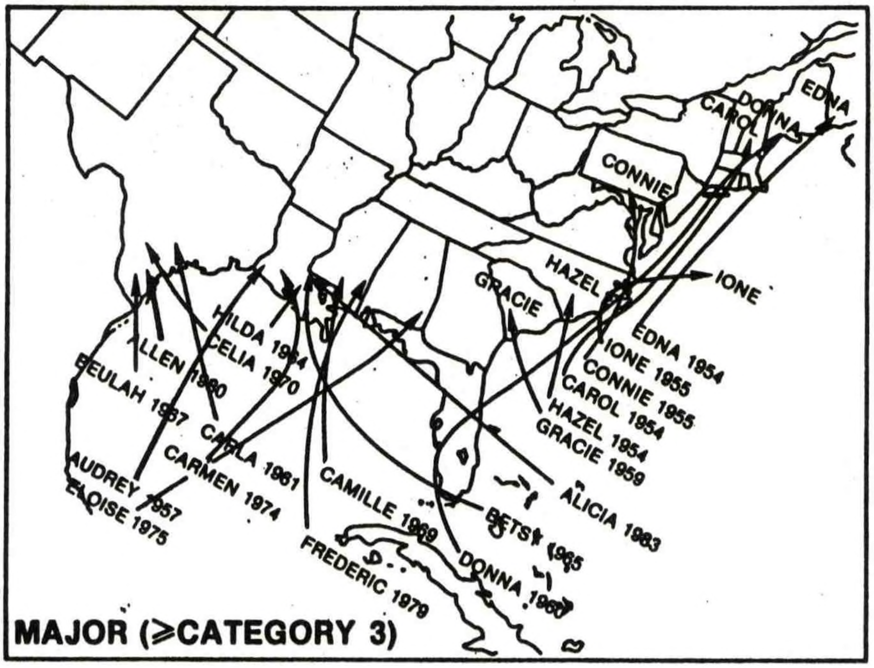
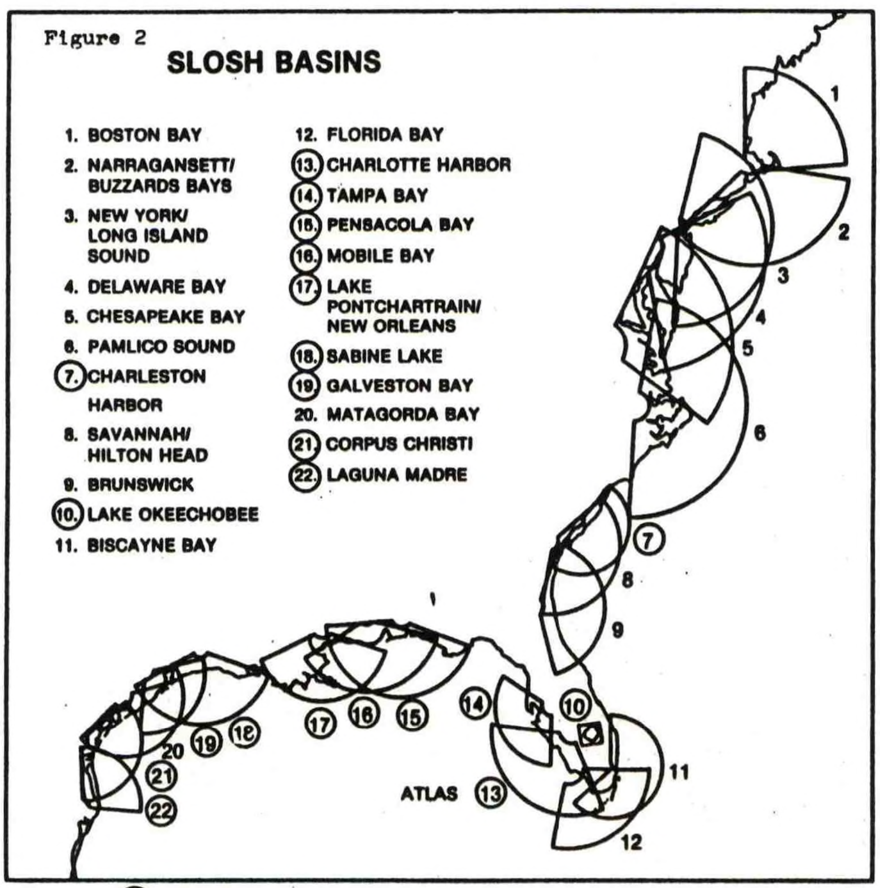


U.S. HURRICANES **1951-1960 ———**

Figure 1 **1961-1970 ———**



PHASE II COMPLETE INCLUDING MEOW .

Table..1

SAFFIR/SIMPSON HURRICANE SCALE RANGES

SCALE NUMBER (CATEGORY)	CENTRAL PRESSURE MILLIBARS	INCHES	WINDS (MPH)	SURGE (FT)	DAMAGE
1	⩾980	⩾28.94	74 - 95	4 - 5	MINIMAL
2	965 - 979	28.50 - 28.91	96 - 110	6 - 8	MODERATE
3	945 - 964	27.91 - 28.47	111 - 130	9 - 12	EXTENSIVE
4	920 - 944	27.17 - 27.88	131 - 155	13 - 18	EXTREME
5	<920	<27.17	>155	>18	CATASTROPHIC

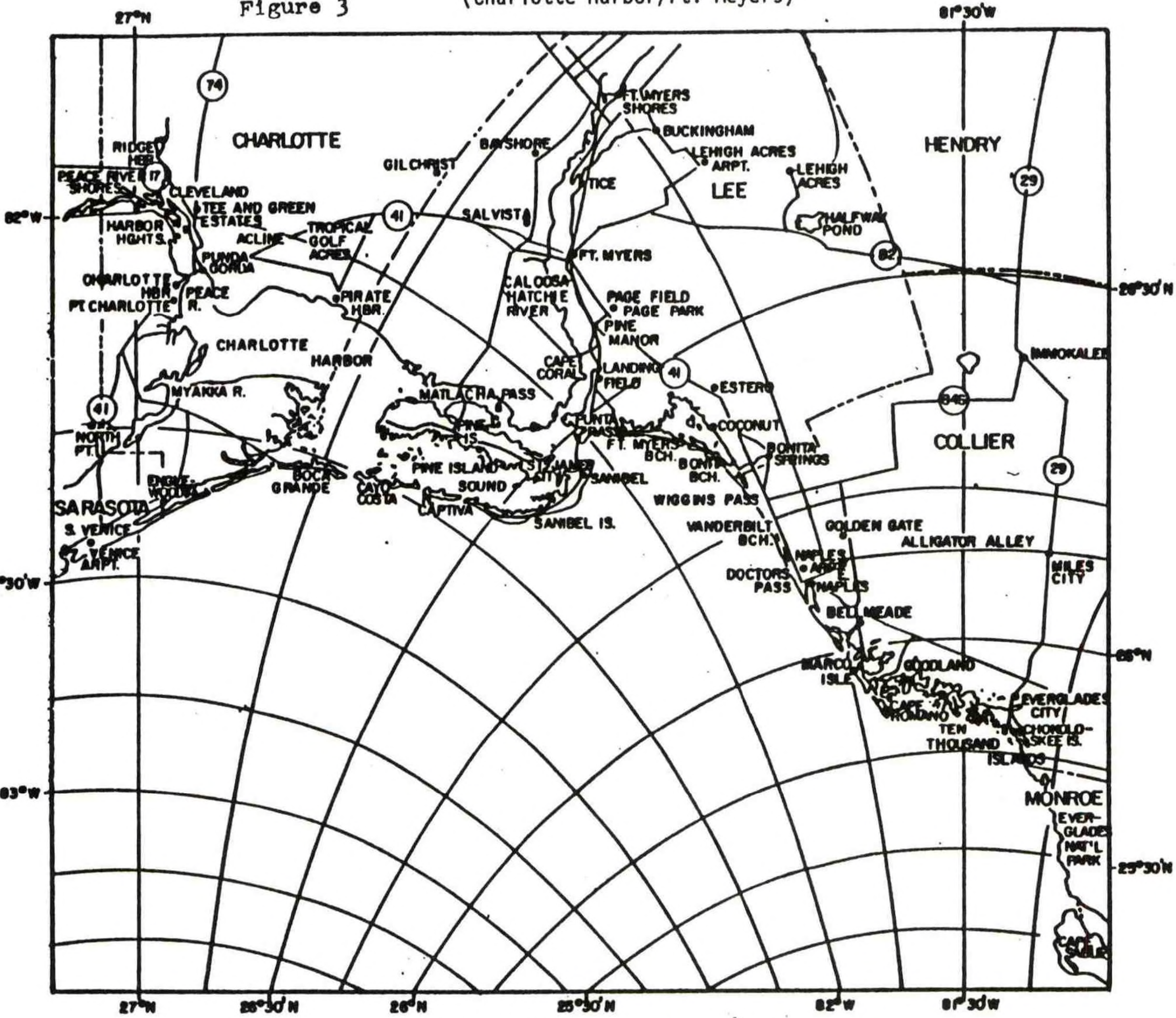
Table 2

DEADLIEST ATLANTIC & GULF COAST HURRICANES
LEVELS 3-4-5 (1951-1984)

HURRICANE	YEAR	CATEGORY	DEATHS	DAMAGE (MILLIONS $)
AUDREY (LA/TX)	1957	4	390	150
CAMILLE (MS/LA)	1969	5	256	1,420
HAZEL (SC/NC)	1954	4	95	281
BETSY (FL/LA)	1965	3	75	1,420
CAROL (NE U.S.)	1954	3	60	461
DONNA (FL/EAST U.S.)	1960	4	50	387
CARLA (TX)	1961	4	46	408
HILDA (LA)	1964	3	38	125
CONNIE (NC)	1955	3	25	< 52
FREDERIC (AL/MS)	1979	3	22	2,550
ALICIA (TX)	1983	3	18	1,000

SOUTHWEST FLORIDA
(Charlotte Harbor/Ft. Meyers)

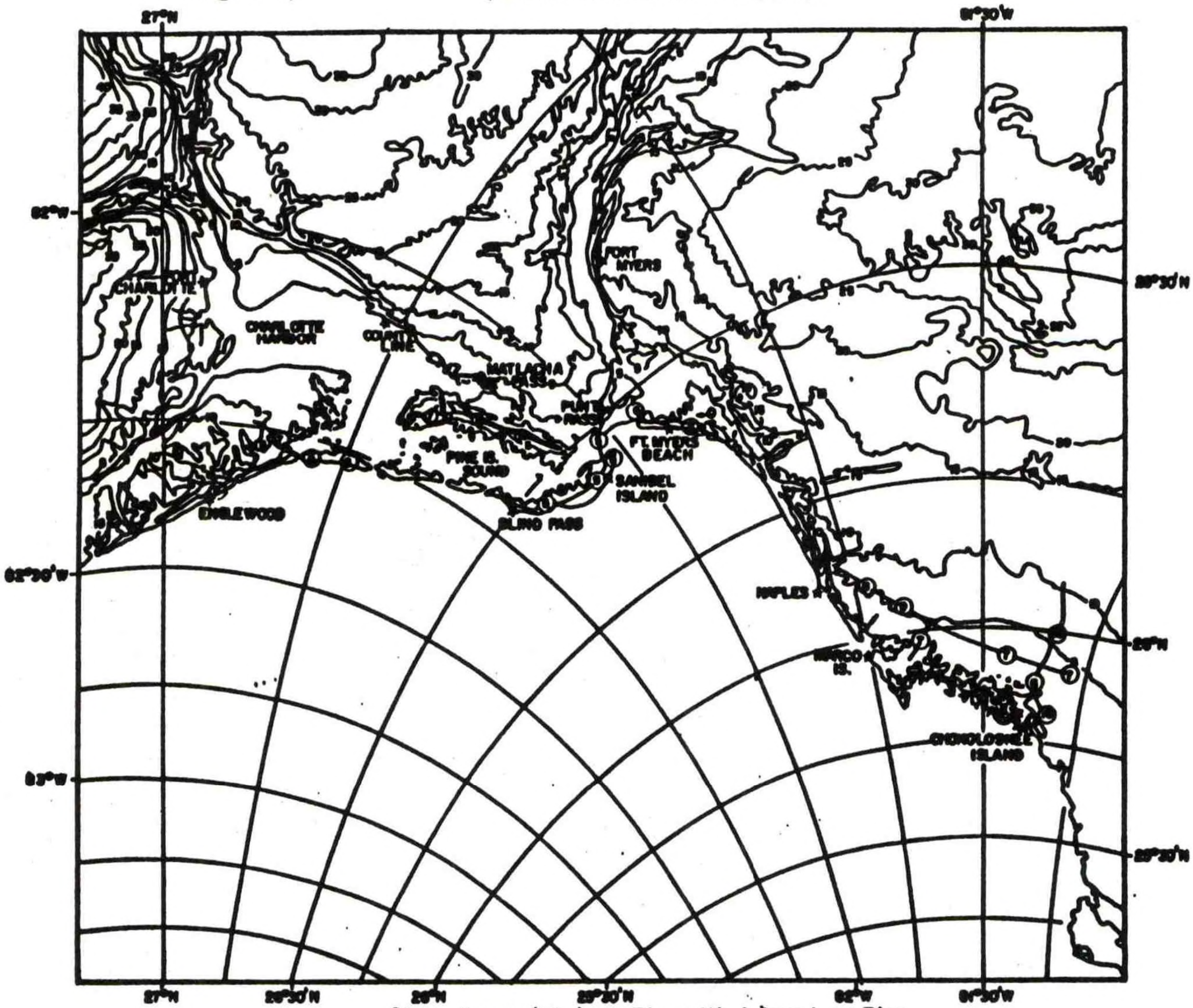
Figure 3



Major Highways, Principal Towns/Areas
(Overlay Chart)

Figure 4

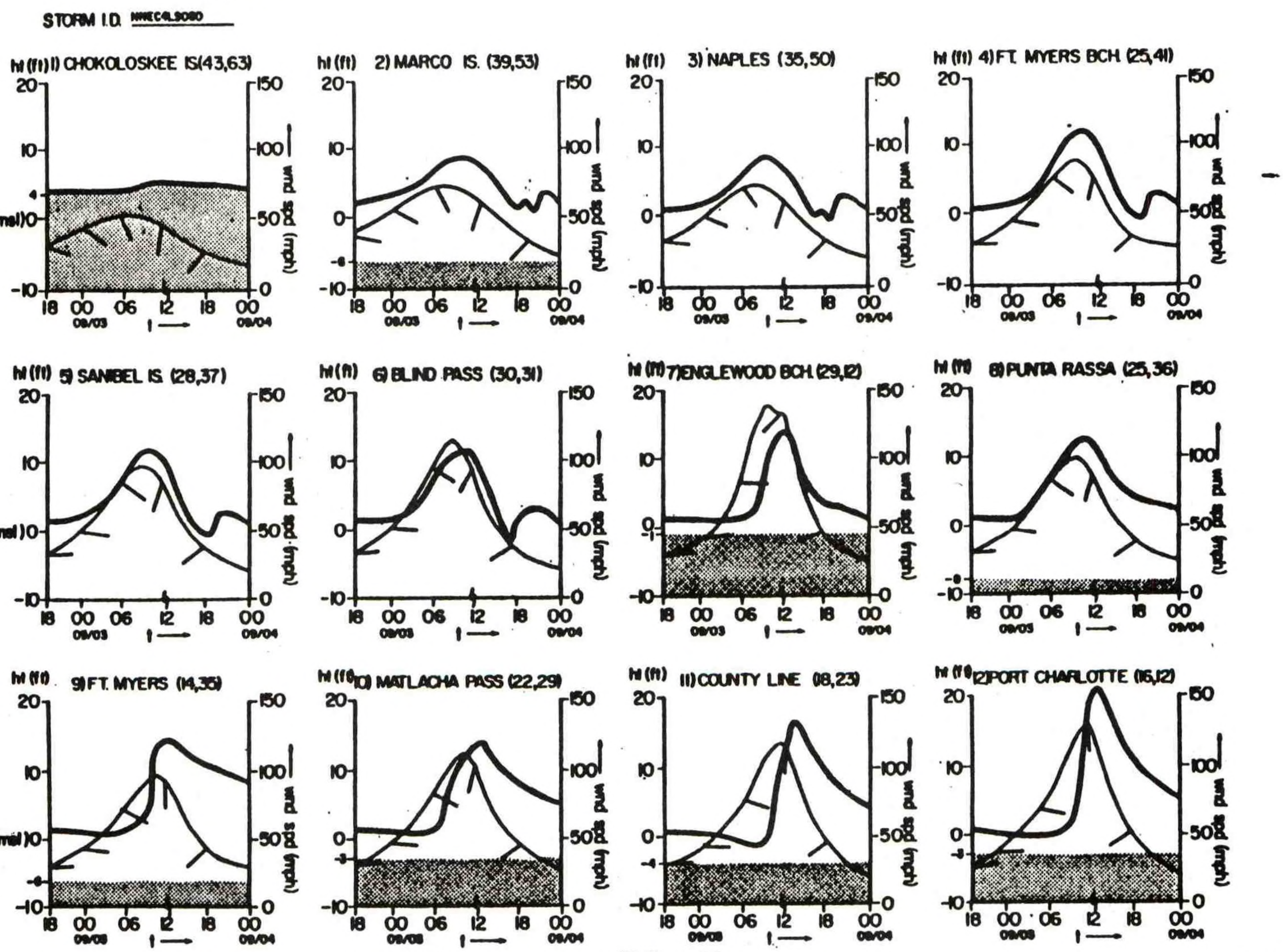
SOUTHWEST FLORIDA
(Charlotte Harbor/Ft. Meyers)



Storm Surge (Ft.) vs Time; Wind Speed vs Time
Graphs available for each of areas listed
(Overlay Chart)

SOUTHWEST FLORIDA
(Charlotte Harbor/Ft. Meyers)

Figure 5



Graphs of: Storm Surge (Ft) vs Time
Wind Speed vs Time

For 12 Areas

(Charlotte Harbor/Ft.Meyers)

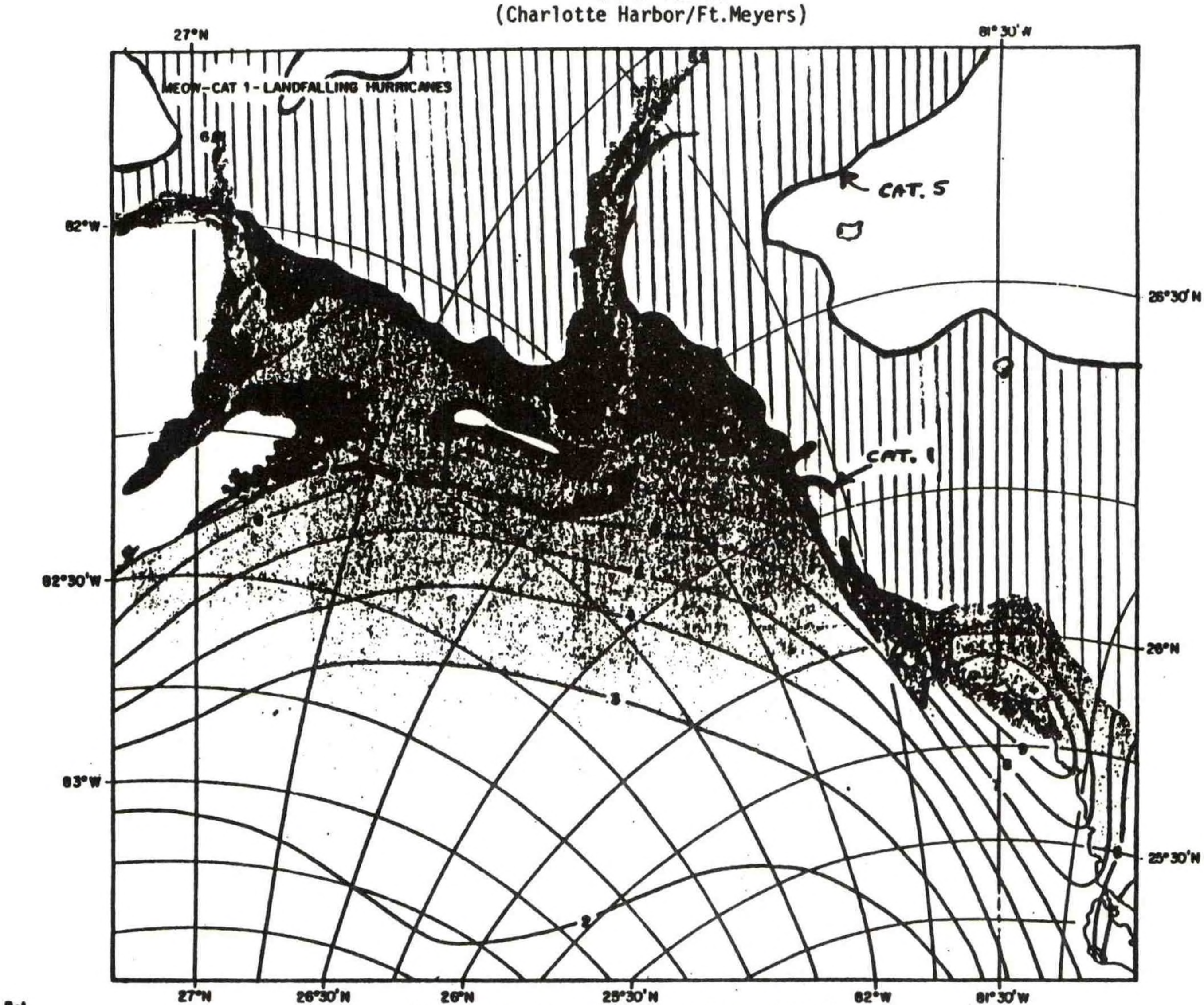


Figure 6

Maximum Envelope Overland Water (MEOW)
Integration of Simulated Runs for Category 1
Landfalling Hurricane
5

The New Sail Training Ship "Nippon Maru"

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Preface:

New large sails have rarely been built worldwide and have never been built in Japan for this half a century. The "Nippon Maru" completed on September 14, 1984 by Sumitomo Heavy Industries, Ltd. at its Oppama Shipyard for the Institute for Sea-Training of the Ministry of Transport is a new large sail built in Japan for the first time during past half a century.

1. Background for Construction

The construction of first generation dates back to more than 50 years ago when the old "Nippon Maru" was built in 1930. This sail had been in service for training ship together with its sister vessel "Kaiwo Maru". During the Second World War the sail was reconstructed to remove the rig, and after the War, it engaged in transporting ripatriate and it was reequiped in 1952 and placed back as sail training ship again. These were really hard times for the ship. The hull became so old that the building of new sail was expected.

The Institute for Sea-Training has decided the following basic direction for this new sail to be built.

(i) The new vessel will be built based on the old "Nippon Maru" and "Kaiwo Maru", but designed for basic marine engine training, too.

(ii) The new vessel will have durability with dignity and beauty, giving consideration to the long years service.

(iii) To give thorough consideration to its hull strength, righting moment, noise-proof, vibration-proof and heat-proof.

(iv) The new vessel will have the training equipment and facility necessary for practical training, and as well be equipped with the best fitting for training of sailing quality (including training of mind and body, "sea-worthy") and acquisition of practical seaman-ship.

(v) To make living conditions as comfortable as possible and to give consideration to sailors' healthy life on board.

2. Design Considerations

A few years before the Meiji Era, Japan imported steamers as well as large sailing vessels. Accordingly, Japan entered into the age of power vessels without going through the age of clippers, which means that Japan did not get used to designing the large sailing vessels, especially for the sails.

Thus, five large sail training ships (including first generation of the "Nippon Maru" and the "Kaiwo Maru") built in Japan before completion of the second generation of the "Nippon Maru" were designed and built in Japan, except the designing for the sail which came completely from U.K.

As there is no appropriate guideline available in Japan for designing of the large sailing ships, we were forced to rely upon the data in Europe and the U.S.A. However, most of such data was a sort of "folktale" far from modern design book. Therefore, we analyzed these obsolete documents which could be called "Museum Property", confirmed our analysis by means of the wind tunnel test and the tank test, and finally interpreted and generalized the "folktale" sail designs through the modern naval architect, spending a lot of energy to arrive at optimum design data.

I cannot introduce all of these works on this limited report, so I will take up and explain a few of them.

2-1 Wind Tunnel Test
As to the sail, the most essential part of the sailing vessels, we performed the wind tunnel test to make researches on its shape, masts distance and its relation with the hull. The part of the test is described in Photo 1, Fig. 1 and Fig. 2. Further, the speed rate as resulted from the test is described in Fig. 3.

2-2 Roll Damping Test
It has been known since old days that sailing vessels do not have much rolling. However, no one has ever succeeded in analyzing it theoretically or technologically. We recognized in the test result of the "Shin-Aitoku-Maru" that the sail had an effect on the roll damping. This effect is prominent in case of the sailing training vessel, with large

areas of the sail. The scene of the tank test and the part of test results are described in Photo 2, Fig. 4 and Fig. 5. These test results are reflected on the evaluation of dynamical stability, and the stability of this new vessel fulfils the requirements of the passenger ship.

2-3 Strength of Mast and Stay

As to deciding the scantling for mast, stay and yard, considering the influence effected from the material difference, we analyzed the scantling through direct calculation, referring to the Rule and Regulations of Lloyd's Registers (1906/1907) and German Lloyd's (1903), etc. The computer program we adopted is the 3-Dimensional Structure Analysis Program (ICES-STRUDLE-II) as modified for mast and stay. We analyzed the scantling using wind pressure acquired from the wind tunnel test or acceleration of the ship motion acquired from the tank test and the theoretical calculation, as the external force, and the part of this analysis results are described in Fig. 6.

It is so difficult to verify the calculation results that we confirmed the reasonableness of our calculations by collecting many dismast photos, verifying dismast positioning and maximum stress occurring position, and also varying pretension in many ways when the stay is mounted on the vessel and measuring precisely the deformation of mast and stay.

Several types of vessels are tested for resistance, self propulsion and manoevability, which is common to general vessels. As sailing vessels, which are different from ordinary vessels, decline to wind pressure and sail in an oblique state with helm angle, we made a search for hydrodynamics derivatives in several conditions through oblique towing test. Further, we made a search for the characteristic of sailing ships through several tests including the test for confirming the bar keel effect upon drifting.

3. Fitting and Equipment

For fitting and equipment, traditional method was adopted. However,

3-1 Sail Making

We put the machine sewing sail and the hand sewing sail to the endurance test. As a result, we came to confirm that the hand sewing sail has higher durability, and so selected the hand sewing sail for the new vessel.

There is no problem regarding sail making for the new vessel after going into service, because cadets hoist its sails. However, the number of workmen was so restricted while the new vessel was under construction that we had to spend long time to hoist its sails.

3-2 Standing Rigging

The main standing rigging was treated elaborately so that it can be used for a long time period. After various reviews, we decided to give traditional serving treatment to the primary standing elaborately, and we gave protective treatment at the three stages of worming, parcelling and serving. For end treatment, we adopted the socket method as opposed to the traditional end-up-sizing method.

3-3 Running Rigging

Nylon rope has higher strength. However, the diameter of the rope is confined to the grip size, so we cannot make the rope thin even if the rope has high strength. The block, strength of which is equivalent to the running rigging, necessarily increases its size. It is necessary for us to consider the balance between the diameter of the running rigging and the block size.

It is in the field of the fitting and equipment that we will find a lot of other problems if we try to manufacture with modern material, based on the traditional shape. As to the engine department and the navigation equipment, I will state only that we made the automation and the automatic measuring devices equal to those of modern vessels, for the purpose of educational training.

4. Nippon Maru

After making the foregoing efforts in design and building, we decided the principal particulars for new "Nippon Maru" as described in Table 1 in comparison with the ex "Nippon Maru". The comparison between both vessels is described in Fig. 7 and the general arrangement plan is described in Fig. 8. The completed sailing condition is shown in Photo 3.

5. Conclusion

The foregoing is in an attempt to outline the technological approach we had for the building of the large sail training vessel "Nippon Maru" while its sailing performance must be confirmed with the actual servicing which largerly depends on the marine weather conditions and the degree of the sail operating skill, I believe that it must be more excellent than that of the ex "Nippon Maru". I also believe that much technological knowledge and experience regarding sailing vessels acquired at the time of building of this new vessel will contribute so much to the designs of the modern sailing vessels.

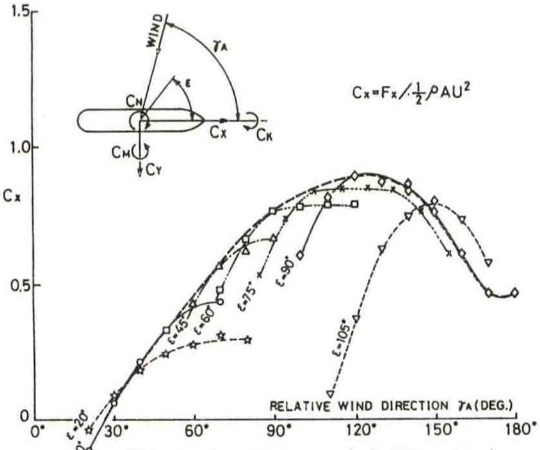

FIG.1. Cx-Curves (Full sail)

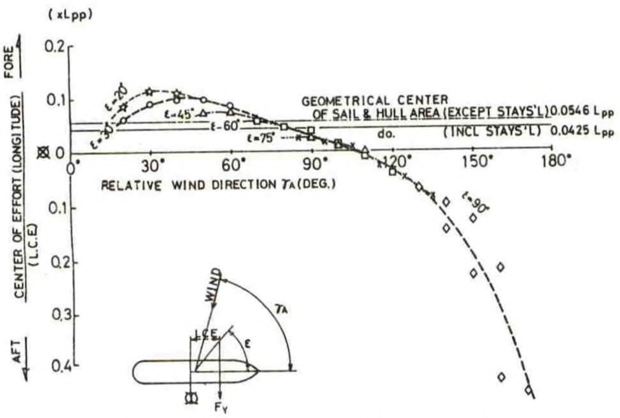

FIG.2. L.C.E. Curves (Full sail)

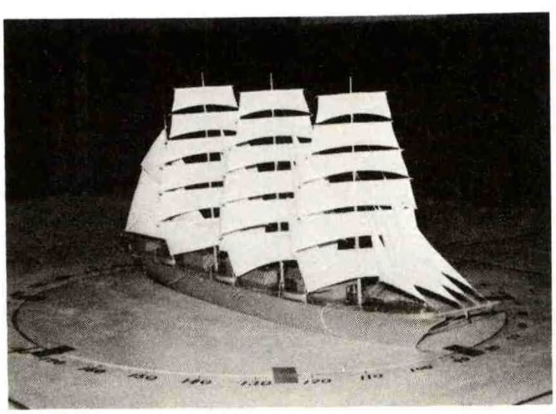

Photo 1 Wind Tunnell Test

Let me end this report by emphasizing that the satisfactory completion of this sailing vessel owes to extreme enthusiasm and energy of all people who joined in this building project, among others the Institute for Sea-Training, seniors in shipbuilding industry d and related suppliers.

I 'express my deepest thanks to all of them.

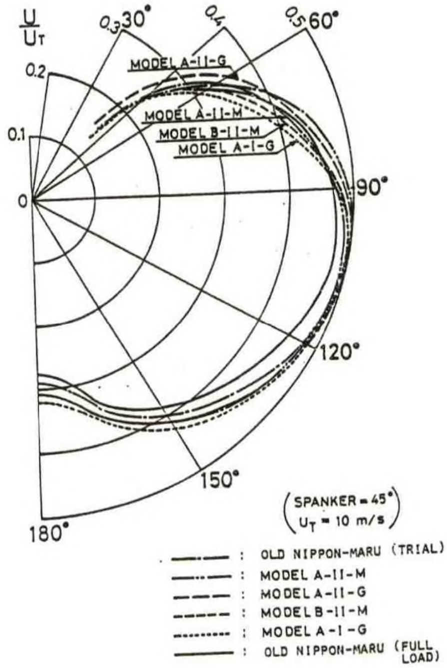

FIG.3. Speed Rate

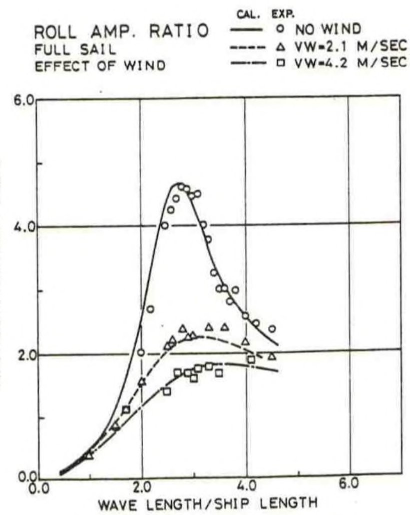

FIG.4. Roll Amplitude in Wind and Waves

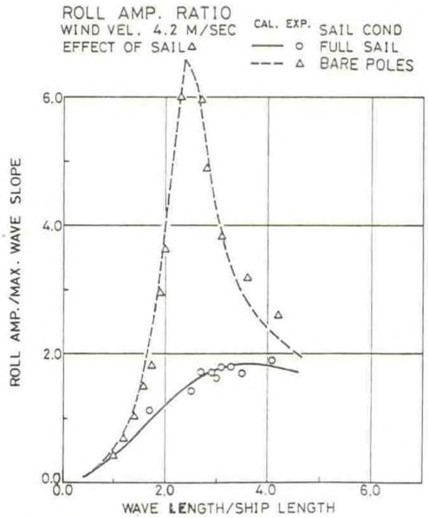

FIG.5. Sail Effect for Roll Amplitude

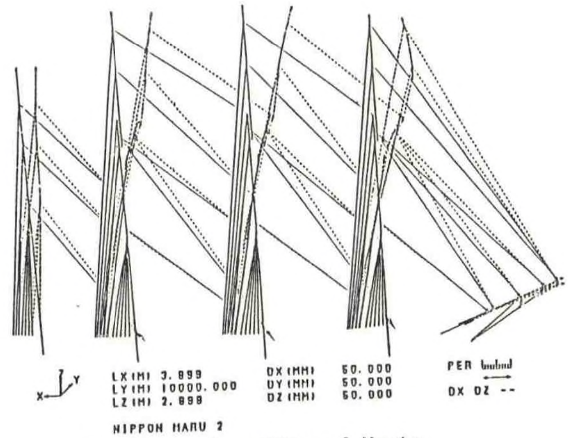

FIG.6. Deformation of Masts

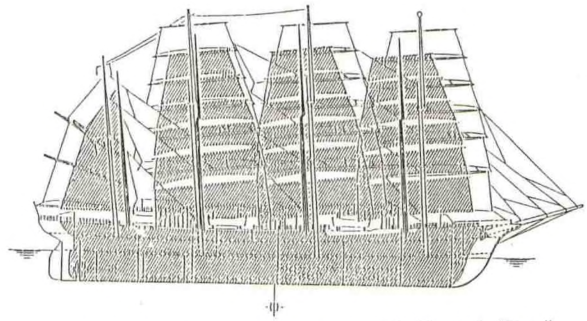

FIG. 7. Comparison between "Old" and "New"

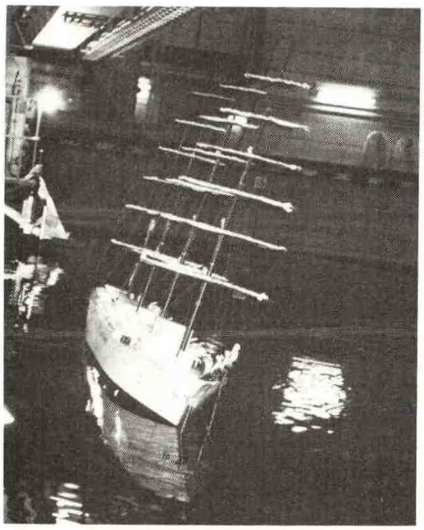

Photo 2-a Rolling Test (Bare Poles)

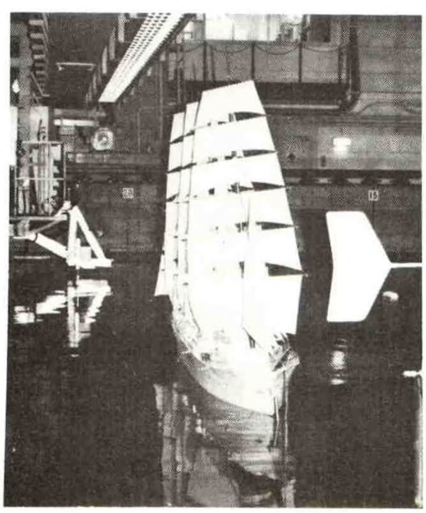

Photo 2-b Rolling Test (Full Sail)

Table 1. Principal Particulars

Item	NIPPON MARU	Ex.NIPPON MARU	Remarks
Keel Lay	1983-4-11	1929-4-17	
Launch	1984-2-15	1930-1-27	
Completion	1983-9-14	1930-3-31	
Ship Type	Complete Super Structure Deck Type	Well Deck Yype	
Sailing Rig	4 Masted Bark	4 Masted Bark	
Principal Dimension			
Length Overall	110.09 m	97.05 m	Incl.Bowsprit
Length p.p.	86.00 m	78.23 m	
Breadth mld.	13.80 m	12.95 m	
Depth mld.	10.70 m	10.29 m	Up to Super-str. Deck
Loaded Draft mld.	6.29 m	6.15 m	Above B.L.
Gross toonage	2,570 GT (abt.2,950 GT*)	2,284 GT*	* Old Rule
Service Speed	13.2 Knt	abt. 8 Knt	30% sea margin
Main Engine	2x1,500 PS	2x600 PS	
Complement			
Crewa	70 p.	66 p.	
Cadets	120 p.	120 p.	-
Total	190 p.	186 p.	
Number/Area of Sail			
Square Sail	18/abt.1,790m	18/abt.1,531m	
Fore & Aft Sail	18/abt. 970m	18/abt. 866m	
Full Sail	36/abt.2,760m	35/abt.2,397m	
Max.mast height	abt.55.52 m	abt.50.61 m	Above B.L.

Photo 3 Completed Full Sail Condition

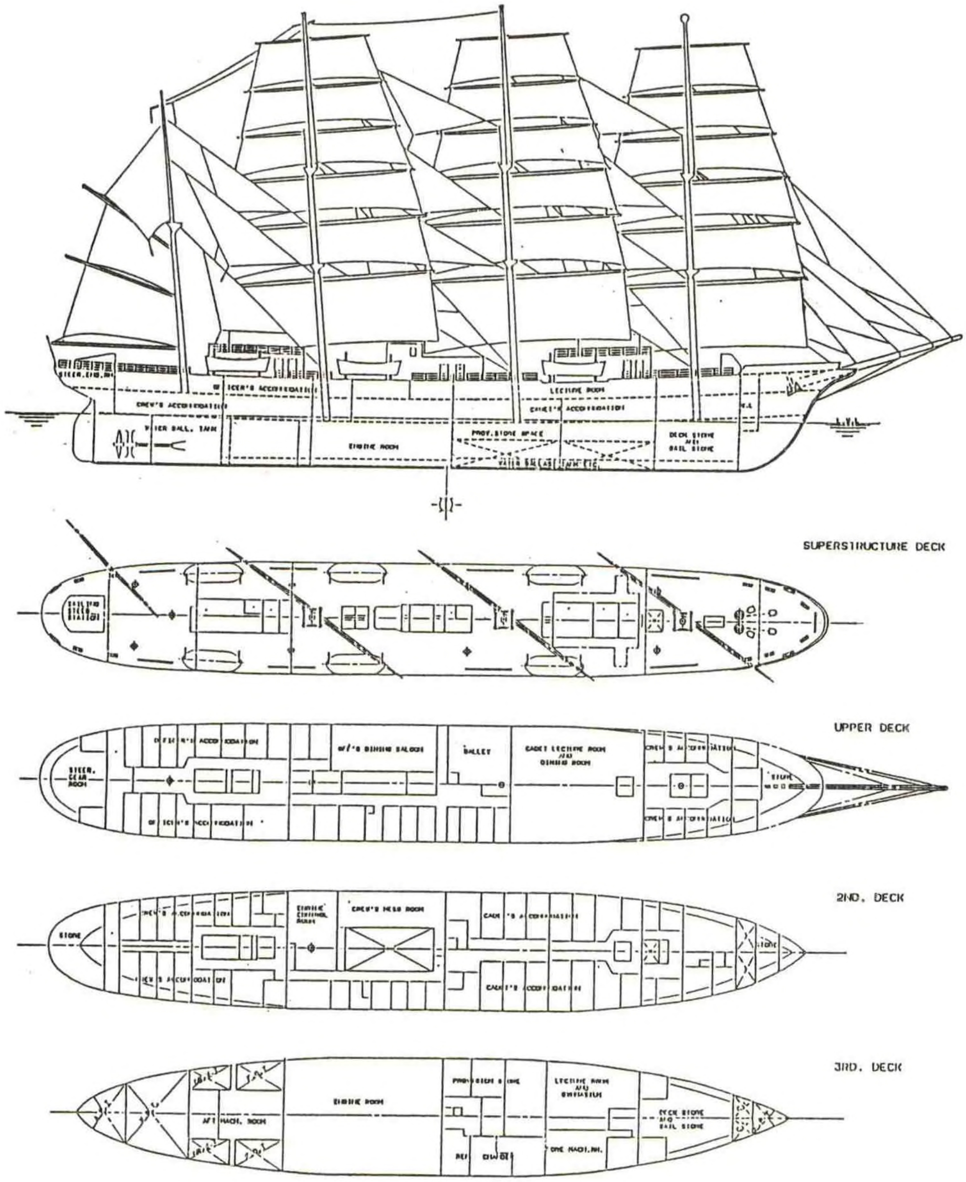

FIG.8. General Arrangement Plan

Voice Control of Mooring Winch

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1. Preface

In parallel with the advancement of hardware and software technology of computer, automatic devices using computer is being actively adopted by ships and vessels.
Man-Machine Communication applied to such automatic devices are mostly indirect method, but there is voice information treatment technology which enables direct communication through the human invoice.
If at the busy port-entering and port-leaving time, ship and vessel navigator is able to operate directly mooring winch like "Open Sesame" in well known Ali Baba Story by the use of this voice information treatment technology, operation error can be avoided and labour saving will be attained.
In this respect, this paper reports the co trol system recently adopted to three mooring winches of DW200,000 T Ore Carrier "TSUKUBA-MARU".

2. Basic policy of Mooring Winch Voice Control

Navigation of ships and vessels involves high judgement ability, wide working areas. And, the route from issuance of direction to execution of works are mostly as follows:

(1) Highest responsible person who directs and controls the navigation of ship and vessel

(2) Headman who possesses high judgement ability and causes the direction to be executed

(3) Operator who performs the works as directed

This route and method is frequently seen in the operation of main engine and operation of deck machineries at the port entering and leaving time, at wharf leaving time, at the mooring time.
If in the above direction route, the relevant machines could work without any error by the highest responsible person, the above 2) and 3) can be omitted and labour saving effect will be obtained.
Since the biggest number of operators are required in the mooring works, much labour saving effect will be attained if mooring can be made by voice control.

3. Voice Input and Pre-treatment

Working principle of voice recognition part used as voice control of the moored ship is shown in figure 1.

(1) Voice input and pre-treatment.
Voice is collected by microphone, and amplified to the appropriate level by amplifier. Amplified voice signal is supplied to spectrum analyzer. Voice signal inputted into spectrum analyzer is then analyzed by band filter of 16 channels which are divided according to the disbribution of standard information amount.
The output of filter of respective bands are smoothed through low area filter which is rectified to detect the signal level within belts and supplied to analogue multi treatment A/D converter thereby being converted to digital signal. These information is sampled at every 5 mil-seconds and similar treatment is made.

(2) Digital treatment of voice signal
Digitalized voice signal is treated by coding compressor to compress the data. Word detector detects the opening and closing of respective voices and compresses to a certain pattern irrespective of inputted word length, thereby symbolizing.

(3) Preparation of Reference Pattern
Human being does not necessarily speak in a same accent when he speaks any language, but there are certainly, variations.
In order to memorize such variation, persons who make voice input are required to make three repetitive speakings so that form of reference pattern is made by pattern collector. Such reference pattern is memorized in the reference pattern memory, representing the expression of respective specific words.

(4) Classification of Input Voice
At the recognition mode, the correlation between the inputted voice and reference pattern memory for each language is calculated by bit and scores indicating the discrepancy degree are given.
Scores of average discrepancy at the reference pattern making time are calculated in advance and furthermore discrepancy margin scores for each language is added. This is reject level. If the score of discrepancy between reference pattern and inputted voice is within the reject leverance, the input is judged to be effective, and if the discrepancy exceeds the

level, it is rejected and no signal is emitted.

4. System Structure and Specifications

The System structure is shown in Figure 2. and the specifications of respective equipment are shown in the table 3 & 4:

5. Characteristics of the System

This system possesses the following characteristics:

(1) Content of Control
Content of control is determined as shown in Table 1.
In so determining, actual mooring works, questionnaires results, opinions of navigators at the shipyard were taken into account.

(2) Control Method
Prior to the operation, usage language by means of the director is inputted and registered as reference pattern.
In case of change in a director, reference pattern of new director is registered.
Since it is nuisance to register the reference pattern at each time of change in the director, there is a way that voices of all directors are inputted and reference pattern is memorized in small magnet disc and small magnet disc is replaced by an appropriate disc.
When a director makes an instruction by voice, voice recognition device recognizes the content and the recognized content is echoed in the voice recognition device. If such echo coincides with the instruction, working signal is emitted and the devices begins to work.

(3) Characteristics of the system
The characteristics of voice control of the moored ships are as follows:

(i) Director can make an instruction for the movement of the mooring winch by voice, whether treating hawer or auditing rope tention

(ii) Director has only to make an instruction of required movement to the mooring winch, drum or warping end: clutch change, speed control and brake change are automatically controlled by pre-setting sequence.

(iii) In case of the occurrance of trouble in voice input or voice recognition, simultaneous stoppage can be made by emergency stop switch.

(iv) In case of any trouble in the system, change to electrical

(v) Since registration of director's voice with pattern check can be made, the system does not work by the third party's voice other than that of director.

(vi) Noise is automatically removed by the automatic noise sampling.

6. Acknowledgement

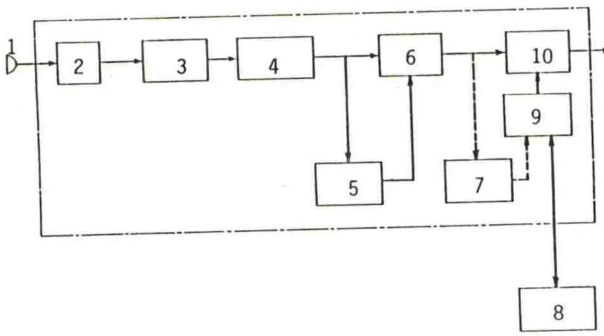
We have tried to control mooring winch using voice as direct Man-Machine Communication.
At present, it is operating very smoothly and we believe that said control method would be further improved by continued study of usage language, syntax, recognition logic etc, by collecting the date of actual operation. We have achievements of voice control of marine equipment such as the main diesel engine control of "Kinokawa-Maru" (built by Sumitomo Heavy Industries, Ltd.), mooring winch voice control which is the subject of this report and in the steering engine voice control built by Hitachi Zosen.
The development of this voice control has been made with the financial aid of the Japan Foundation of Shipbuilding Advancement (JAFSA). We wish to appreciate JAFSA's assistance and Daiichi Chuoo Kisen who provided an opportunity for the adoption of the voice control.

Table 1. Categories of Voice Recognition Technology and its possibility

Type of Voice Entry / Speaker	Discrete Speaking		Continuous Speacking
	Word	Monosyllable	Word/ Sentence
Speaker Dependent	Practical use	First stage of Practical use	Under study (Partially Practical use)
Speaker Independent	Partially Practical use (Too expensive)	Under study (Partially Practical use	Future Investigation

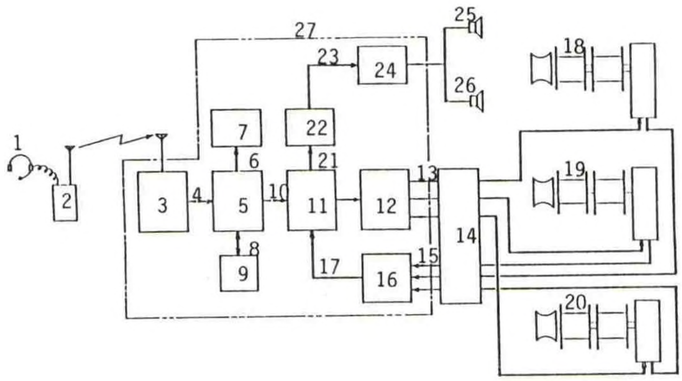
Table 2. Items Controlled by Voice

Mooring Winches	Drums	Items
No.9 Mooring Winch	Port Drum S.B Drum	Direction (Slack Off or Heave in Rev. (L.M.H.) (8 Slack Off or Heave in)
No.10 Mooring Winch	Both side Drum	Break on/off
No.11 Mooring Winch	Warping Heads	Clutch on/off



1 Speech signal
2 Amplifier
3 Spectrum analyzer
4 Analog multiplexer/A-D converter
5 Word boundary detector
6 Coding compressor
7 Reference pattern compensator
8 Micro floppy disk
9 Reference pattern memory
10 Correlation processor
11 Output interface
12 Mooring winch

FIG. 1. Block Diagram of Voice Recognition Unit



1 Headphone-microphone for speaker
2 Portable transceiver
3 Stationary wireless unit
4 Voice signal
5 Voice recognition unit
6 Display command
7 Display unit
8 Voice pattern write/read
9 Micro floppy disk
10 Code of recognized word
11 Micro computer for control
12 Output interface including D/A converter
13 Output signal
14 Interface panel
15 Input signal
16 Input signal interface
17 Input signal
18 Mooring winch
19 Mooring winch
20 Mooring winch
21 Voice synthesizing command
22 Voice synthesizer
23 Synthesized voice
24 Loud speaker amplifier
25 Speaker
26 Speaker
27 Voice control system rack

FIG. 2. Block Diagram of Mooring Winch Voice Control System

Table 3. Major Equipment

Mooring Winch	3	Control Micro Computor	1
Portable Transceiver	1	Output Interface	1
Throat Microphone	1	Input Interface	1
Directional Headphone Microphone	1	Voice Synthesizer	1
Stationary Radio Unit	1	Amplifier	1
Voice Recognition Unit	1	Speaker	1
Micro Floppy Disk	1	Interface Panel	1
Alfa-Numeric Display	1	Simulation Test Panel	1

Table 4. Specifications of major devices
(refer to Figure 3)

(a) Portable transceiver

Coverage	30m radius
Battery	Charging type Ni-Cd 2.4V (4 hour Available)
Emission	F3
Receiving frequency	117.395 MHz
Transmitting frequency	140.35 MHz
Microphone	Throat microphone Directional headphone microphone

(b) Stationary wireless unit

Electric source	AC, 100V
Emission	F3
Receiving frequency	140.35 MHz
Transmitting frequency	117.395 MHz
Output power	0.02 W
Antenna	75 proof

(c) Voice recognition unit

Type of voice entry
Discrete word speaking
Speaker dependent
Voice recognizing method
non-linear pattern
DP matching
Recognizable max. number of words
80 Words
Length of word
0.1 - 1.3 sec.
Space of voice entry
0.1 - 0.25 sec.
Response time
within 2 sec.
Recognizing accuracy
99.8%
(by 5 times repeat of 100 words)

Auxiliary output	RS-232C
Electric source	AC. 100 V

(d) Micro floppy disk

Capacity	8K Bytes
Recording type	FM
Dimensions	67mmx67.8 mmx1.5 mm
Frequency of use	2000 times or more

(e) Display unit

Type	Plasma display
Display	16 charactersx1x1 line
Character	128 kinds
Dimensions	10.2mmx175mm

(f) Voice synthesizer

Synthesizing method	PARCOR
Frequency	Man: 100Hz - 2KHz Woman: 150Hz - 4KHz
electric source	DC, 5V

(g) Micro Computer for control

CPU	8 bits
PROM	8K bytes

(h) Loud speaker

Amplifier output power	Max 30W
Speaker	10 W water

(i) Mooring Winch

Capacity	20Tx15m/min
Drum	Hawser drum 2 Warpind head 1

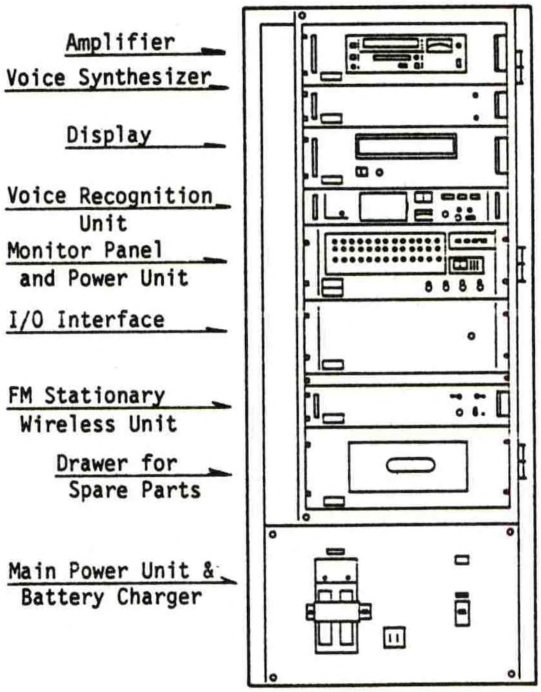


FIG. 3. Contents of Voice Control System Rack

A Handy-type Ship Maneuvering Simulator

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ABSTRACT

This paper presents an outline of a handy-type ship maneuvering simulator, which was developed for purposes such as maneuverability evaluations in the ship design and maneuvering safety studies in the port design. System description is made first, and then some examples of the simulator study reuslts are presented. The simulator is extensively utilized now as a very useful and powerful tool for such purposes as the above.

1. INTRODUCTION

Recent progress in the maritime transportation has brought about development of various kinds of ships, such as high-speed container ships, liquefied natural gas carriers and oil tankers from handy-sized product carriers to ULCCs. In connection with problems of the navigation safety in ports and waterways, the diversification in ship types and the growth in ship size, mentioned above, have greatly enhanced the significance of the ship maneuverability.

For the naval architect, it has become very important to precisely predict the ship maneuverability at the preliminary design stage. Moreover, at the time of ship completion, the maneuvering information is required for posting in the wheelhouse of ships, as is recommended by IMO. In addition to the ship design area, in the area of the port design, it has become necessary to perform maneuvering safety studies of ships which are expected to enter the port to be planned.

For these kinds of purposes, namely in order to flexibly meet these kinds of needs, the simulation calculation technique may be considered to be the most useful and powerful tool. Paying attention to this point, in Mitsui Engineering & Shipbuilding Co., Ltd., extensive studies have been made on the ship maneuvering simulation. Major emphasis was placed on development of a practical calculation method for wide range of the ship maneuvering motion, namely for various kinds of the ship maneuvering motion under various environmental conditions. A mathematical model for the fundamental maneuvering motion in calm and deep water was developed first[1]. Then this mathematical model was improved and its applicability was extended to the wide range of the ship maneuvering motion, namely such ship maneuvering motion as that under external forces of wind, wave and current in shallow water area. Thus a highly sophisticated mathematical model of the ship maneuvering motion for practical use was successfully developed[2].

Based on the versatile results obtained and accumulated through the above mentioned studies, an attempt was made to develop a handy-type ship maneuvering simulator with which such work as the maneuverability evaluations in the ship design and the maneuvering safety studies in the port design can be performed extensively in the practical sense. The simulator thus developed is not a real-time one, but a highly sophisticated mathematical model is employed in it. This paper describes an outline of the simulator showing some examples of the simulator study results.

2. SYSTEM DESCRIPTION

The mathematical model of the ship maneuvering motion in this paper is based on coupled motion equations of surge, sway, yaw, roll and propeller revolution, and they can be written in the following form.

$$\begin{aligned}
\text{Surge}: \quad & m(\dot{u}-vr) = X_H + X_P + X_R + X_L + X_W + X_{WV} + X_F \\
\text{Sway}: \quad & m(\dot{v}+ur) = Y_H + Y_P + Y_R + Y_L + Y_W + Y_{WV} + Y_F \\
\text{Yaw}: \quad & I_{zz}\,\dot{r} = N_H + N_P + N_R + N_L + N_W + N_{WV} + N_F \\
\text{Roll}: \quad & I_{xx}\,\dot{p} = K_H + K_P + K_R + K_L + K_W + K_{WV} + K_F \\
\text{Propeller revolution}: \quad & 2\pi I_{pp}\dot{n} = Q_E + Q_P
\end{aligned}$$

where the terms (in the right-hand side) with subscripts H, P, R, L, W, WV and F represent hull forces, propeller forces, rudder forces, LTU (lateral thrust unit) forces, wind forces, wave drifting forces and other forcing functions respectively, and Q_E represents main engine torque. The shallow water effects are taken into account in the estimation of hull forces and rudder forces.

In this simulator, the ship maneuvering simulation can be performed through dialog with a computer terminal with the graphic display function, which is connected to a larged-sized host computer. The system configuration of the simulator is shown in Fig. 1. The simulator is basically composed of four major parts, namely simulation terminal, motion program, support programs and peripheral devices. The "motion program" with which the ship maneuvering motion can be calculated with high accuracy is based on the mathematical model mentioned above.

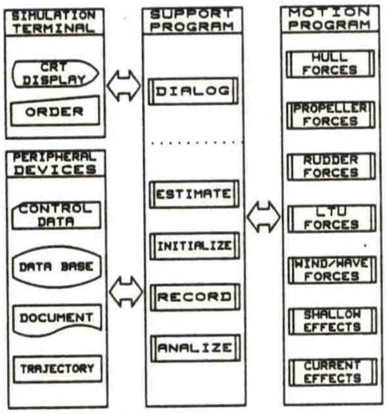

Fig. 1 System configuration

Standard simulator operation consists of three phases of preparation, simulation run and completion. In the preparation phase, huge data base stored in the large-sized computer system is fully utilized in order to estimate coefficients which are necessary for calculation of the ship maneuvering motion. For instance, hull force derivatives, propeller characteristics and rudder force coefficients can be estimated with the data base or the estimate formulae by knowing values of only the fundamental factors, which are usually given in the simulator study, such as the principal particulars of ship hull together with propeller and rudder geometry. Thus by inputting the minimum necessary data, versatile simulation results for the wide range of the ship manueuvering motion can be relatively easily obtained in this simulator.

In the phase of the simulation run, time histories of ship motion variables (ship velocity etc.) calculated by "motion program" are displayed at every moment on the CRT of the simulation terminal together with motion trajectory. Watching the results displayed graphically and numerically in this way, the simulation run is executed by giving the order of rudder and main engine operation etc. interactively. The simulation can be completed by repeating this procedure as long as necessary, although the simulation execution is not a real-time one because of the time sharing operation of the large-sized computer system.

In the completion phase, the simulation results are outputted and recorded both in graphical and numerical forms. Then according to purpose of the simulator study, analyses and evaluations are made.

3. SOME RESULTS OF SIMULATOR STUDY

Some examples of the simulation results obtained in two cases of simulator studies are presented here. One is a leaving maneuver in a port (through narrow waterway to outer sea) of a bulk carrier, and the other is an entering maneuver in a port (from outer sea to berthing area) of a container carrier.

(1) Leaving maneuver of a bulk carrier in Port "A"

A large-sized bulk carrier was planned for transportation of raw materials form Port "A", which has a crooked narrow waterway at entrance part of the port. The newly planned ship was such a large-sized ship (220,000 DWT) that had never entered into the Port "A". In this context, the maneuverability of the bulk carrier was carefully investigated at early stage of its design, placing major emphasis on the transit maneuver through waterway at fully loaded condition. In the following, typical examples of the simulation results for the waterway transit maneuver obtained in this investigation are presented, where ship operations were performed by professional ship officers.

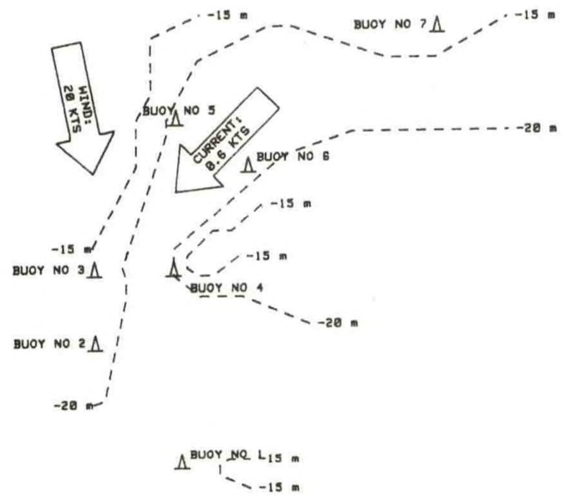

Fig. 2 Schematic plan of Port "A"

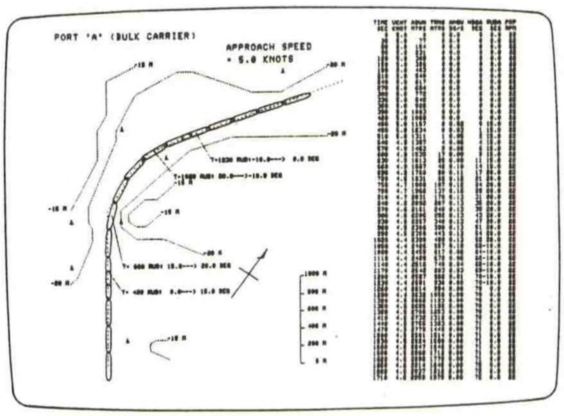

Fig. 3 Leaving maneuver of a bulk carrier in calm water

A schematic plan of the crooked narrow waterway of the Port "A" is shown in Fig. 2 together with water depth contour and buoy arrangement. In this maneuvering simulation, ship enters into

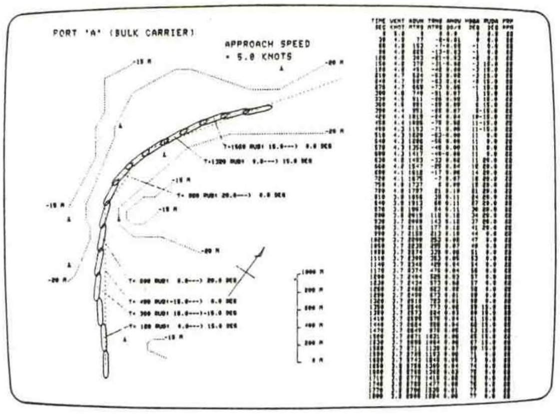

Fig. 4 Leaving maneuver of a bulk carrier in wind and current

the waterway (the ratio of water depth to ship draft = 1.2) with an approach speed of 5.0 knots and proceeds changing its course along the crooked waterway to the port exit.

Fig. 3 shows the result of the waterway transit maneuver at the calm sea condition. Fig. 4 shows the result under the wind (wind speed of 20 knots) and the current (current speed of 0.6 knots) condition, where directions of the wind and the current are referred to Fig. 2. These figures indicate that the subject bulk carrier would have no problems regarding its transit maneuver through the waterway in the Port "A", although some difficulty may be expected under the condition of external forces acting as is seen in Fig. 4.

(2) Entering maneuver of a container carrier in Port "B"

Maneuvering safety studies of a very large-sized container carrier (the maximum size of the Panama Canal passable hull form) were performed in connection with the port design of Port "B". Typical simulation results obtained in this investigation are presented here, which are for an entering maneuver from outer sea to berthing area.

Fig. 5 shows a schematic plan of the Port "B", where a waterway with constant water depth (the ratio of water depth to ship draft = 1.4) comes into berthing area from outer sea bending its direciton. In this maneuvering simulation, the ship is operated according to an operating procedure prepared by well-experienced ship masters. The operating procedure for the entering maneuver consists of the following three phases. The first phase: the ship passes over the point "A" (the entrance of the waterway) with an approach speed of 8 knots, and proceeds to the point "B" changing its heading along the waterway bend. The second phase: when the ship reaches the point "B", the order of "Engine Stop" is made. And then the ship proceeds to the point "C" only by its inertia. After passing over the point "B", the ship is accompanied by 4 tugs with maximum capacity of 3,000 HP each. Thereby in the stopping maneuver after the point "B", aid of tugs can be utilized so that ship can run on the waterway even under

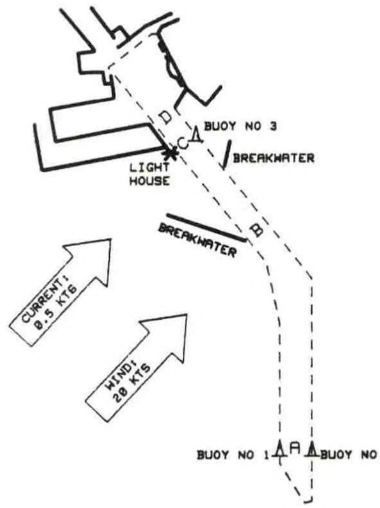

Fig. 5 Schematic plan of Port "B"

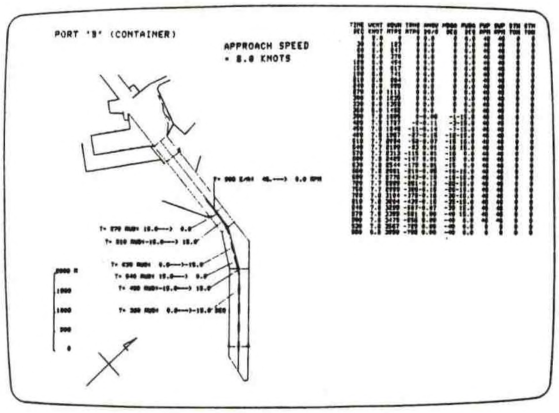

Fig. 6 Entering maneuver of a container carrier in calm water (1)

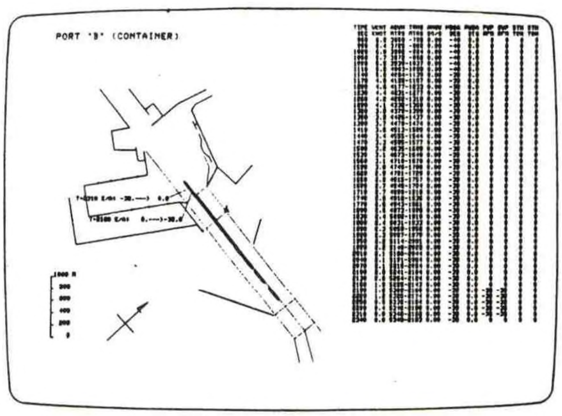

Fig. 7 Entering maneuver of a container carrier in calm water (2)

external forces (such as wind and current forces) acting condition. The third phase: after passing over the point "C", the ship is operated to stop at the berthing area, the area behind point "D". The main engine operation

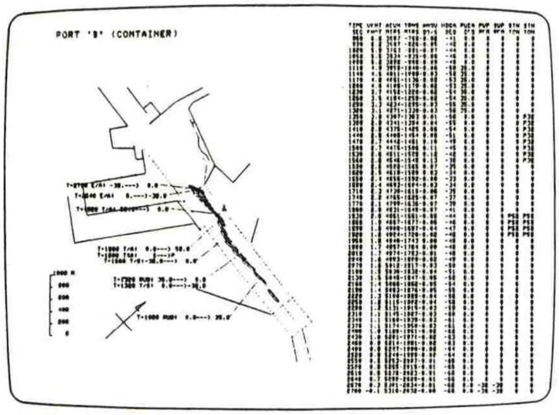

Fig. 8 Entering maneuver of a container carrier in wind and current

with the order of "Slow Astern" propeller rpm is made in the last part of this phase, and the simulation is ended when the ship stops.

The simulation results for the calm sea condition are shown in Figs. 6 and 7. The result in the first phase is given in Fig. 6 and the result in the succeeding second and third phases is given in Fig. 7 where necessary portion of the port layout is zoomed up on the CRT display. Fig. 8 shows the result of the simulation under the wind (wind speed of 20 knots) and the current (current speed of 0.5 knots) condition for the stopping maneuver after the point "B", where direction of the wind and the current are referred to Fig. 5. In the ship handling shown in Fig. 8, the aid of tugs is fully utilized in order to keep the course on the waterway. It may be seen from these figures that external forces could considerably affect the entering maneuver of the subject container ship.

4. CONCLUDING REMARKS

A handy-type ship maneuvering simulator was developed for purposes such as the maneuverability evaluations in the ship design and the maneuvering safety studies in the port design. System description and some examples of the simulator application are presented in this paper. The simulator is not a real-time one, but the mathematical model employed in it is a highly sophisticated one. The simulator presented here is extensively utilized now as a very useful and powerful tool for such purposes as those mentioned above.

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THE SPERRY ADVANCED INTEGRATED NAVIGATION SYSTEM

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ABSTRACT

This paper describes a sophisticated integrated navigation system that Sperry developed for use on a geophysical exploration ship owned by a major multi-national oil corporation. The system can optimally process navigation data from a large set of navigation sensors which includes Doppler sonars, gyrocompasses, navigation satellite receivers, Loran C receivers and as many as four (from a set of eight) radio navigation aid receivers. The system also provides for many other functions including automatic steering along survey lines, control of the seismic shot events, and logging of navigation and other data at seismic shot times. The system has many applications including deep sea mining, cable laying and mine hunting.

INTRODUCTION

Sperry has produced what may well be the world's most sophisticated commercial Integrated Navigation System (INS). The system was developed for use in seismic and geophysical oil exploration by a multi-national oil corporation. This corporation selected Sperry to develop the system because Sperry had in-depth capability in the following essential areas:

- o System engineering
- o Navigation optimization
- o Ship control
- o Computer Programming
- o Computer Technology
- o Display Techniques

Because the system provides optimal navigation and accurate steering along survey lines, the system is expected to have wide application in at least the following areas:

- o Geophysical Exploration
- o Oceanographic Exploration
- o Deep Sea Mining
- o Cable Laying and Positioning
- o Precise Military Navigation
- o Mine Hunting
- o Mine Sweeping

The development of the system started in December 1980. By July of 1982, the system development was completed and the system was installed on its host ship which was built by Mitsubishi at their shipyard in Shimonoseki, Japan. The ship was sent to the Gulf of Mexico where, in the Autumn of 1982, the system underwent at-sea test, tuning and demonstration. Since March of 1983, the ship with its Sperry Integrated Navigation System has been conducting geophysical surveys.

GENERAL NAVIGATION REQUIREMENTS

The claim for sophistication stems in part from the general navigation requirements that were imposed on the system by the customer. The system was to operate world-wide in water depths to 6000 feet with or without land-based radio navigation aids. In addition, the system was to use data from all or parts of a large set of navigation sensors and, at the same time, provide optimal processing of the available sensor data. The set of navigation sensors with which the system was to work is listed below:

- o Sperry deep-water Parametric Array Doppler Sonar (PADS)
- o An intermediate depth (1000 ft.) Doppler sonar
- o Two Sperry water speed logs
- o Two Sperry high-accuracy MK 29 gyrocompasses
- o A satellite navigation receiver
- o Two Loran-C receivers with a Rubidium frequency standard
- o Any four of the following eight radio navigation aids

- ARGO
- Decca Hi-Fix
- Decca Navigation
- Maxiran
- Miniranger
- Raydist
- Shoran
- Syledis

OTHER REQUIREMENTS

Besides the above navigation requirements there are many other requirements that the system meets. One of the requirements that reinforces the claim of sophistication is the requirement for automatic steering of the ship along the survey line. Depending on weather conditions, the automatic steering function can maintain the ship to within one meter of the survey line for extended periods of time.

Another control requirement, in this case customary with such systems, is the control of the seismic shot events. "Shots" are the compressed air explosions whose sonic reflections from beneath the sea bed constitute the primary data collected in seismic surveys.

Because Operator errors can lead to re-shooting survey lines (at about $10,000 per line), the Operator controls and displays had to be user-friendly. The controls have to allow for such things as:

- o Selection of the navigation sensor data to be used in the navigation solution
- o Entry of navigation parameters e.g. geographical coordinates of radio-navigation aid transmitters
- o Entry of navigation system calibration parameters and/or control of navigation system calibration processes
- o Entry of the geographical coordinates of the end points of lines to be surveyed
- o Control of the distance or time spacing between shot events
- o Control of the magnetic tape data logging system

The displays had to provide for complete, user-friendly visibility of the state of the system. The displays had to include the following:

- o A specialized large-character display of the survey status (including ship position relative to the line) for personnel on the ship's bridge.
- o A graphic display of the trajectory of the ship and its position and orientation relative to the survey line.
- o Displays of all aspects of the navigation situation which includes the identification of sensor data used, the analysis of the performance of each sensor and the comparison of sensor data with each other.
- o Elevation and plan view graphic displays of the depth and shape of the seismic streamer (a 3 Km long array of hydrophones with depth and heading sensors).

The system had to include a subsystem of two magnetic tape transports and associated electronics to provide for recording of shot event navigation data. In addition, records had to be kept of the status of the system so that on shore post-processing of the data could isolate anomalies not detected onboard. As an aid to this post processing, the Operator had to be able to record comments on the magnetic tape and on a printed record of the survey. The capability of providing an overview printed record of events during the survey was also a system requirement.

The system was also to have the electrical and communication interfaces with equipments provided by the customer. These equipments included the following:

- o A Sperry Gyro-pilot
- o Two Sperry Collision Avoidance Systems
- o A gravity/magnetic data acquisition system
- o A streamer data acquisition system (for streamer heading and depth)
- o A fathometer
- o The seismic data acquisition system

SPERRY SOLUTION

The centerpiece of Sperry's solution for meeting the above requirements was the use of a powerful, disc-based 32-bit minicomputer with 1 Megabyte of memory. The capacity of this mini-computer gave systems analysts and programmers complete freedom to implement whatever algorithms, logic and data manipulation that were required to meet the formidable requirements described above.

The control and display requirements were met by using four "smart" alpha-numeric/graphic CRT terminals. One was mounted on the bridge and the other three were in the ship's Recording Room for use by the system Operators. These terminals had RS-232C interfaces with the mini-computer. It can be seen in Figure 1 that many of the equipments chosen had RS-232C interfaces. The choice of an established standard interface, where possible, obviated the need for many special interface electronics. For the most part, when non-RS-232C interfaces were required for customer-supplied equipment the interface electronics were chosen from a standard line of interface modules available through the minicomputer manufacturer.

The optimal integration of navigation data was provided by two well established statistical techniques. One is the method of Maximum Likelihood estimation. This technique generates a "best" position (or velocity) from a set of position (or velocity) sensors provided that an estimate of their accuracy is available. In this application the technique reduces to weighted-least-squares estimation.

The other statistical technique used was the Kalman filter. The Kalman filter is specifically designed to estimate the states of a system from observations (measurements) of linear combinations of the system states. The Kalman filter is therefore ideally suited for calibrating systems whose underlying error processes are well understood. Such is the case in common navigation systems such as dead reckoners. The Kalman filter was used in the system for the following purposes:

- Calibration of the two Doppler-gyrocompass dead reckoning subsystems
- Integration of heading data from two gyrocompasses
- Calibration of Loran-C transmitter chains

The functional relationships among the various computer program modules is shown in Figure 2.

The concept of the user-friendly interface with the Operator was implemented by providing the Operator with "form fill-out" CRT display pages and by providing the Operator with the ability to call any three of a large number (28) well designed display pages. On all the form fill-out pages, the page has an example of the kind and format of the data required for entry by the Operator. This approach makes it easy to train the Operators to enter data and to make the entries free of errors.

The top of each alpha-numeric page is reserved for computer generated alert messages designed to apprise the Operator when an anomalous condition exists. If several such conditions exist in queue, the number of them is displayed and the Operator can scroll the display to exhibit them one at a time. The system has more than 100 canned alert messages.

As an aid to onshore post-processing, the minicomputer maintains a reserve bock of 10,000 words of memory (called Datapool) to store all the important system variables and the status of all keys. This block of words is logged on the magnetic tape once each minute. The magnetic tape thereby contains an exact and complete description of the state of the system. This Datapool is the final resort for the analysis of any problems that might escape the numerous other defenses built into the system.

Finally, the system was provided with an uninterruptible power supply to perserve essential functions from disturbances in the ship electrical power system. A further protection against disturbances is special re-start software that allows operations to resume operations without the re-entry of navigation and other parameters.

RESULTS

The complex and sophisticated system described above is now fully operational and is on station performing its intended function. The Sperry deep-water Doppler has demonstrated reliable operation in water depths exceeding 5000 ft. The Kalman filter calibrated dead reckoning subsystem yields excellent results(0.13% of distance travelled). The Kalman filter calibration of Loran-C chains has allowed their use as a primary reference for surveys. The system has met with enthusiastic Operator acceptance because of its reliability, its ease of operation, its automatic steering and the full visibility of system status that it provides. The multinational oil corporation that originally ordered the system is especially pleased with the reliability and accuracy of navigation data produced.

PRESENT AND FUTURE PLANS

The system described above is the core of a new family of sophisticated integrated navigation systems. A variant of this system has been proposed to the U. S. Navy as a navigation and ship control system for their new class of minesweeper/hunters. Other variants are being considered. One variant will add color CRT terminals to display so-called "binning" data which show the thoroughness of seismic survey coverage required for 3-D surveys.

Other features to be added to the core system include the following:

- Automatic ship control to steer the apparent source of seismic echoes
- More radio navigation aid options
- New technology alphanumeric/graphic CRT terminals
- Integration of Global Position System hardware and data

Sperry is committed to the Integrated Navigation System business and Sperry expects to continue to be a prime supplier of such items.

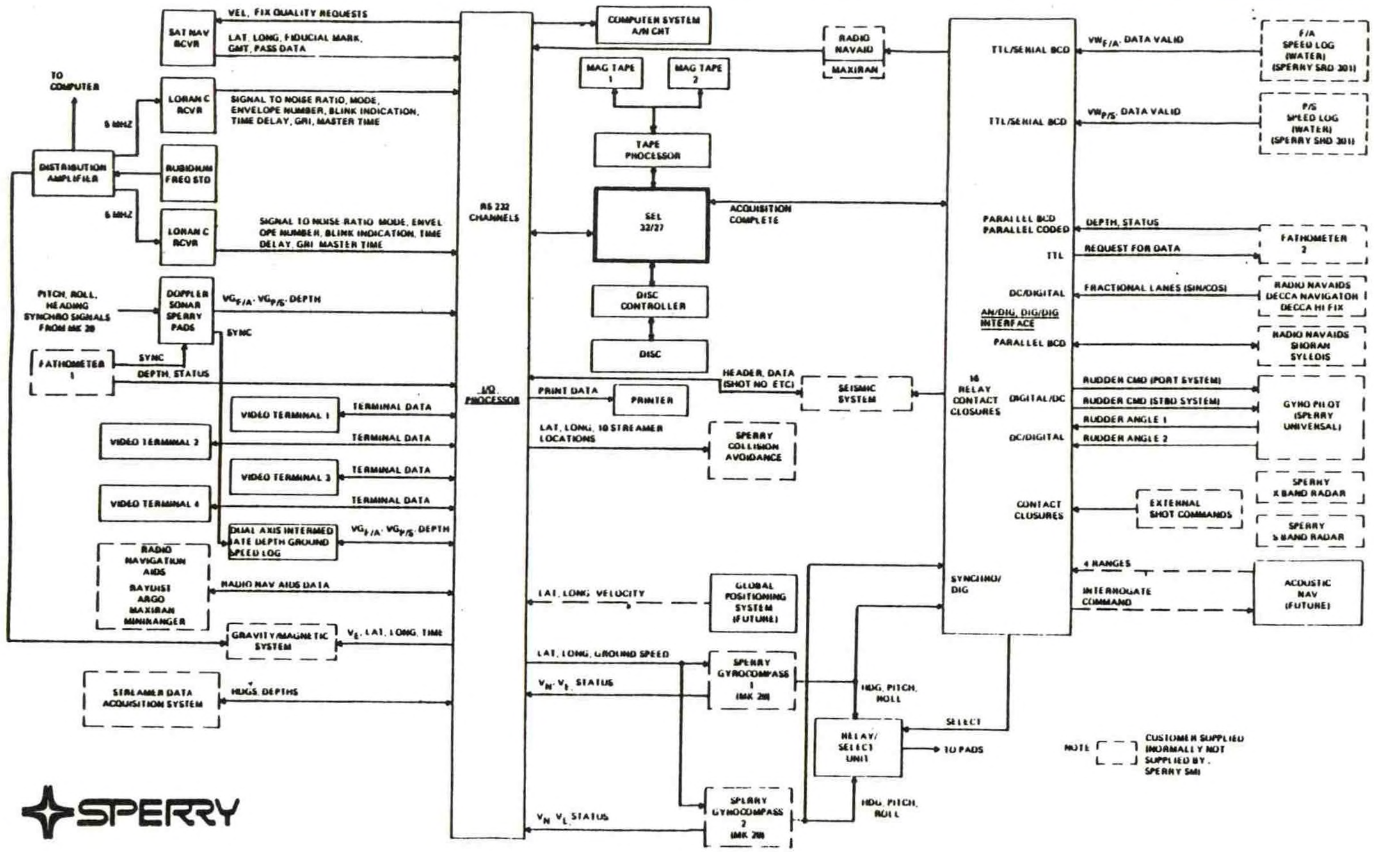

Figure 1   Integrated Navigation System Hardware/Interface Block Diagram

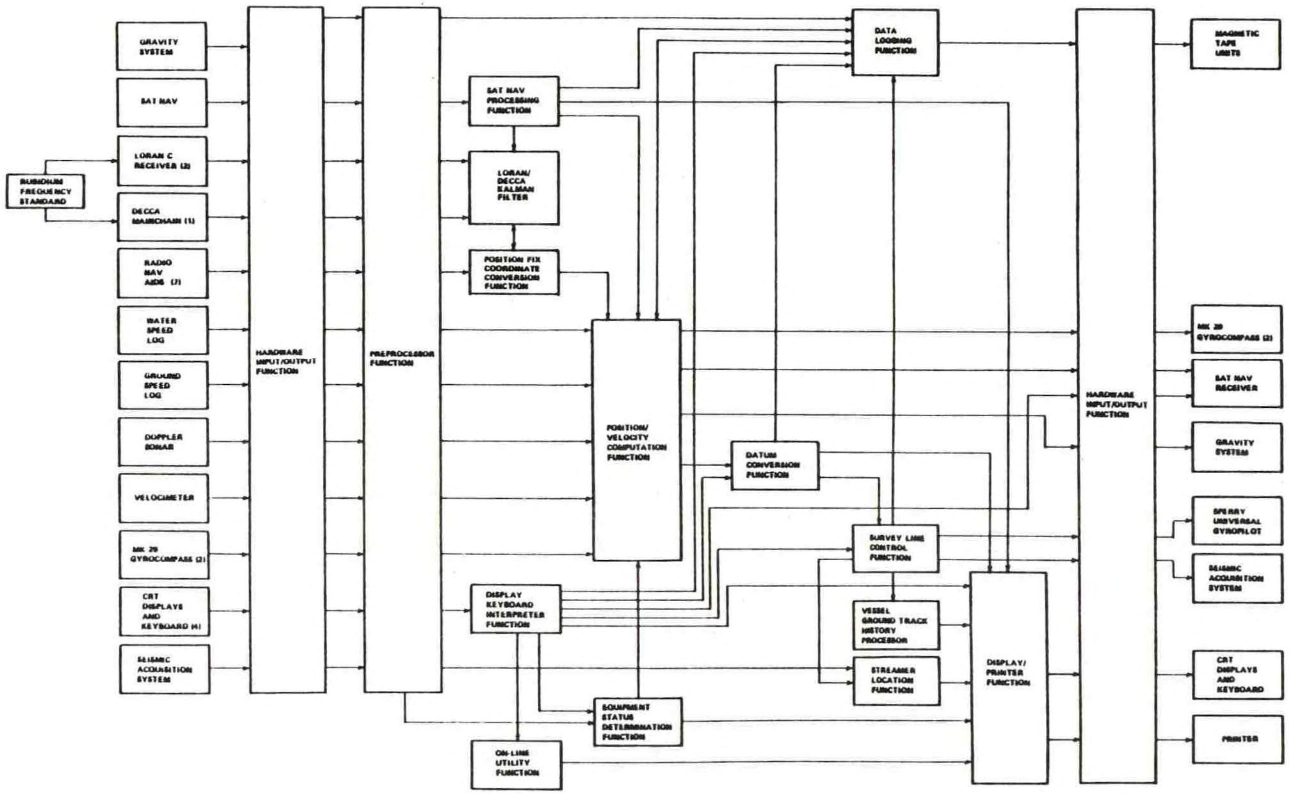

Figure 2 System Functional Block Diagram

NEW NAVIGATION SYSTEM

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ABSTRACT

Work of the captain on board in ship's operation is divided into a recognition, a judgement and an operation.

Development of micro-electronics and automatic control techniques has made it systemized (softwarized) the recognition and the operation of the captain's work. From now on, systemization (softwarization) of the judgement will become an object of automation, and in the future, almost all the captain's work will be automated.

However widely the software of a system may be sophisticated, it can not become a real assist system if the hardware of the system is not easy to operate.

Upon this, an ideal way of the future total navigation system is reviewed, and the navigation console which makes one man watch/control possible is presented.

INTRODUCTION

Since the magnetic compass was first applied around 1200 as the navigational instrument, various kinds of navigational instruments have been invented and improved until today.

In the beginning, the navigational instruments were developed as a tool for safe navigation. But, appearence of the system with automatic control function like an auto pilot made it possible to save the man-power, and furthermore, progress of the hyperbolic navigation or satellite navigation system contributed for economical navigation as well as safe navigation. And now, systems aiming at the shortest route, the shortest time, and minimum fuel oil consumption have been developed, utilizing micro-computers. And finally in the future, the navigation system will go forward toward the total navigation system under synthetical consideration of economical efficiency, safety and punctuality.

As above mentioned, the softwares of the navigation system have been remarkably developed according to a progress of the micro-computers. On the other hand, however, the hardwares of the system are independently composed for every system, and the bridge of the ship is now very crowded with many electronic navigation systems.

If the ship is fully equipped with sophisticated navigation systems, she ought to be operated by one operator at one position in the bridge in the future, as a cockpit on an airplane. In order to realize this, it is indispensable to make the hardware of the systems simple and compact.

Taking these circumstances into account, a new navigation console for the future will be discussed.

DEVELOPMENT OF NAVIGATION SYSTEM

In general, the captain operates a ship doing the following procedures as illustrated below;

First - to recognize informations necessary for the ship's operation, consulting signals from sensors,
Second - to judge, adding his navigation know-how on the informations, and
Third - to operate the ship, utilizing actuators.

$$\begin{array}{ccccc} \boxed{\text{Recognition}} & \dashrightarrow & \boxed{\text{Judgement}} & \dashrightarrow & \boxed{\text{Operation}} \\ \uparrow & & & & \downarrow \\ \text{Sensor} & & & & \text{Actuator} \end{array}$$

The following sensors are nowadays used for this purpose;

- ° Bearing - Gyro compass and Magnetic compass
- ° Depth - Echo sounder
- ° Ship's speed - Electro-magnetic log or Doppler log/sonar
- ° Ship's position - Loran, Decca, Omega and NNSS
- ° Target - Radar
- ° Direction - Direction finder
- ° Others - Anemometer, Barometer, Thermometer, Current meter, etc.

and, as actuators;

- ° Propulsion control system
- ° Steering control system

Techniques of micro-electronics and automatic control have so far automated the recognition and the operation of the captain's work.

For example, as the recognition system;

- ° Position fixing by dead reckoning basing gyro compass and log
- ° LAT/LON position signal translated from LOP signal on hyperbolic navigation system
- ° Recognition of targets by computer processing of radar video signal (ARPA)

and, as the operation system;

- ° Auto pilot
- ° Automatic course keeping/route tracking system

The aboves are the so-called systemization (softwarization) of the navigation, and this systemization will more and more expanded in the future according to development of micro-electronics technique. Coming subjects are how to systemize the judgement of the captain's work.

LATEST ADVANCED NAVIGATION SYSTEM

Navigation systems which have already been developed for practical use as a substitute or a support system for the captain's judgement are introduced below.

(1) Hybrid navigation system

Sensors for positioning have their own merit and demerit in accuracy, continuity and availability. This is such a system as to mix merits of each sensor (NNSS, Omega, Loran, Decca and Dead reckoning), to increase accuracy and redundancy. But this system will be replaced with the GPS when it becomes to practical use.

(2) Navigational planning

This is such a system as to plan a navigation route (course and speed) of the minimum fuel oil consumption and the shortest time, basing upon the ship's operation schedule, the weather and sea condition, the dangerous zone, the navigation mode, etc.

(3) Adaptive pilot

This is such a system as to automatically adjust the weather control, the counter rudder setting, etc. for the auto pilot which the captain manually set on the conventional system, considering the weather/sea condition, the ship's condition, etc.

(4) ARPA

This is sush a system as to automatically track the other ships' targets in the radar raw video signal, to display their course and speed in vector, to judge the dangerous ship(s) for alarm, and to plot past positions.

(5) Digitized chart

This is such a system as to digitize the chart informations into a magnetic tape, so that the chart can be displayed on the CRT together with the radar raw video, and the grounding dangerous or the course deviation can be warned.

TOTAL NAVIGATION SYSTEM

Advanced navigation systems introduced last chapter are all independent system and their hardwares are also independent. For one man watch/control in the future, these independent systems are not always useful, even if they have excellent respective function.

For the future system, it is indispensable to totalize all the functions into one system. Here, what the total navigation system in the future should be is considered.

(1) System software

The system is to have the following functions at least;

° Optimum route planning

Navigation calculation for the great circle, the rhumb line and the composite great circle route has been completely established so far, and the coming subject will be an establishment of know-how to define the optimization, such as planning of a real optimum route both for the minimum FOC and the shortest time, considering effective utilization or avoidance of the current and the wind, the sea worthiness, etc.

° Ship's position fixing

There seems to be few practical problem for the merchant ships on the positioning by the existing hybrid system. Much less if the GPS is of service. No further development for the ship's positioning will be necessary after the GPS.

° Sea/weather condition grasping

At present, the weather routing service, basing on remote sensing by the satellite and the statistical data, is offered. Insufficiency of the local data makes it difficult to increase the accuracy of the service. It is much necessary to get the local accurate data to set the most optimum sailing route. Such local data will be automatically obtainable by a wave sensor for which further development is required.

° Automatic navigation

Such a system as to keep the set course or to track the planned route, has already been established, as far as automatic steering is concerned. However, the problem is a selection of the most optimum ship's speed. There is not so much ripe system at the present to automatically select the ship's speed together with a selection of the route, considering the voyage schedule, the sea/weather condition, the current, the seaworthiness, the propulsion system condition, etc., in order to realize the real minimum FOC and shortest time. The technique how to select the optimum speed should be further sophisticated.

° Danger avoidance

Danger avoidance includes the collision avoidance, the grounding avoidance and the wind and waves avoidance, and is important for the ship's safety, about which the captain most worries during the voyage.

Collision avoidance :- ARPA was recently obligated to be equipped for safe navigation, but it only has a warning function against a collision dangerous. The coming subject is to develop a software to automatically control the course and the speed of the ship and to develop a high-performance radar which can discriminate even small boat in order to avoid collisions perfectly.

Grounding avoidance: An active sonar was once developed for this purpose, but there is a problem in straight propagation of the supersonic wave in the water just below the sea surface. There seems to be a limit on the active sonar for the detecting of the shoal. Effective means of the grounding avoidance will be collation to the chart. It is desired to put the digitized chart to practical use.

Wind and waves avoidance:- Such a system as to calculate the deliverate speed loss or the course to change in the rough sea will be greatly helpful for protection of the hull. Development of any sensors to detect fources against the hull and the propulsion system is wanted.

(2) Navigation console

Fig (1) shows one of the future navigation console images on which all the navigation systems are totalized. The navigation console is equipped with four displays, a steering wheel, a main engine control handle, communication devices, etc., and each display has the following functions;

° Main navigation display (A)

This is a large sized color graphic display unit on which various major informations along the sailing route, such as the radar raw video, the electronic chart, the planned route, the track chart, the ARPA data, the weather chart, the wind and waves chart, etc., are displayed simultaneously and independently in the distinguishable color vision.

On the display surface, a transparent touch sensing panel is put so that one can access to the data on the display by a finger touch.

And this has also such functions as to automatically keep the set course and avoid the danger by connecting to the steering control system, and give the proper revolution to the propulsion control system.

° Sub navigation display (B)

This is a color graphic display unit on which the navigational planning is proceeded through the man-to-machine interface, and the ship's position, course, propeller revolution, rudder angle and speed, the distance and time to next way point, the wind velocity and direction, the depth, the time, etc. are displayed at the ordinally time. And the trends of the ship's course, the depth, etc. can also be shown by a mode change.

And, the display is covered with a transparent touch sensing panel so that switching operation for the navigation/signal lights, etc. can be done by a finger touch on the switch panel mode on the display.

° Propulsion monitoring display (C)

This is a color graphic display unit on which the propulsion system condition is always monitored. And if any trouble happens in the propulsion plant, suitable instructions from the diagnosis system are given on the display, and one can remotely operate each control system according to the instructions by a finger touch on the display.

° CCTV display (D)

Surrounding conditions (ship's fore, after and both sides) are always monitored on this display through CCTV cameras which can be remotely controlled from the console.

AFTERWORD

An idea of the total navigation system has become remarkable by appearence of the micro-computer, and now is at its starting point historically. And from now on, the total navigation system will be extended toward a splendid system with the development of the micro-electronic technique.

The navigation console which makes one man watch/control possible, presented on this paper, is believed to be effective for realization of the real total navigation system.

REFERENCE

1) Japan Marine Standards Association, 1981 Report on "Investigation for Standardization of Bridge System"

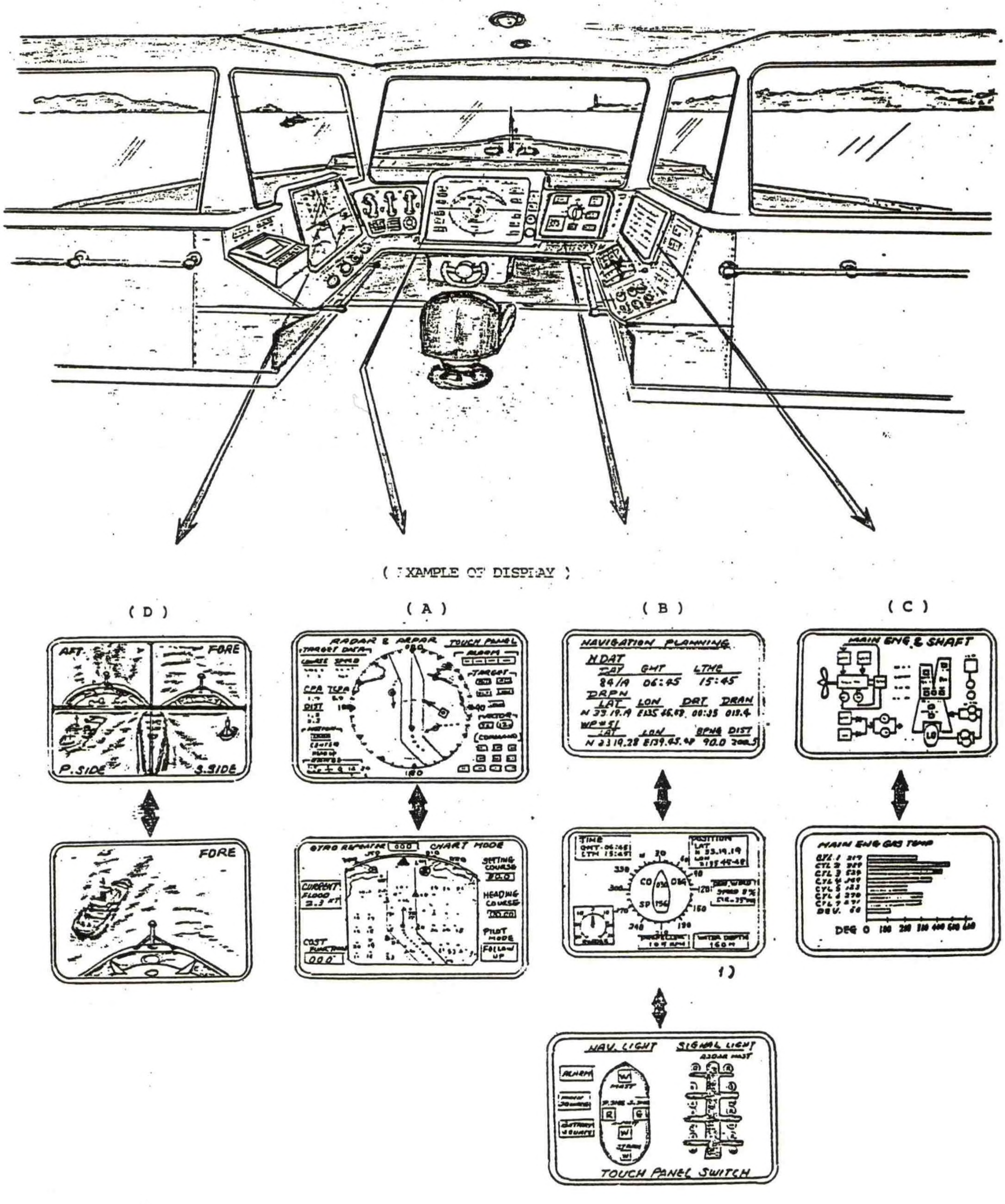

Fig (1)   Navigation Console

MARINER SURFACE SHIP SYSTEM IDENTIFICATION *

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ABSTRACT

The techniques of System Identification (SI) applied in conjunction with a Radio Controlled Model (RCM) of a surface ship to identify the full non-linear horizontal plane maneuvering equation of motion are presented. The identification results are found to be in excellent agreement with full-scale test data. When compared to captive model test data, the results only agree with planar motion mechanism based data for maneuvers associated with small rudder angles and rotating arm facility data for maneuvers associated with large rudder angles.

INTRODUCTION

System Identification (SI) is a technique for mathematically characterizing a system based on knowledge of the responses of that system to some known input. In this ship maneuvering application, the ship, (or its model) is subject to precisely determined control deflections and the response is measured precisely enough to permit working backwards to deduce the value of the coefficients in the maneuvering equations (parameter identification) or to determine the form of the maneuvering equations as well (system identification). Due to the large number of unknowns (both the form of equations and associated parameters), the technique is dependent on great experimental precision and efficient computer based estimation methods. The computer based estimation methods were Kalman filtering, regression and maximum likelihood. The David Taylor Naval Ship R&D Center (DTNSRDC) has developed a methodology for applying System Identification techniques employing a RCM for the identification of the maneuvering equations for marine vehicles. It has been the experience at DTNSRDC that the SI technique, described in this paper, is the only way that a math model suitable for the stringent requirements of ship control can be developed. In order to demonstrate the techniques developed, a program to apply these techniques for the "identification" of a surface ship was proposed and funded under the DTNSRDC Independent Research (IR). The MARINER was chosen as the candidate surface ship because: (a) extensive captive model test data are available, (b) A model was readily available; and (c) some full-scale trial data are available.

A more thorough treatise of the subject matter covered in this paper is given in reference 1.

DESCRIPTION OF MODEL AND TEST FACILITY

The MARINER, model 4414, is the same model used by Gertler[2] for captive model tests.

The RCM was fitted with propeller 4630. The pertinent characteristics for this propeller are given in reference 1.

The tests were conducted in the 360-foot (109.7 meters) long, 240 foot (73.2 meters) wide, maneuvering basin of the Harold E. Saunders Maneuvering and Seakeeping (MASK) Facility shown.

The RCM utilizes commercial frequency modulated (FM) and pulse code modulated (PCM) telemetry equipment to telemeter the commands to the model and the data from the model, respectively.

PROCEDURES EMPLOYED

The procedure employed at the Center for identifying marine vehicles is as follows:

1. The rudder is deflected to a predetermined fixed rudder angle in order to attain a desired steady angle of sideslip and turning rate. A small amplitude sequence is then superimposed on this constant rudder deflection which imparts small perturbations about this steady equilibrium.

2. For the same steady equilibrium condition, the procedure is repeated for several different input sequences, and each input sequence is repeated at least one time.

3. These perturbation runs are then used to identify parameters for a local linear model.

4. The above steps are repeated over a predetermined range of steady equilibrium conditions resulting in a set of local parameters for each condition.

5. The variations in the local parameters as a function of the equilibrium states defined at each of the steady conditions are then used

* Presented by Dr. Alan Powell

to identify the structure for the full non-linear set of maneuvering equations that apply to the range of steady conditions tested.

6. Once the full non-linear equations are known, the parameters for these equations can be easily determined from a regression analysis in which the dependent variables are the local parameters identified at the equilibrium conditions and the independent variables are the unbiased steady states.

INPUT DESIGN

Input design is the process wherein the inputs (rudder angle and propeller RPM) are selected in such a manner as to enhance the identifiability of the system. Properly designed inputs not only yield accurate parameter estimates, but require less test data.

The candidate inputs are a set of Walsh functions which resemble square waves whose highest frequency is beyond the ship response range. An optimal subset is chosen that combines several Walsh functions.

TESTS PERFORMED

Two sets of experiments were performed. The first set consisted of a series of steady turn maneuvers corresponding to full-scale speeds of 10, 15 and 20 knots. Nominal rudder angles of ±15, ±25, and ±35 degrees were employed. Constant propeller RPM was maintained during the maneuver. The run duration was approximately one full-scale minute after steady conditions were obtained. The second set of experiments were performed for the purposes of system identification, and consisted of two types of maneuvers; diagonal runs and spiral runs. The spiral runs consisted of steady turns that were performed on an inward spiraling path.

GLOBAL MODEL

The manner in which the local linear parameters varied as a function of each of the steady state conditions suggested global equations for the lateral force and yawing moment as shown in Table 1. The values of the global parameters were estimated such that:

a. The values of the partial derivatives of the global equations evaluated at the equilibrium states agreed with the local parameters estimates at the equilibrium states.

b. The solutions of the global equation passed through the mean value of the equilibrium states for all the identification runs.

Several forms of the global structure were investigated before the final structure was determined. For example, several forms for explaining the variation of $Y_{\delta r}$ and $N_{\delta r}$ at different equilibrium states were investigated, and the term that best explained this variation was $\delta_r(1 + \tan^2\beta_t)$. Furthermore*, it was found that this form of the equation best fitted rotating arm data taken from reference 1. Similar procedures were used to determine the other non-linear terms.

TABLE 1

TABLE 1 - LATERAL FORCE AND YAWING MOMENT MANEUVERING EQUATIONS AND COEFFICIENTS OBTAINED FROM SYSTEM IDENTIFICATION

$$m(\dot{v} + ur) = \frac{\rho}{2}\ell^2\left[Y_* u^2 + Y_v uv + Y_{v/v/} v/v/ + Y_{\delta r} u^2(1 + \tan^2\beta_t)\delta r\right] + \frac{\rho}{2}\ell^3\left[Y_r ur + Y_{\dot{v}}\dot{v}\right] + \frac{\rho}{2}\ell^4\left[Y_{\dot{r}}\dot{r} + Y_{r/r/} r/r/\right]$$

$$I_z\dot{r} = \frac{\rho}{2}\ell^3\left[N_* u^2 + N_v uv + N_{v/v/} v/v/ + N_{\delta r} u^2(1 + \tan^2\beta_t)\delta r\right] + \frac{\rho}{2}\ell^4\left[N_r ur + N_{\dot{v}}\dot{v}\right] + \frac{\rho}{2}\ell^5 N_{\dot{r}}\dot{r} + \frac{\rho}{2}\ell^6 N_{rrr} r^3/u$$

where $\tan\beta_t = \frac{v + x_t r}{u}$

LATERAL FORCE PARAMETERS		YAWING MOMENT PARAMETERS	
Y_*	$= .503 \times 10^{-4}$	N_*	$= .271 \times 10^{-4}$
Y_v	$= -.145 \times 10^{-1}$	N_v	$= -.42 \times 10^{-2}$
Y_r	$= .255 \times 10^{-2}$	N_r	$= -.2 \times 10^{-2}$
$Y_{\delta r}$	$= .287 \times 10^{-2}$	$N_{\delta r}$	$= -.138 \times 10^{-2}$
$Y_{v/v/}$	$= -.225 \times 10^{-1}$	$N_{v/v/}$	$= .105 \times 10^{-1}$
$Y_{r/r/}$	$= .208 \times 10^{-2}$	N_{rrr}	$= -.311 \times 10^{-2}$
$Y_{\dot{v}}$	$= -.748 \times 10^{-2}$	$N_{\dot{v}}$	$= .4355 \times 10^{-4}$
$Y_{\dot{r}}$	$= -.975 \times 10^{-4}$	$N_{\dot{r}}$	$= -.401 \times 10^{-3}$
x_t	$= -.48$	I_z	$= .428 \times 10^{-3}$
m'	$= .7976 \times 10^{-2}$	ℓ	$= 528.01$

In order to satisfy these criteria, it was necessary to adjust the zero equilibrium condition values for Y_v and N_r by 6% and 10% respectively. Since these zero rudder parameters were based on much shorter run lengths (80 to 100 seconds), they were in all likelihood biased. Table 1 lists the values of the global parameter

*After this paper was prepared, it was realized that there exists a high correlation between $(1 + \tan^2\beta_t)$ and the propeller propulsion ratio. Thus, it is possible that the $(1 + \tan^2\beta_t)$ term could be due to the propeller slip stream on the rudder. This needs to be investigated further.

FULL SCALE VALIDATION

Two types of validations were performed, local and global. An example of the local validation is shown in figure 1 which compares the system identification results with a full scale zig zag maneuver reported in reference 2. An example of the global validation is shown in figure 2. This figure which shows the variation in drift angle with non-dimensional turning rate, and defines the operating range of the ship. It also shows that the identified model and the radio controlled model agrees extremely well with full scale.

COMPARISON WITH CAPTIVE MODEL DATA

Since it has been demonstrated above that the SID model estimates of steady drift and non-dimensional turning rate are practically identical to both the RCM and full-scale values for these variables, these estimates can be used as a basis to assess the estimates of maneuvering equations determined from captive model techniques. Figure 3 presents steady values of non-dimensional turning rate as a function of rudder angle for equations based on 3 different types of tests: RAF-designates rotating arm tests, SL-represents large angle PMM tests, and HY-A represents plane motion tests. This plot shows the following trends:

1. For small rudder angles the SI predictions are in closest agreement with the predictions based on the PMM techniques.

2. For large rudder angles the SID predictions are in closest agreement with the predictions based on RAF techniques.

The significance of these differences between SID and captive model based predictions can be assessed by comparing stability predictions for small rudder angles and turning diameter predictions for large rudder angles.

Stability estimates for small rudder angles indicate similar stabilities for the SID, HY-A and SL models. The RAF stability estimates indicate that the ships is two times more stable.

The turning diameter, in ships length, is defined by

$$T_d = 2/r'$$

For a 40 degree right rudder, the turning diameters predicted by the four sets of maneuvering equations range from 3.1 to 5 ship lengths. The RAF prediction differs by only 0.2 ship lengths from the SID value of 3.5 ship lengths.

CONCLUSIONS

Based upon the results reported herein, it is concluded that:

1. The system identification procedures developed and originated DTNSRDC have been successfully demonstrated for MARINER. Furthermore, it has been shown that a complete non-linear maneuvering mathematical model can be developed without any apriori information concerning the equations of motion with the exception of knowledge of the mass, mass moment of inertia, added mass and added mass moment of inertia.

2. The RCM and the identified maneuvering equations both predict full-scale behavior during turns. No significant effects between ship models and full-scale were observed.

3. Rudder effectiveness increases in a turn. This effect is due to either the local drift angle or the effect of the propeller slip stream or both.

4. The identified maneuvering equations are in close agreement with PMM based maneuvering equations around the equilibrium condition defined by small rudder angles and in close agreement with the Rotating Arm based maneuvering equations around equilibrium conditions defined by large rudder angles. Neither the PMM nor RAF techniques by themselves are adequate for predicting turning characteristics for the whole operating range of MARINER.

5. For those surface ships configured with twin screws and/or thrusters, consideration should be given to the use of multiple inputs. This would decouple the states v and r and greatly simplify the identification process.

6. Inputs for the surge equation and roll equation require tests.

7. Tests to further define the effect of propeller ship stream on rudder effectiveness should be included in future SI testing.

8. Finally, additional system identification tests, both RCM and full-scale, should be performed in order to generalize these conclusions to other surface ships.

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(1) Thomas Moran, et al, "Mariner Surface Ship Identification" presented at the Seventh Ship Control Systems Symposium, 24-27-September 1984, Bath England.

(2) Gertler, Morton, "Cooperative Rotating Arm and Straight Line Experiments with ITTC Standard Model", DTNSRDC Report 2721, June 1966.

(3) Morse, R.V., and Price, D., "Maneuvering Characteristics of the MARINER Type Ship (USS COMPASS ISLAND) in Calm Seas", Sperry Gyroscope Publication G7-2233-1019 prepared for the David Taylor Model Basin under Contract No nr 3061 (00).

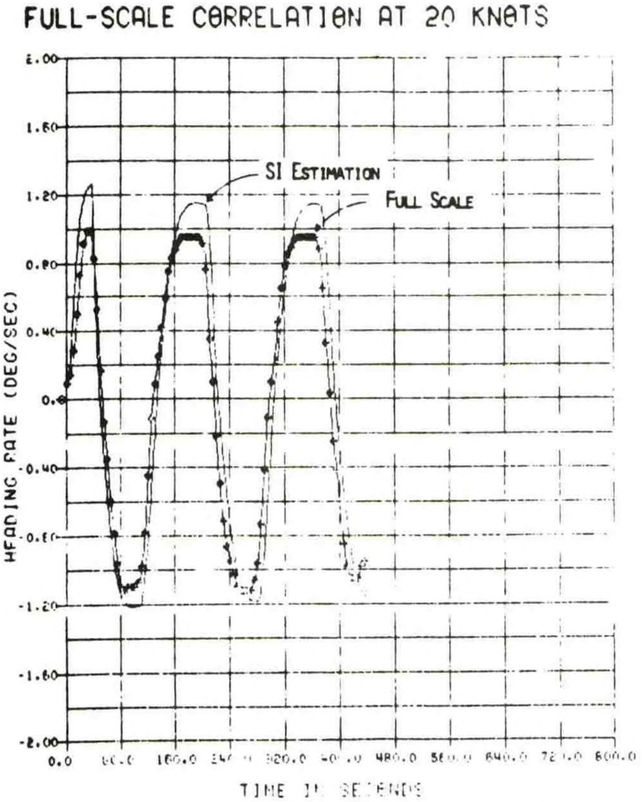

Figure 1a - Full-Scale Measured and SI Estimation of Heading Rate for a Typical Validation Run

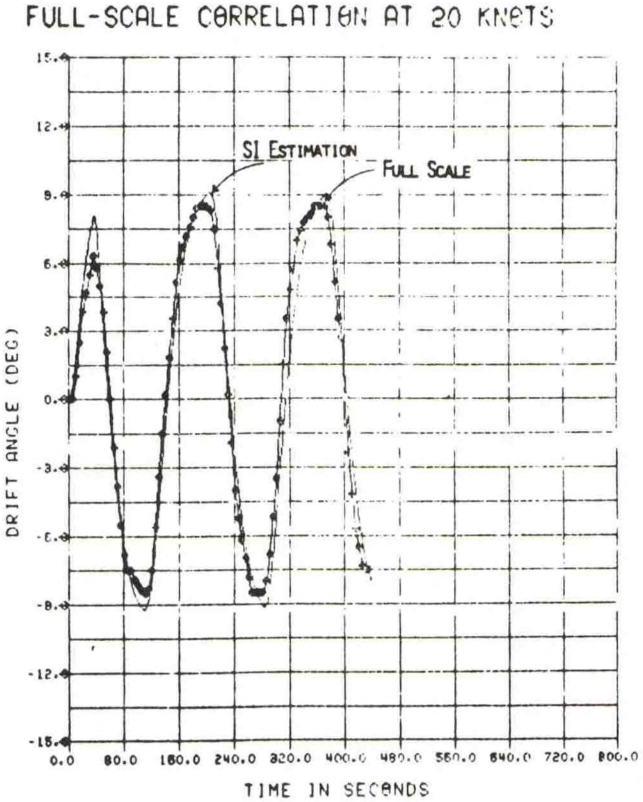

Figure 1b - Full-Scale Measured and SI Estimation of Drift Angle for a Typical Validation Run

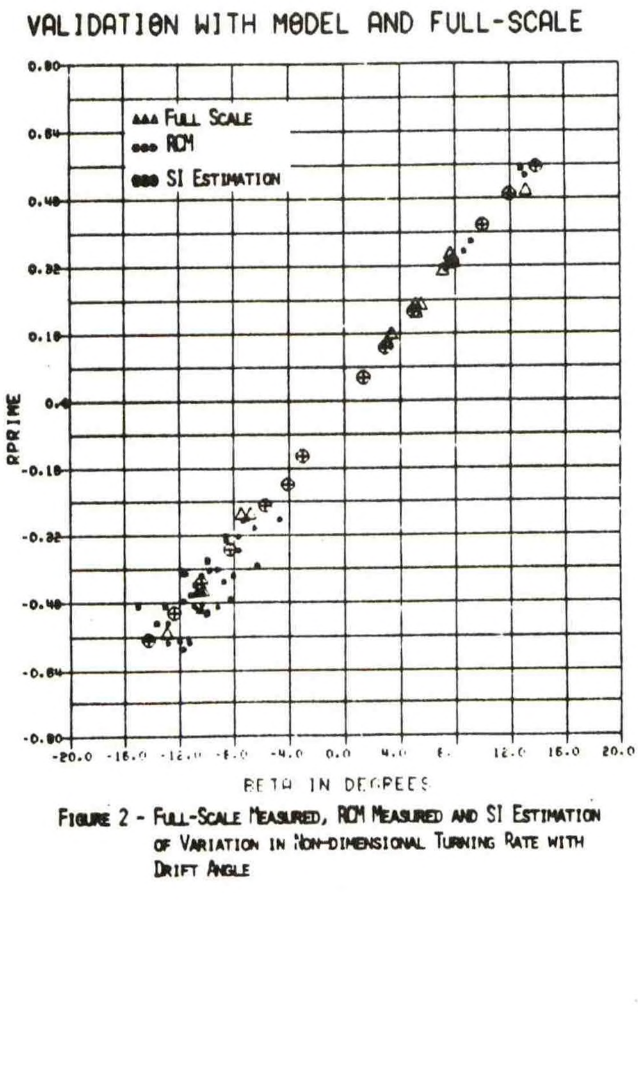

FIGURE 2 - FULL-SCALE MEASURED, RCM MEASURED AND SI ESTIMATION OF VARIATION IN NON-DIMENSIONAL TURNING RATE WITH DRIFT ANGLE

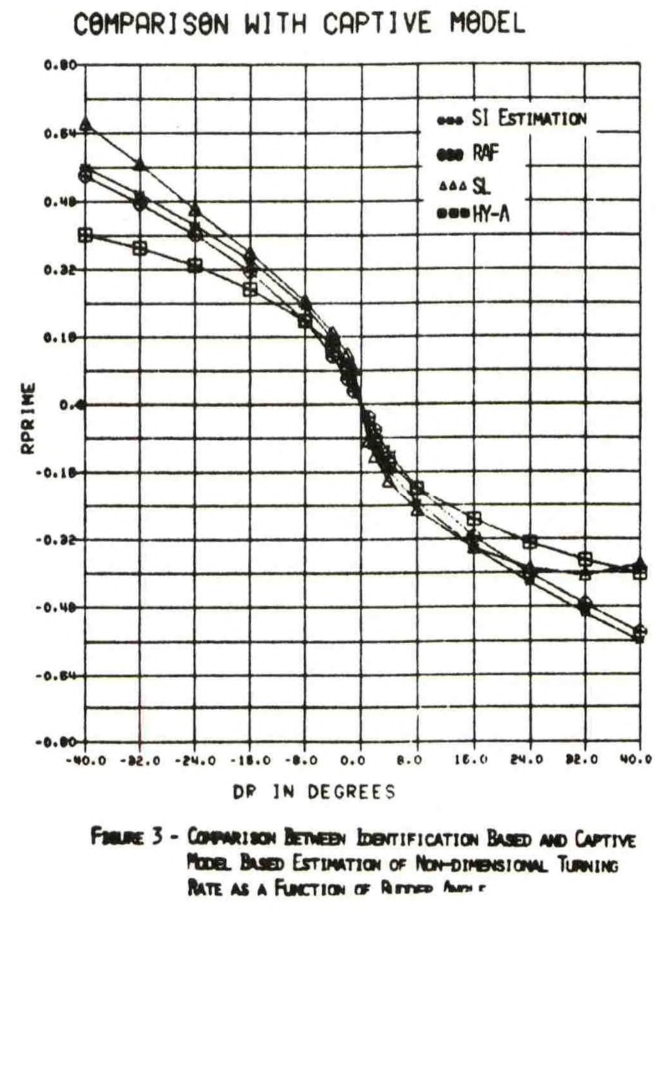

FIGURE 3 - COMPARISON BETWEEN IDENTIFICATION BASED AND CAPTIVE MODEL BASED ESTIMATION OF NON-DIMENSIONAL TURNING RATE AS A FUNCTION OF RUDDER ANGLE

Research and Development of Advanced Marine Vehicles in the United States Coast Guard

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ABSTRACT

During the next decades and into the coming century the cost of buying and maintaining new vessels for the U. S. Coast Guard will be in the billions of dollars. The Coast Guard needs to maximize every design detail and make better use of current technologies in preparing specifications for new vessels in order to get the most out of them in operational mission performance. This paper describes what the Coast Guard Research and Development Staff is doing to reach that goal.

INTRODUCTION

Our Research and Development role in applying the economics and technologies of advanced marine vehicles (AMV) in the U. S. Coast Guard is directed towards three objectives. They are to support:

(1) the acquisition process for various cutter replacements

(2) ad hoc procurements of advanced craft for operational use by the Coast Guard, and

(3) operational program manager decisions concerning fleet composition and operation considerations which will maximize the effectiveness of our fleet.

BACKGROUND

In March 1982 the "COAST GUARD ROLES AND MISSION" report recommended that (1) the Coast Guard should continue to pursue R&D projects such as evaluating advanced marine vehicles and advanced technologies which enhance the effectiveness of ship resources, and (2) the Coast Guard should continue to examine the possibility of augmentation of its current fleet with more specialized and less costly platforms in certain geographic regions where specific operational characteristics permit.

This latest and most comprehensive effort that we are describing was instituted to continually evaluate the utility of evolving advanced marine vehicle (AMV) technologies within the context of USCG operational missions.

The advanced state of AMV technology at present is one of the most important strengths of this project. The general categories of advanced marine vehicles with proven demonstrator craft in the size range of primary interest to the Coast Guard (100-3000 tons) are the following: fully submerged hydrofoils, surface piercing Surface Effect Ship (SES), planing craft, and Small Waterplane Area Twin Hull (SWATH) craft. In all cases, these craft surpass the Coast Guard mission effectiveness of conventional cutters of the same general size due to (1) a superior speed capability (in calm water and/or in a seaway) and/or (2) a superior seakeeping capability. However, these benefits may be at the expense of other fundamental mission tasks such as towing, boarding, range, and payload. Each improvement normally has a commensurate impact on life cycle cost.

TECHNICAL APPROACH

The project is divided into three major project elements: Acquisition/Technical Support, Test and Evaluation, and Craft Hydrodynamic Characteristics.

The first project element, Acquisition/Technical Support, provides for the primary project results, i.e., planned replacement acquisition support. The operations analysis (OA) and operations

*This paper is the sole responsibility of the authors. It does not necessarily reflect official U. S. Coast Guard policy.

research (OR) portions serve this purpose directly by providing the primary inputs required by the cost effectiveness analysis. The principal source of the input information is the database which will contain all pertinent physical and performance features of existing conventional and advanced craft which are in the range of interest for Coast Guard cutters. (At present, the range of interest is 100-3000 tons; however, this may change in the future). The database has been established on the Digital Equipment Corporation Model PDP 11/34 computer with future plans to expand to the Digital Equipment Corporation VAX computer. It will be updated regularly from the technical literature and from the output of the other two project elements to ensure that current information is available on very short notice. The technical support portion of the project provides general technical services. It provides for the development of notional craft designs which can be used to supplement database information for those advanced craft for which there are few in-service demonstrators in the size range of interest. Additionally, a reliability, maintainability, and availability methodology will be developed in order to improve the cost effectiveness analysis methodology, which does not consider craft availability at present. The cost effectiveness output is also of value by identifying those craft characteristics which are most important for any given set of performance requirements. This feature helps us to make the most efficient use of project resources by concentrating them in the areas of highest "pay-off".

The second project element, Test and Evaluation, provides the primary full-scale vessel input to the database. Due to the type of work undertaken within this project element, e.g., leasing and long-term field testing of advanced craft, it requires the greatest commitment of funds. Nevertheless, it is of great technical and demonstrative value to the project.

The third project element, Craft Hydrodynamic Characteristics, provides a means for obtaining performance data for designs which do not exist in service. This type of analytical and experimental work is necessary due to the limited number of in-service demonstrator craft under many of the craft categories. Additionally, the literature reviews which will be conducted continuously will provide an important source of information to the database. The three portions of this project element are: Resistance and Propulsion, Seakeeping and Stability, and Special Topics. The first two headings are stated explicitly since, according to the OR/OA work done over the past year, they are the most significant craft performance characteristics for the purposes of acquisition and usage decisions.

CUTTER ACQUISITION SUPPORT

Here we will look at the vessel's characteristics such as speed, seakeeping, maneuverability, range and availability. We will do this by running analytic and simulation models of the pertinent missions. These models integrate realistic mission scenarios with ship characteristics obtained from recent technical evaluations and currently available engineering design information. This system will manage a large amount of historical data on the entire project, and will provide Coast Guard managers with the ability to access, analyze, compute, and display historical data and future predictions. The system will be useful in forecasting resource utilization, productivity, and the performance of candidate craft for acquisition.

A preliminary in-house study will be conducted on the deployment of Remotely Piloted Vehicles (RPVs) from multi-mission AMVs. Study will include a literature search of existing RPVs, historic utilization of RPVs on conventional craft including sensor payloads, and the benefits of RPVs for "over the horizon" Coast Guard missions.

A feasibility study of a hybrid craft will also be conducted. This will be a follow-on effort to the work begun in 1984 (See Figures 1-4) and will develop a new design, rather than retrofit an existing one.

An in-house study on human factors considerations for AMVs will be conducted. This study will look at the effects of craft motions on crew members and the ability to effectively conduct mission objectives.

TEST AND EVALUATION

This includes full-scale test, evaluation and demonstration of various marine vehicle craft. Testing is accomplished through technical and operational evaluations. A technical evaluation is a short duration look at a vessel's performance characteristics. It is in this stage that we take hard seakeeping performance data. The operational evaluation is an extended look (6-12 months) to provide a true evaluation of the vessels' ability to perform Coast Guard missions. We will evaluate the 44 foot Motor Life Boat and later our 41 foot boats in addition to the SES-200 Surface Effect Ship on loan to us from the Navy.

In addition to full-scale craft evaluations, craft subsystems are also evaluated. This fiscal year installation of a ride control system on one of the Coast Guard's Surface Effect Ships will be completed. An advanced propulsor will be installed on a 41 foot utility boat (UTB) for evaluation of pre-swirl vanes.

CRAFT HYDRODYNAMIC CHARACTERISTICS

Our in-house effort to program and evaluate computer models which may be used to predict AMV seakeeping performance, maneuvering and stability characteristics, and prediction of speed loss in a seaway will be augmented with work done by contract. The development of a Surface Effect Ship motions computer model in the frequency domain and a parametric study of the effect of hydrostatic parameters such as Longitudinal Center Gravity and Metacentric on SWATH ship seakeeping will be done. We will also study seakeeping, powering and loss of speed in a seaway for an SES design and a SWATH ship design using model tests in a towing tank. The models will be towed in head and following seas. A research project in conjunction with the British Department of Transport and Vosper Hovermarine, Ltd. will continue work in the area of SES stability using radio-controlled model tests to predict safe operating limits for SES.

Preliminary model tests will be conducted in a towing tank and in a rotating arm basin to provide the initial hydrodynamic data for an in-house study to develop roll/yaw stability and turning/maneuvering criteria for planing hulls. In addition, seakeeping, powering and loss of speed in a seaway will be studied for two notional patrol boat (WPB) designs. The effect of changes in forebody shape on the seakeeping, powering and loss of speed in a seaway for planing hulls will be systematically investigated using model tests in a towing tank.

The time dependent pressures on a planing hull will be measured for head seas in towing tanks. These pressures will be correlated with the velocity and acceleration of the hull and the wave motion. Three hulls with different deadrise angles will be tested.

Steady state pressure distributions on a planing hull will be studied in the circulating water channel at the U. S. Coast Guard Academy.

Seakeeping, powering and the loss of speed in a seaway will be studied for 95 foot patrol boats (WPB), 44 foot motor life boats (MLB), 180 foot buoy tenders (WLB) and 327 foot cutters (WMEC) using model tests in the U. S. Naval Academy towing tank. The models will be towed in head and following seas. The seakeeping of the 210 foot WMEC, 95 foot WPB, 44 foot MLB and 180 foot WLB will be studied using self propelled models in a seakeeping basin. The models will be tested in head, bow, beam, quartering and following seas. This group of tests will complement each other and provide baseline data for future comparison.

A preliminary in-house study will be conducted on the survivability of advanced hull designs in ice, including AMV usage for low density icebreaking. This work will support Coastal Buoy Tender Replacement.

An experimental evaluation of the effects of shaft inclination on propulsor performance is also planned.

BENEFITS

The activities of this project provide important inputs to the decision making process which will involve several billions of dollars in acquisition costs over the next twenty years and several times that amount for support (personnel, fuel, maintenance, facilities) costs. As a result of this project we can provide Coast Guard management with credible information which will enhance our understanding of the performance and economic benefits of advanced marine vehicles versus those of conventional vessels.

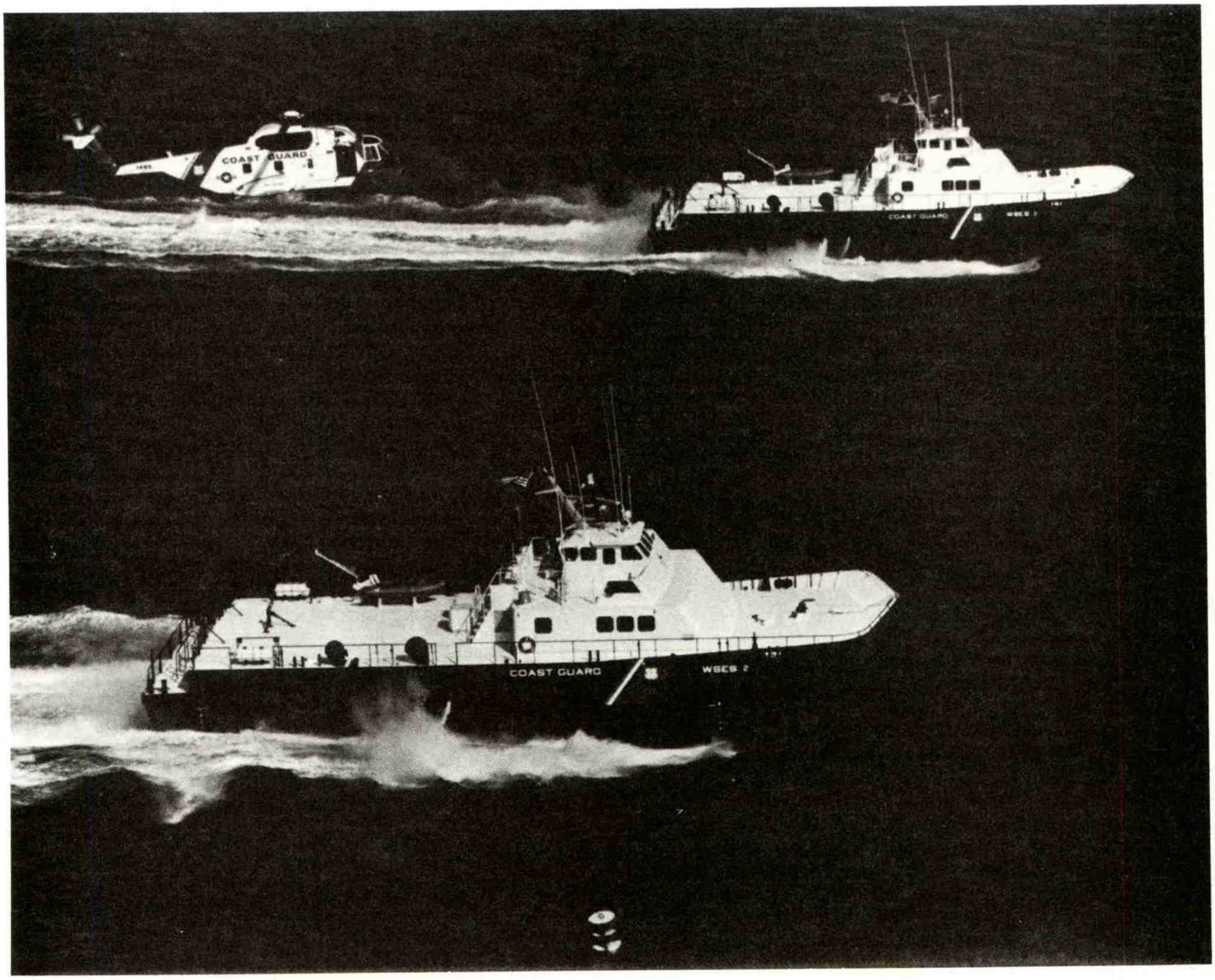
Advanced marine vehicles offer improved performance (effectiveness) over conventional vessels in the following categories: crew safety, seakeeping, speed, energy efficiency, reduced crew manning, reduced maintenance and support costs, and improved crew habitability. Construction standards of present advanced marine vehicles are compatible with marine industry standards. The general trend is toward greater simplicity, reliability, and managable costs. The resulting construction costs are now becoming comparable to conventional vessels using similar materials and as this improves, we will see more acceptance of advanced unconventional craft in the Coast Guard.

AN ARTISTS CONCEPTION OF THE HYBRID SWATH (HYSWAS) VESSEL.

Figure 1

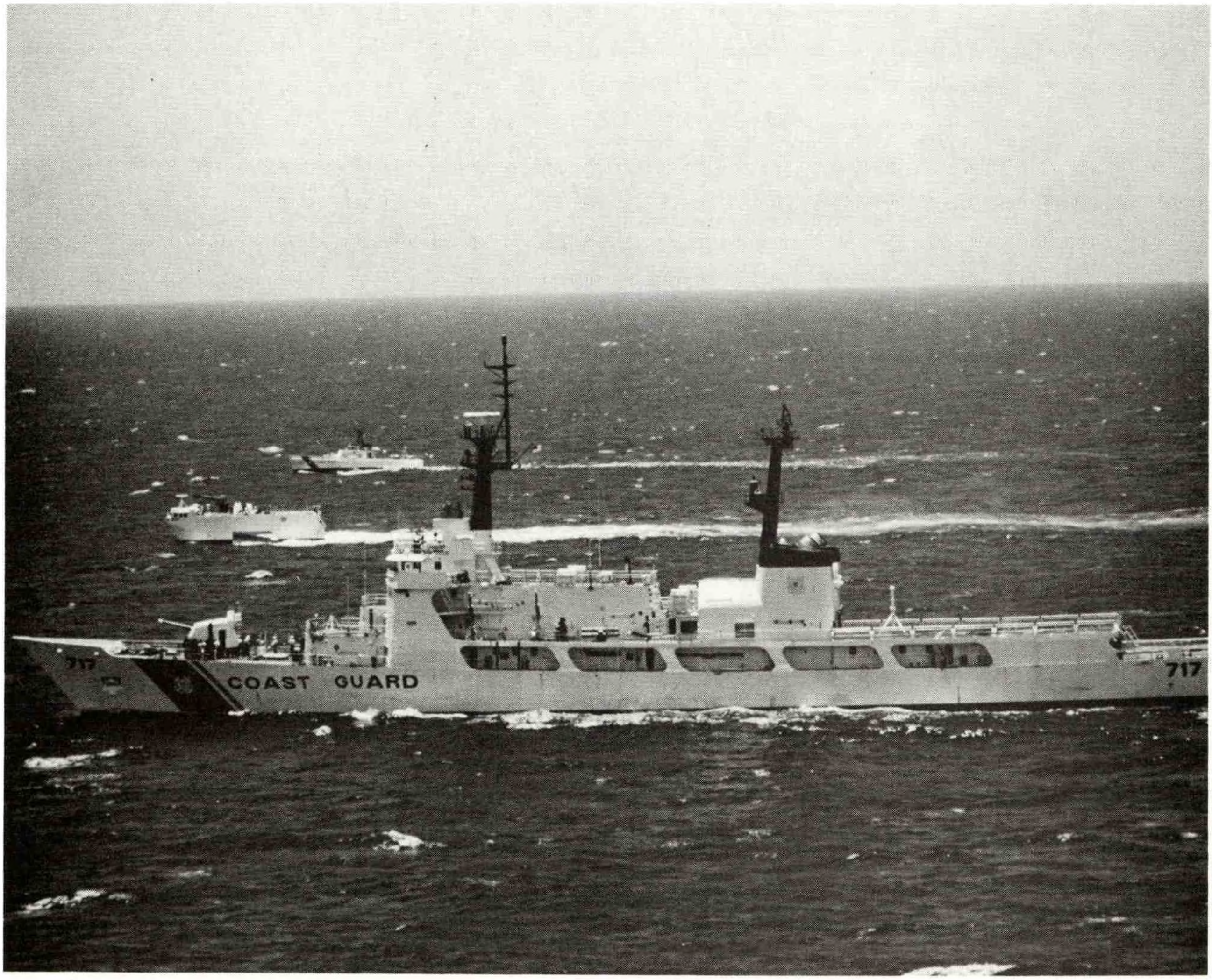
SIDE-BY-SIDE TRIALS OF SWATH KAIMALINO AND COAST GUARD BUOY TENDER.

FIGURE 2



TWO CG SURFACE EFFECT SHIPS MANEUVER TOGETHER NEAR KEY WEST, FLORIDA

FIGURE 3



SIDE-BY-SIDE COMPARISON TRIALS BETWEEN 89 FOOT LONG SWATH KAIMALINO, CG 95 FOOT LONG PATROL BOAT, AND 378 FOOT LONG CUTTER SHOWED THE MUCH SMALLER SWATH RODE VERY SIMILAR TO THE LARGER 378 FOOT CUTTER.

FIGURE 4

D/W 26,000 M.T. Modern Sail-Assisted Log and Bulk Carrier "USUKI PIONEER"

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1. Background

Since the Japan Marine Machinery Development Association (JAMDA) embarked on the development of the world's first modern sail-assisted tanker, the 'Shin Aitoku Maru', which was notable for the fact that it required no extra crew to handle the sails, other ships of the same type, all using wind power to reduce energy costs, have come into service. The 'Shin Aitoku Maru' was launched in 1980, and since then a total of six other sail-equipped ships have been launched and are now in service in domestic waters. The 'Shin Aitoku Maru', which has now completed its fourth year of service, has shown a fuel saving in use of 50% compared to conventional ships of the same size, type and age.

These modern sail-assisted motor vessels have shown good results not just in terms of fuel saving, but also in terms of dynamic performance. They exhibit considerably reduced rolling, pitching and yawing when compared to conventional ships and this is a further factor in their success.

In this new ship, we have tried to make the best possible use of the lessons learned and the experience gained from the previous ships in order to produce a large modern sail-assisted bulk carrier. The new ship has been built at Usuki Iron Works' Saiki Shipyard. (Fig. 1, Table 1)

As may be seen from the specifications, the ship employs two main engines which drive a single low speed large diameter controllable pitch propeller through reduction gearing. This is by no means a new system, and can be seen on many recently designed ships, but the difference is that on this ship the relationship between the two engines, the propulsion obtained from the sails, and the propeller pitch can be freely controlled by computer to give optimum fuel efficiency. The use of two engines also means that the load factor can be reduced to as low as one fifth (about 1320 PS) while still burning grade C heavy oil. This differs from conventional heavy oil burning engines which have to switch to grade A oil at low loads.

In addition to the sail system, the ship incorporates a considerable number of other energy saving measures, and it is felt that it will be possible to achieve fuel savings of between 15 and 40% as compared to conventional fuel efficient ships. The initial target is a fuel consumption of less than 15 tons per day at normal running speed.

Note: Modern sail-assisted ship

The term 'modern sail-assisted ship' as used here refers not to existing ships which have been retrofitted with sails, but to those ships which have been designed for sail use from the outset. Such design includes not only the design of the most suitable hull for sail use, but also the design of the sails and engines as a complete energy-saving unit capable of making the greatest possible use of the gains achieved by the sails.

2. The Component Parts of the Energy Saving System - Details

2.1 The Modern Wing Sail System

The ship employs a fully automatic sail system which was designed aerodynamically after considerable research into wing theory. This sail system has a dual role, it reduces fuel costs, and also it serves to reduce pitching, rolling and yawing, thus greatly increasing the ship's stability.

(1) There are two parallel furling aerofoil type sails mounted on the ship, each of which is made of cloth mounted on a steel frame.

(2) Each sail measures 16 m. in height and 20 m. in width, giving a sail area of 320 m^2 per sail and a total sail area of 640 m^2. Each sail is also divided into upper and lower sections which can be furled and unfurled separately. This enables the ship to make effective use of winds of up to 25 m/s.

(3) The sails are controlled by a computer which sets the sails to the optimum angle after

measuring the wind speed and direction. The system is completely automatic and no extra crew members are required in order to operate the sails. The ship's complement is the same as that of a conventional ship of this size.

(4) The positions of the sails and the cranes have been carefully arranged so that the sails in no way interfere with loading and unloading operations.

(5) In view of the need for the ship to pass under low bridges when entering ports in America, the air draft has been fixed at 40 m.

(6) The ship will be sailing the Northern Pacific route, on which cold conditions are often encountered. In consideration of this, the sail cloth has been specially chosen to resist cold, and the sails are fitted with a de-icing system.

2.2 The Hull Design

In addition to designing the ship's hull for minimum resistance, the height of the superstructure was also reduced with a view to improving the ship's stability.

(1) In order to achieve the lowest possible hull drag, we commissioned the University of Tokyo to design a new type of low drag hull.

(2) Five different designs of model were subjected to comparative tests in order to ascertain the best hull shape. Tests using models were also carried out at the Japan Shipbuilding Technology Centre.

(3) The use of a special bulbous bow and bulbous stern means that the ship can use much less powerful engines than would normally be fitted to a 26,000 D.W.T. bulk carrier.

(4) We were very much aware of the need to ensure safety in a large sail-equipped vessel of this type, and to this end we carried out basin and wind/current generator-equipped basin tests using models in order to confirm the ship's safety.

(5) The ship's superstructure is of a new, low height design aimed at reducing wind resistance.

2.3 The Propulsion System

In order to achieve maximum fuel economy under a wide variety of sailing conditions, the ship employs, in addition to its sails, two main engines which drive a single propeller shaft through reduction gearing. The propeller is a large diameter low speed controllable pitch type.

This two engine/one shaft system is run by computers which automatically control engine speed and output, balance load between the engines, and regulate the ship's sailing speed. The computer system regulates in addition the pitch of the propeller and the relation between engine power and sail power. When a higher power output from the main engines is required, the computer system switches in both units, but when there is a good wind and there is sufficient propulsion being generated by the sails, the computer cuts out one engine. This system enables the ship to make the best possible use of its sails at all times. (Fig. 2 ~ 4)

(1) The main engines are two Hanshin 6EL40 units rated at 3300 HP each. These engines exhibit very good combustion characteristics even under partial load.

(2) The use of a two engine/one shaft system means that grade 'C' heavy fuel oil can be burnt even at loads as low as one fifth (about 1320 PS).

(3) Over the full load range, (including start up and stopping but not including periods when the engines are stopped for a long time,) both of the engines are capable of burning fuel with a calorific value as low as 380 cst (50°C).

(4) The ship uses a large diameter (6.4 m) low speed (88 rpm) 4 blade controllable pitch propeller which gives a high level of propulsive efficiency.

(5) The propeller surface is ground to a very high level of finish (5 μ), which further improves propulsive efficiency.

2.4 The Exhaust Gas Economizer, Boiler, and Oil Circulating Preheating System

(1) The Oil Type Exhaust Gas Economizer.

(a) The heat exchange process is as follows: exhaust gas → air → heating medium (oil) → areas to be heated (fuel oil etc.) This system allows exhaust gas to be used with a high degree of efficiency for heating purposes, and does not suffer from the problem of corrosion caused by exhaust gas.

(b) The high efficiency of the system means that it is capable of supplying not only all the heating needs of the crew quarters, but also that it has sufficient capacity to heat the ship's fuel and lubricating oil.

(2) The Oil Circulating Boiler

(a) The boiler is a closed cycle type which uses oil as the heating medium instead of steam. This means that, in addition to achieving a high level of efficiency, the system needs no water tank, thus saving weight and also saving engine room space.

(b) The fact that the boiler system operates in a closed cycle means that there is no contact with the air,and no high temperature oxidation takes place.

The use of oil as the medium in both the exhaust gas economizer and the boiler also means that there is no risk of pipe corrosion.

2.5 The De-Icing System

(1) The system uses closed circulation type heat pipes designed for use in extreme cold. (Fig. 1)

(2) The system is capable of maintaining a temperature of 5–10°C on the heated surfaces with minimum consumption of electricity. It serves both as a de-icer and as an icing-prevention system.

(3) Operation of the system is carried out automatically by means of temperature sensors on the system's surface.

2.6 The Automatic Radio Navigation System

(1) Position Determination Control System

The system incorporates navigation receivers for 4 systems (Loran C, Decca, Omega & NNSS), and is controlled in such a way that a reliable and accurate position may be obtained by processing data from either single or plural receivers.

(2) Navigational Information and Ship's Course Display

Navigational information such as course, distance to destination, course deviation, etc. and the ship's present course are displayed on a CRT display screen.

(3) Compact Design

The system is extremely compact, and even including the automatic receiver control unit it is only half the size of conventional systems.

2.7 The Ship's Computer Systems

(1) The Sail Control Computer

This computer provides fully automatic control of the sails, and its use means that no additional crew members are required in order to operate the sails.

(2) The Automatic Load Computer

This computer controls the engine load, engine speed and propeller pitch and automatically chooses the most economical settings for each.

(a) Automatic Load Control

The system takes into account the power being gained from the sails at any given time and increases or reduces the engine speed accordingly. It also makes the decision whether to run both engines or only one. The engine speed and load are always set to the optimum figure in terms of fuel economy.

(b) Automatic Load Balancer

This system ensures that loads are always evenly balanced between the two engines.

(c) Automatic Sailing Speed Control

The system increases or reduces engine speed automatically as necessary in order to maintain a preset sailing speed.

(3) The Stability Confirming and Navigation Manual Computer

This computer calculates the 'C' coefficient on the basis of the amount of cargo in the holds, works out the required speed and amount of fuel required, and also calculates the ship's E.T.A.

2.8 Others

(1) Self-Polishing Antifouling Paint

In order to prevent any increase in drag caused by fouling on the hull, the submerged sections of the hull are coated with self-polishing antifouling paint.

(2) Auxiliary Machinery Capable of Burning Low Grade Fuel Oil

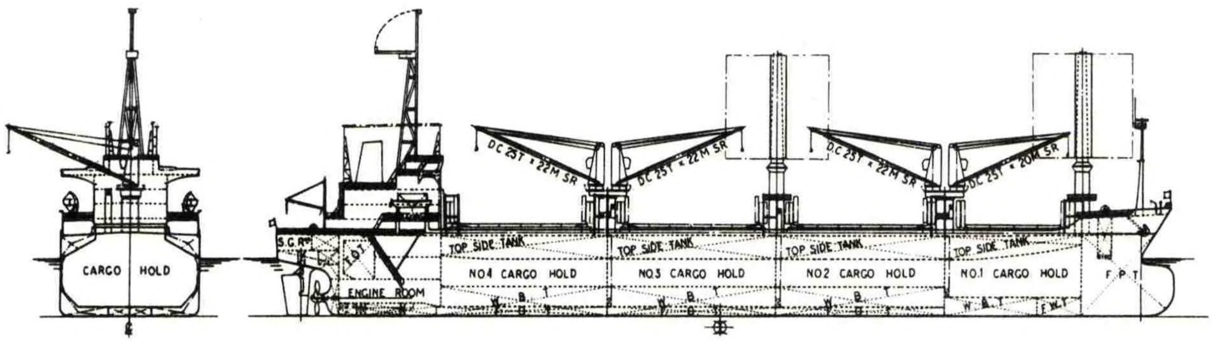
The generator driving engine is run on low grade fuel oil, thus reducing the cost of electricity generation.

(3) The Homogenizer

The homogenizer system crushes sludge mixed with the fuel and passes the mixture to an ultra-fine mesh filter which removes all metallic impurities before the fuel is burnt in the engines.

Fig. 1 The general arrangement of the D/W 26,000 MT Modern Sail-Assisted Log & Bulk Carrier

"USUKI PIONEER"



Keel laid	June 6th 1984
Launched	August 30th 1984
Completed	November 19th 1984

Table 1 D/W 26,000 MT Modern Sail-Assisted Log & Bulk Carrier - Principal Particulars

Length o.a.	about 162.50 m	Hold capacity (grain)	about 32,000 m^3
Length b.p.	〃 152.00 m	Hold capacity (bail)	〃 30,000 m^3
Breadth mld.	〃 25.20 m	Fuel oil tank (C oil)	〃 970 m^3
Depth mld.	〃 14.80 m	Fuel oil tank (A oil)	〃 60 m^3
Designed load draft	〃 10.57 m	Fresh water tank	〃 450 m^3
Gross tonnage	about 15,700 tons	Water ballast tank	〃 9,500 m^3
Dead weight	〃 26,000 tons	Complement	22 + 6 persons
Service speed	about 13.5 knots	Equipment	
Endurance	about 12,000 sea miles	Deck cranes	El-hydraulic 25 t × 12 m/min. × 4
Main engines		Navigational instruments	
Type & No.	HANSHIN 6EL40 × 2		Automatic Radio Navigation System
Max. output	3,300 PS × 240.0/88.0 r.p.m.		(Loran C, Decca, Omega & NNSS) × 1
F.O. consump. (MCR)	133 gr/bhp. hr (Lu=10,200 kcal/kg)		Gyro compass & auto pilot × 1
Propeller			Radar × 2
Type & No.	C.P.P. type 4 blade × 1		Echo sounder × 1
Electric generator			Direction finder × 1
400 kW, 445 V A.C. 60 Hz, 4 cycle diesel driven × 2			Radio tele. × 1
Thermo oil boiler & Exhaust gas economizer			Electric magnetic log × 1
Thermo oil circulating type		Computers	Sail control computer
Boiler × 1 (400,000 kcal/Hr)			Automatic load computer
Economizer × 2 (200,000 kcal/Hr)			Stability confirming and navigation manual computer

Sail rig:
Two sets of parallel folding rigid sails with a total area of about 640 m^2 Maximum wind speed when sails unfurled: 25.0 m/s

Fig. 2 Plan of propulsion system

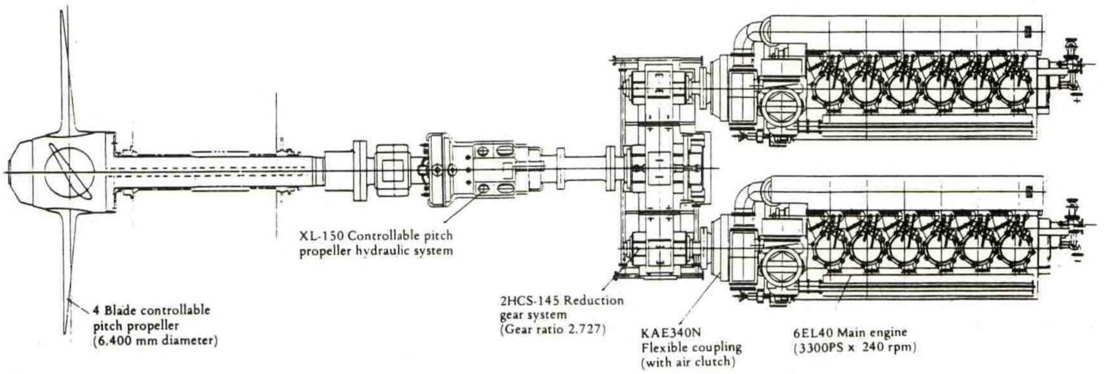
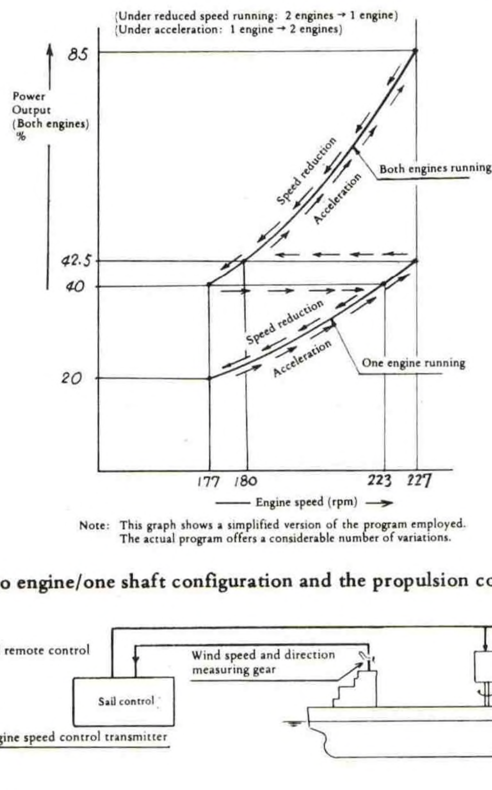
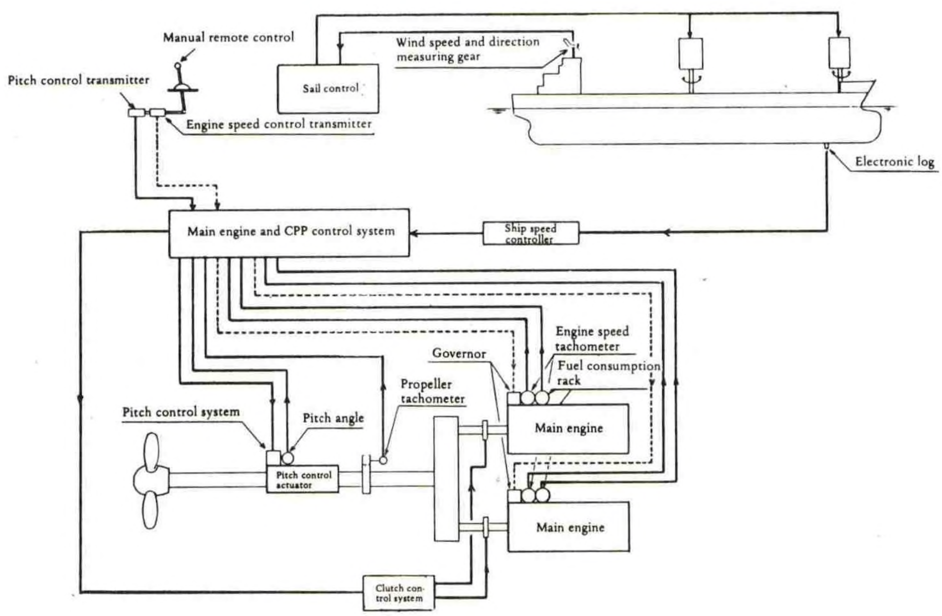


Fig. 3 The No. 1 ⟷ No. 2 engine auto switchover system



Note: This graph shows a simplified version of the program employed.
The actual program offers a considerable number of variations.

Fig. 4 The two engine/one shaft configuration and the propulsion control system



AN ONLINE SHIP PERFORMANCE MONITORING SYSTEM

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Abstract

The paper describes a microprocessor-based, onboard, real-time ship performance monitoring system. Those features which represent a major advance in ship performance monitoring technology are detailed. The capabilities of the system for achievement of improved maintenance management and reduced maintenance costs, and improved operational performance accompanied by reduced operating costs are presented. It is shown that, by the design approach used and its implementation as a distributed digital processing system, this technology is compatible with current marine onboard control and surveillance systems design goals. The potential applicability to merchant ships is discussed.

1. Introduction

Fuel consumption is not only a function of the operational variables of ship speed, displacement, trim, machinery plant operation, and variations in hull and propeller conditions, but also the environmental factors of wind, sea, temperature, and ocean currents which change in random patterns that have defied precise prediction by either theoretical or statistical techniques. To reduce these variables to manageable proportions, there is a need for an improved system of measurement and analysis aboard every ship to derive a rational input to ship operations economic analyses. In particular, the in-service performance monitoring of ship speed-to-power relationships is an essential input to techno-economic analyses relating to hull and propeller maintenance, determination of optimum operating conditions of the ship-machinery-propeller system at any given time, and proper design of service margins.

This paper presents a description of a microprocessor-based, real-time ship performance monitoring system that is now being developed and tested as a part of the U.S. Maritime Administration's advanced ship operations research and development program. This paper is directed to those aspects of the system's capabilities related to condition-based maintenance and improved operating efficiency of ship and fleet. The method is outlined by which the critical performance parameters of the ship/propeller/engine system are automatically measured and monitored in real-time using a few key measurement sensors and online digital processing techniques, to identify and track the changing propeller/propulsion parameters in all weather as a function of hull and propeller degradation and environmental factors.

The means are described by which the system, using online identification, estimation and performance monitoring technology, has been designed to be both self-learning and adaptive to various ship systems and operating conditions to reflect the current speed/power/thrust relationships of the ship, so allowing the simultaneous online performance measurement/analysis of all ships on which the system is installed in real-time. A description is also given of the configuration of the system aboard ship as a distributed intelligence network, to enable local decision-making and control at various points on the ship to achieve optimum short-term performance, in addition to providing information to efficiently project maintenance resource requirements in the longer term. The relevant human/computer interface features of the system are presented.

The system design is shown to be independent of whether the ship is turbine or diesel-driven. Further, the design principles employed as shown to be compatible with current marine designs for digital distributed condition/control and surveillance systems. In particular the paper shows that the real-time performance monitoring software can be implemented either within an existing computer or in an additional microprocessor of these digital distributed systems, and uses sensors needed for surveillance and control purposes. The paper demonstrates the potential of this technology for significant gains in availability and performance, and reduction in the cost of ship maintenance and operation.

2. The In-Service Performance Problem

Shortly after a ship has entered service, deterioration in ship performance begins. This deterioration, resulting in speed/power/fuel losses, arises from both design effects and operational procedures. Deterioration in the operation of the ship in the open seas has been shown to be in the following main areas: (1) power plant and auxiliaries, (2) propeller efficiency, (3) hull resistance, and (4) navigation, steering, and routing (1). Controllable factors which affect fuel efficiency include operational procedures, plant efficiency, and ship propulsion efficiency. Various attempts have been made to improve operational efficiency, e.g., (2-4). Other efforts have been directed toward improving design techniques to optimize power margin as opposed to operating procedures, for example, the work of Prochaska (5), Sinclair and Eames (6), and Kresic and Haskell (7) in relation to propeller design.

It is generally accepted that the largest achievable gains in fuel efficiency are realizable through the optimization of ship propulsion, e.g., (1). The greatest potential for fuel savings in this area appears to be by the minimization of hull and propeller roughness occurring from surface fouling, pitting, and corroding. Through the implementation of an effective hull maintenance program, it has been shown that significant reductions in fuel consumption may be achieved, e.g., (8-10). The work of Prochaska (5), addressing the effects of hull roughness on propeller efficiency and the effect of propeller blade roughness on ship performance, showed not only the interdependence of hull condition and propeller, but also the magnitude of the resulting estimated losses due to the increasing wake fraction in addition to those resulting from propeller blade surface degradation. The results were based on a statistical analysis of the in-service performance of many ships over a ten-year period. Based on these studies, Figure 1 (extracted from (5)) shows Prochaska's estimates of the three main influences contributing to

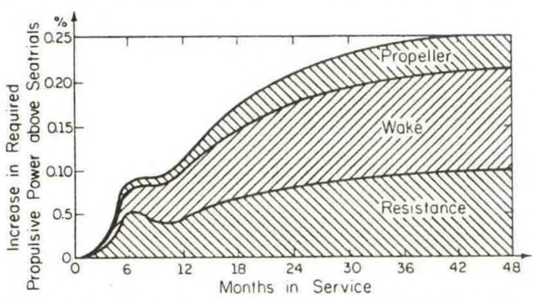


Figure 1 Components of Ship Power Increase with Time: Approach to the Chronological Development of the Growing Power Requirement Illustrated by Enveloping Curves Showing the Distribution of the Detrimental Causes.

Note: Constant Propeller Speed, Dry-Docked Regularly and Restored with Conventional Paints, Valid for Full-Formed Ships, C_B = 0.80 (Approximately) Average Service Speed = 14 Knots, Trading World Wide.

power losses over the ship's total time in-service. On the basis of service data analysis of more than 100 ships over the ten-year period, Prochaska concludes that after four to five years service and shortly before the regular drydocking (assumed to be every one and one half years), an additional 30 percent power over that required during the ship's initial sea trials is required to maintain design speed. This increasing power demand is attributed equally (15 percent) to rippling and roughening of the hull and propeller roughening ("permanent" loss), and the regular biological fouling of the shell plating ("removable" loss).

The estimates made for partial recovery of both types of losses by a proper condition-based maintenance and performance monitoring/management program are gains of 4 to 6 percent between subsequent dry-dockings realizable through hull shot/sand blasting, propeller repolishing, improved paint effect and application, and optimum scheduling of dry-docking for maximum revenue (11). By optimization of propeller design for service condition (5), a further 2 percent savings could be made. Further, by making use of, and understanding, the means to optimize ship's operating performance, some 7 percent fuel savings could be made. Optimization of the ship's performance includes achievement of the correct operating point of the ship/machinery/ propeller system at any given time, and the correct trim and draft, the correct steering controls, navigational and weather routing practices for particular loading and environmental conditions.

It is clear that the propeller efficiency plays a major role in propulsion losses by recent work. e.g., (12-14) in examination of the effects of propeller roughness on power losses. Using analytical techniques based on roughness measurements of a great number of propellers, Byrne, et al. (12), have shown that the economic penalties resulting from propeller roughness are very severe. In the case of the containership examined in their research it was shown that if the increase in delivered power due to deteriorative effects required to maintain a given service speed is proportioned between hull roughness losses and propeller roughness losses, ignoring losses due to other effects, this proportion was about 2/3 due to hull roughening and 1/3 due to propeller roughening.

A successful hull and propeller maintenance program must include the capability to monitor ship condition/performance changes as a function of hull and propeller surface degradation with respect to some baseline set of ship and environmental conditions. By hull degradation is meant the unavoidable mechanical, chemical and biological deterioration of the hull; by propeller degradation is meant primarily propeller blade roughness and damage. Such a program could also include a quantitative evaluation of various new hull coatings in terms of a common base of performance measurements, and the cost/benefits associated with various propeller polishing methods, e.g., (15). A requirement for measuring the effects of a degraded hull or propeller is the capability to effectively determine either average speed loss at standard conditions (in particular, power), or average power increase at standard conditions (in particular, speed) since the last dry-docking, etc., (16).

Losses due to machinery plant operation, the operational variables of speed, displacement and trim, and the dynamic effects due to ship motions, steering, and weather are also considerable, and must be separated from losses due to hull and propeller degradation if the losses resulting from the latter two effects are to be successfully identified (15). The detection and attribution of both long-term effects and short-term dynamic effects on speed, power and fuel consumption is therefore dependent on a continuous and critical monitoring of ship condition/performance while in-service. By inclusion of a thrust measurement, the means is provided to track propeller efficiency and its progressive degradation, and to separate hull and propeller losses by the knowledge of thrust in addition to torque as provided by a shaft torque measurement.

Of the other involuntary losses, those related to steering have recently been shown to be significant, even in calm water operation (17). Recent theoretical and full-scale experimental work by Reid, et al. (17), has quantified the potential penalties in speed/power losses associated with limit cycle behavior of a wide range of ship types resulting from bang-bang steering gear controllers. There are few ships which are not fitted with this form of steering gear control. This work shows that between 2 and 4 percent of full power can be lost in the steering system. Figure 2 abstracted from (17), contains rather dramatic evidence of the effect of steering gear control on performance. Figure 2 shows the results of full-scale tests for a diesel-powered containership using different steering gear control systems in essentially calm water. Both heading and rudder angle recordings, and measured steering and propulsion performance are included. The changeover from proportional steering gear control to bang-bang control resulted in an average decrease of 1.8 percent in ship speed and an average increase of 0.4 percent in shaft torque over the measurement period. The wear of the steering gear, as discussed, e.g., in (18), will also have an impact on propulsion performance.

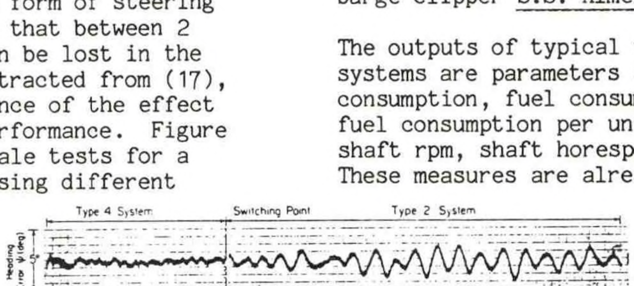
It is therefore clear that the inclusion of the means to monitor steering related speed/power losses online in any performance monitoring system is mandatory, both for proper analysis of the effects of roughness/fouling on ship performance given the apparent magnitude of the steering losses, and for more accurate determination of the extent of these losses and the degradation of the steering gear with time. It also seems clear that the means to achieve what are considered the rather conservative assessments of potential fuel savings described above are necessarily predicated on performance monitoring in real time.

3. The Online Ship Condition/Performance Monitoring System

3.1 System Capabilities

It is against the background described in Section 2 that the Maritime Administration has developed a real-time, automated ship performance monitoring system. An onboard, online microprocessor-based system has been designed and developed to identify long-term speed/power losses due to hull and propeller degradation, and short-term losses resulting from ballasting/loading practices, operational practices and environmental factors. The system is presently undergoing testing aboard the sea barge clipper S.S. Almeria Lykes.

The outputs of typical vessel performance systems are parameters such as specific fuel consumption, fuel consumption per unit time, fuel consumption per unit distance, propeller shaft rpm, shaft horsepower, and ship speed. These measures are already available to, and



Time	Rudder Servo Type	Rudder Angle Variance $(\overline{\delta^2} - \bar{\delta}^2)$	Yaw Rate Variance $(\overline{r^2} - \bar{r}^2)$	Mean Square Heading Error $(\overline{\psi^2})$	Average Speed through Water $(\bar{U})$	Average Shaft Torques $(\bar{Q})$
0-12 min	Type 4	0.108 deg^2	0.0037 $(deg/sec)^2$	0.033 deg^2	18.77 knots	72.85% of max.
24-36 min	Type 2	1.783 deg^2	0.0066 $(deg/sec)^2$	0.495 deg^2	18.43 knots	73.15% of max.

Figure 2 Measured Steering and Propulsion Performance: Proportional versus Bang-Bang Steering Systems, 610 ft. Long Containership in Calm Weather, North Atlantic, February 1982.

used by, ship personnel in performance assessment and reporting. Knowledge of these measures does not in general enable determination of the source of fuel penalty or performance degradation. Further, the error bands attributable to the raw measurements of speed through the water and fuel oil flow rate are generally greater than the source of the fuel penalty under investigation. These measures are basically used as inputs to our condition/performance monitoring system, in which models of the ship/machinery/propeller relationships are embedded (16).

The output of our system is the identification and attribution of each source of speed/power/fuel losses in real time. Specifically the following principal long-term ship performance trend data are calculated:

* Long-term "standard" speed
* Long-term wake fraction
* Long-term propeller efficiency
* Long-term hull efficiency
* Long-term propulsion plant efficiency
* Long-term steering gear efficiency

By standard speed is meant the ship's fair-weather speed through the water calculated at standard (nominal) power, trim, draft, and weather conditions. The present capability does not include the means to identify and analyze the individual components of the propulsion plant which may be contributing to degraded power plant efficiency, though this capability could be realized rather easily, as is discussed in Section 4. In addition, the following dynamic ship operating performance data are calculated in real time:

* Speed/power/fuel losses due to steering
* Speed/power/fuel losses due to ballasting/loading practices
* Speed/power/fuel losses due to trimming practices
* Speed/power/fuel losses due to wind, waves, and weather.

On the Almeria Lykes, this performance data is calculated on the basis of measurement data from the 10 sensors listed below:

* Water speed log
* Gyrocompass
* Satellite navigator
* Propeller shaft torque sensor
* Propeller shaft tachometer
* Propeller shaft thrust sensor
* Fuel oil flow meter
* Rudder angle measuring equipment
* Wind speed and direction measurement system

These sensors are automatically sampled by the microprocessor-based system once per second. From these measurements, in the process of calculation of the major performance parameters described above, statistics of the following real-time, short-term ship and propulsion operating performance parameters are calculated and made available for display on operator demand at the various remote terminals of the distributed intelligence network with which the system is configured aboard ship (see Section 3.3) on the basis of (normally) 1 minute, 1 hour, and 24 hour time intervals:

* Fuel consumption rate
* Specific fuel consumption
* Fuel consumption per unit distance
* Ship speed through the water
* Propeller shaft rpm
* Propeller shaft horsepower
* Propeller thrust
* Apparent slip
* Wake fraction
* Ship speed at standard power
* Propeller efficiency
* Horsepower meter bias
* Thrust meter bias
* Speed log bias
* Propeller torque/thrust characteristics
* Steering speed loss
* Mean change of rudder angle
* Heavy weather speed loss
* Trimming speed loss
* Ballasting/Loading speed loss

In addition, as a necessary by-product of the ship performance assessment, the following real-time navigation data is calculated and made available for display at one minute intervals:

* Latitude, longitude
* Heading
* Speed over the ground
* Current North and East components
* Wind speed and direction
* Rudder angle.

Our approach to the performance monitoring problem has been to structure and embed in a shipboard microprocessor-based system a general model of the ship speed and propulsion relationships using trials and model test data for the ship (16). Using online, near real-time identification and estimation techniques implemented in the onboard computer system, the unknown or uncertain parameters of the model are precisely identified, and the model refined to reflect the current speed/propulsion relationships of the ship. This is accomplished on a continuous basis during in-service operation of the ship. This unique approach in fact provides the ability for the model to be adapted to any ship without any changes in the basic online system. Once the model is defined, the system continuously automatically updates its parameters through monitoring of ship/propulsion data, navigation data, and environmental conditions. The system design, further, is independent of whether the ship is turbine or diesel-driven.

3.2 System Principles: Sensors, Data Acquisition, and Real-Time Performance Analysis

To separate power plant fluctuations from ship performance measurement, a direct measure of plant output in terms of shaft horsepower is necessary. Speed values are then adjusted or corrected to a standard level of power. A shaft torque meter is used for this purpose in our system. The separation of hull and propeller losses is made possible only by the knowledge of thrust in addition to torque. This has been accomplished by the installation of a thrust meter on the propeller shaft. The measurement of thrust is treated similarly to that of torque (16). In addition to providing a measure of propeller efficiency and its progressive degradation, the thrust measurement provides additional calibration of the propulsion relationships and thereby improves the accuracy of determination of ship speed and the other key parameters of ship performance.

An essential measurement in the system is ship speed through the water. A doppler water speed log forms part of the existing system. Many factors affect the accuracy of the speed log, in particular those related to ship motion and weather. It is therefore necessary to perform continual automatic checks on measured speed values. Estimates of speed over the ground are used for this purpose. These estimates are obtained using the satellite navigation system. Speed data are also checked on the basis of properly calibrated, theoretical propeller/propulsion relationships, e.g., (16, 19-21). These corrections are achieved in our system design by the use of redundant measurements and adaptive filtering algorithms (16, 22-24), which also determine sensor error and ocean current magnitudes.

In our computer algorithms, the best estimate of speed through the water is obtained by combining information from each of these sources. Based on measured thrust, power and rpm, a theoretical speed value is calculated via the propeller/propulsion relationships of the ship. By incorporating this value along with measured log speed and estimated ground speed, an optimal estimate of speed through the water is determined through an appropriately weighted averaging of these inputs. This is presented pictorially in Figure 3. The weights given to these inputs are calculated dynamically on the basis of error estimates in each by on-line processing.

The use of automatic measurement and collection/logging of data whenever possible is done in the system. Wind and wave factors can change substantially over short time periods and cause significant changes in speed. Since most of the information necessary to quantify speed-weather relationships is lost by averaging over a 24 hour period, a continuous input of data is used to provide an exact description of the losses in real-time, a concept embedded in the online system design.

Information on ship performance during acceptance trials and other measured mile runs and model test data is used to establish and initialize our performance monitoring system. Trials and model data are used for establishing and initially calibrating fundamental propeller/propulsion relationships (19-20); the initial estimates of the effects of draft and trim on speed and wake fraction can also be determined using these data. Both of these facts were established for the Almeria Lykes (16). The relationships developed from these data are particularly important since they essentially represent the best (theoretical) performance the ship will ever achieve.

Aside from other advantages of our performance monitoring system, it enables optimal estimates of system parameters to be continuously calculated to provide measures and trends of ship condition/performance. The decision to implement a system which processes performance data on-board, versus a shore-based facility for post-mission analysis, will have major impact on the potential economic benefits of the system. Using a shore-based facility to do post-mission performance analysis, large time lags can exist between the time the ship delivers condition/performance data and the time it is fully processed and analyzed; maintenance-related problems during this lag time cannot be corrected on a timely basis, i.e., as they occur. The ability to optimize the real-time performance of the ship is also lost in such a system.

3.3 System Configuration: Distributed Digital Processing Architecture

The onboard condition/performance monitoring system is configured as a digital distributed intelligence system. The prototype system has recently been installed aboard the S.S. Almeria Lykes. The Almeria Lykes is a sea barge clipper owned and operated by Lykes Bros. Steamship Co., New Orleans, Louisiana, running between the Gulf of Mexico and either Northern Europe or the

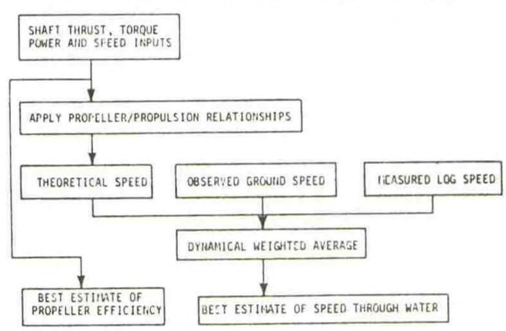


Figure 3 Calculation of Best Estimate of Speed Through Water and Propeller Efficiency

Mediterranean. The ship's length and breadth are approximately 874 ft. (266 m) and 106 ft (32 m), with a full load displacement (corresponding to 36 ft draft) of almost 51,000 tons. The ship has a single propeller/single rudder configuration, and is powered by steam turbines with a rated output of 36,000 shp.

Distributed processing architecture is gradually replacing conventional federated architecture in digital systems due to the rapid advances in digital computer and communications systems due to the rapid advances in digital computer and communictions systems technology. Applications of shipboard distributed computerized surveillance, control and performance monitoring systems relating mainly to rotating machinery for military vessels have been reported in e.g., (25-26). The U.S. Navy's current design objective for control and surveillance systems for new vessels is based on a digital distributed processing concept, in part to replace the traditional miles of point-to-point electrical signal cabling with a few coaxial cables and some multiplexing electronics. Some advanced proposals and current trends relating to this issue have recently been presented by Fastring and Wapner (27,28).

Our ship performance monitoring system is essentially a software-based system. We have designed the system in the modular manner described to enable its portability to various ships' needs and to changing hardware technology. Distributed systems architecture is the digital implementation technology chosen for our system. Aside from cabling considerations, a significant factor aboard the Almeria Lykes where signals have to be transmitted over 850 ft. between the vicinities of the propeller shaft alley and the bridge, various other important benefits accrue from our chosen design. Distributed processing is well suited to the harsh environment of a ship. Apart from the improved physical properties in terms of heat and vibration associated with the inherent chip technology embedded in the components of such a system, the distributed architecture allows the means for concurrent processing, improved local response time capability, and improved "system" reliability by enabling failure diagnosis in real-time and hardware replication of critical functions.

A digital communications network links the sensors with the central signal processing computer and remote terminals of the ship performance monitoring system throughout the ship. Transmission is by means of a twisted pair shielded cable. Microprocessor-controlled network interfaces connect the constituent components of the system to the network. Analog, contact-closure and discrete sensor signals from the various propulsion system, ship and navigation sensors of the system, are digitized and formatted locally at the microprocessor-controlled network interface units. For sensor interfacing aboard the Almeria Lykes those units are located at the aft end of the shaft alley (in a space adjacent to the hydraulic steering gear pumproom) and in the Master Gyro Transmitter Room (directly underneath the bridge). The central signal processing computer with associated terminal and printer is housed in the ship's office, located at the 02 level of the superstructure. Remote computer terminals are provided in the Chief Engineer's office, the Master's office, and in the Chart Room.

The network is transparent to the types of equipment used as the constituent elements of the condition/performance monitoring system. The distributed architecture design therefore allows almost total modularity and flexibility with respect to additional sensors, local processors and terminals. The system is designed for growth, and so yields significant life cycle cost and advantages in the flexibility afforded in adding new performance, surveillance or control functions in new hardware/software modules through the incremental addition of more network "nodes." Aboard the Almeria Lykes, the electrical connection between the network interface to "end user's," i.e., data terminal, equipment, conforms to the RS232-C standard, and the network interface is configured for 9600 Baud, with communications in the form of 7 bit ASCII character code.

3.4 System Performance: Simulation Results

The real-time performance monitoring system is presently undergoing functional and performance testing. In the course of system design, extensive simulation studies were carried out to verify the integrity of system performance, prior to testing in a land based test facility and at-sea testing. The heart of the system, and the key to online performance analysis of the critical ship/engine/propeller performance parameters, is the real-time estimation and identification software embedded in the system. This software uses adaptive filtering algorithms to optimally determine, from the available sensor measurement data, embedded ship/engine/propeller models, and the automatically updated performance parameter data base, the key system performance states and parameters at the current operating conditions necessary to determine both short-term operating performance and long-term performance trends (16).

Figures 4 through 9 are presented to demonstrate the ability of the adaptive filter to estimate key performance states and parameters in real-time from noisy measurements, and in the face of process noise (disturbances to ship/propulsion system dynamics). The figures show the performance of the filter over a period of 200

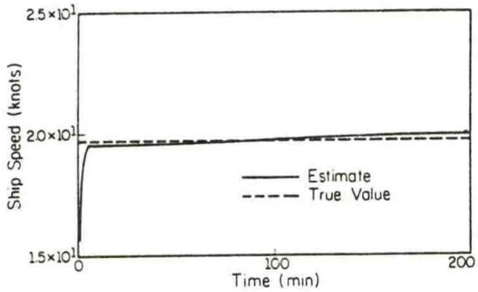


Figure 4 Adaptive Filter Performance: Ship's Speed through the Water

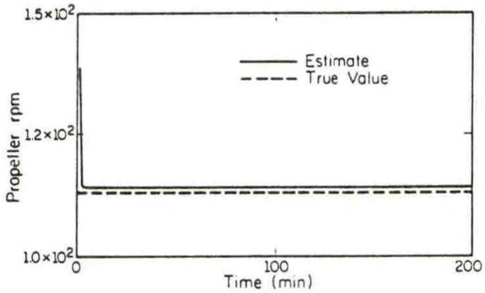


Figure 5 Adaptive Filter Performance: Propeller Speed

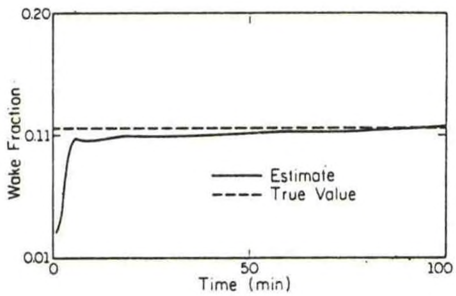


Figure 6 Adaptive Filter Performance: Wake Fraction

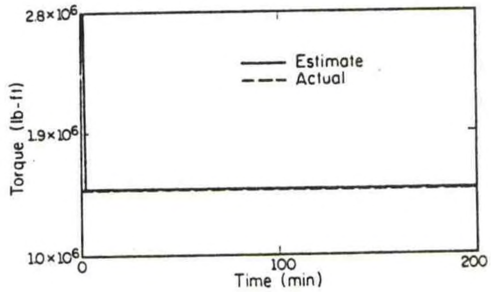


Figure 7 Adaptive Filter Performance: Propeller Shaft Torque

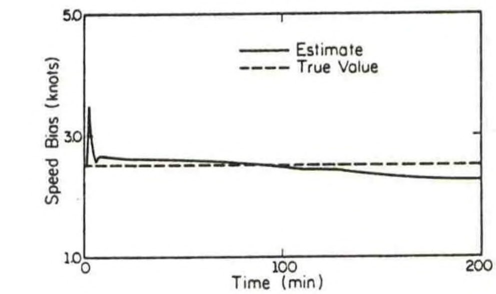


Figure 8 Adaptive Filter Performance: Speed Log Bias

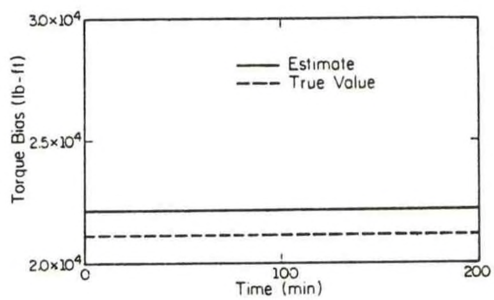


Figure 9 Adaptive Filter Performance: Torque Sensor Bias

minutes of simulated real-time of steady-steaming conditions. The results are intended to demonstrate the ability of the filter to cross-calibrate sensor errors, and to accurately assess key ship/propeller/propulsion performance states and parameters, in the face of: (i) poor initial estimates; (ii) measurement errors; and (iii) process noise.

In the simulation, the true mean ship's speed is considered to be 19.7 knots, propeller rpm 114, propeller shaft torque 1,486,810 ft-lb, and wake fraction 0.11. These conditions, in fact, relate to ship trials/model conditions (16) at 32,000 shp for 32 feet draft. The initial estimates assumed, as input to the performance monitoring system for purposes of this demonstration, were as follows: ship's speed 15.7 knots, propeller speed 139 rpm, and wake fraction 0.03. Further, the speed log is considered to have a measurement bias of 2.5 knots and a random error variance of 0.25 $(\text{knots})^2$; the torque measurement is considered to have bias of 22,150 lb-ft, and a random error variance of 6.201562×10^7 $(\text{lb-ft})^2$; propeller rpm measurements are considered to have a random error variance of 0.09 $(\text{rpm})^2$, and gyrocompass heading measurements a random error variance of 0.25 $(\text{deg})^2$. Additionally the ship dynamics are considered to be perturbed by process noise such that dynamic variances of 0.04 $(\text{knots})^2$, 0.09 $(\text{rpm})^2$, 1.0 $(\text{deg})^2$, respectively, result in actual ship's speed, propeller rpm, and heading about the mean nominal conditions defined above; these disturbances related to process noise corresponding to essentially fair weather conditions.

At the end of 200 minutes, the following estimates of key performance states/parameters are made by the filter:

	Mean Value
Ship's speed through the water	19.9405 knots
Propeller rpm	113.9990
Wake fraction	0.1208194
Torque meter bias	22,205.77 ft-lb
Speed log bias	2.25472 knots
	Variance
Ship's speed through the water	$0.082125(\text{knots})^2$
Propeller rpm	$0.011796\ (\text{rpm})^2$
Wake fraction	0.00025767
Torque meter bias	$302.396\ (\text{ft-lb})^2$
Speed log bias	$0.06115\ (\text{knots})^2$

The trajectories of various performance states and parameters over 200 minutes from the basis of the initial estimates, and in the face of the measurement errors and process noise defined above, are shown in Figures 4 through 9, on which are also shown the corresponding true mean values.

The accuracy of estimation of the true mean values by the adaptive filter algorithms is clearly very good, in the face of rather large measurement errors and initial uncertainties and disturbance noise. Although the simulated speed log has a bias of 2.5 knots and a random variance error of 0.25 knots, the estimation and identification algorithms after 200 minutes estimate the speed to within 98.8 percent (0.24 knots) of its true mean value. The quality of estimation of wake fraction by the filter to within 90.2 percent (an error of 0.0108) of its actual mean value after 200 minutes under the conditions considered is also extremely good. It is the capability of the filter to calculate these two key performance parameters of the ship/propulsion/propeller system to these accuracies which provides the means to accomplish online ship performance monitoring in real time aboard ship.

The reason that these estimates do not converge to exactly the true mean values, in fact, may be attributed to the lack of power variations or ship maneuvers in the simulated conditions. The inability of the filter to properly identify and calibrate exactly the torque meter bias (Figure 9) is due to lack of simulated engine maneuver conditions, and is reflected in the errors exhibited in the filter estimates of ship speed through the water, wake fraction, propeller rpm, and, of course, speed log bias, which also suffers from lack of course variations of the ship in the simulation.

4. Conclusions: Implications for Ship and Fleet Management, and Potential for Merchant Ship Implementation

The capability afforded by the system design and configuration of the ship performance monitoring system described have significant implications relating to ship and fleet maintenance and management, in addition to those relating specifically to the potential provided for reduction in direct fuel usage and operating costs as discussed in Section 2. The system provides condition/performance information both to shipboard and shoreside management. The long-term condition/performance trend information provided (Section 3.1) directed to efficient projection of maintenance resources related to hull and propeller condition/performance, charter party ship performance conditions, and determinations/assessments related to design or retrofit issues falls predominantly under the domain of shoreside management. The importance of knowledge of the in-service performance of the ship/machinery/propeller system in relation to propeller design/re-design decisions has been clearly stated in (5, 7); similar knowledge is also required relating to re-engining assessments. These are also shoreside management's functions. The system generates and updates aboard ship the ship performance data base over time in a manner which is computationally efficient, and automatically performs the long-term trend analyses necessary for these management functions.

The system also provides the means for improved shipboard management, and increased decision-making capability aboard ship. These, of course, have been major issues for the merchant shipping industry for some time, e.g., the work done relating to modern shipboard management, e.g., (29), and decentralization and redefinition of authority in shipping company organization, e.g., (30). The specific performance information provided by the online system described which can be directed to an onboard management information system for improved local decision-making aboard ship is that short-term performance data related to speed/power/fuel losses attributable to trim, ballasting and loading practices, choice of steering control parameters, and navigation and weather routing decisions. The selection of the optimum operating point for the ship/machinery/propeller system under various different operational and environmental conditions is also made possible aboard ship by the real-time short-term ship and propulsion system performance data provided by our system (Section 3.1). This is important in the

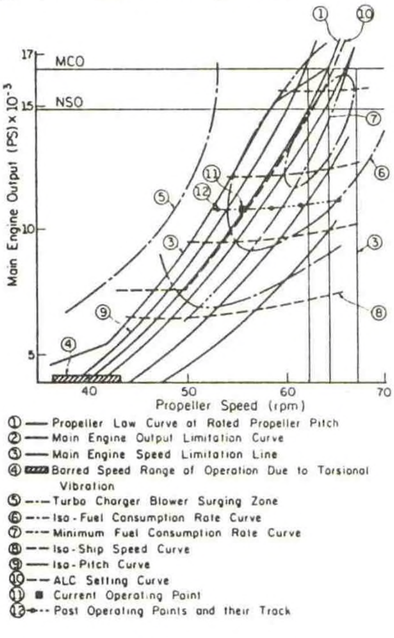


Figure 10 Diesel/CPP Propulsion System: Display and Relationship of System Operating Variables

selection of the correct operating point for a diesel engine/CPP combination, for example, which, as has been shown in (31), is a relatively complex problem, some of the key parameters of which are shown in Figure 10, extracted from (31).

The distributed system architecture of our ship performance monitoring system is further designed to lend itself to local decision-making and control at various points of the ship. Implementation of appropriate human/computer interface design is key to the success of this concept. The remote displays of the real-time ship performance monitoring system in the Chief Engineer's office, Master's office and Chart Room are simple user-friendly, menu-driven displays of the various requested performance data. Hard copy of any particular data presented at remote displays is available, by operator action, at printers directly connected to the terminals. Hard copy and storage of critical short-term and long-term performance data is automatically accomplished by the printer and storage media associated with the central signal processing computer in the ship's office. These outputs are also available for transmission via satellite communications to shoreside facilities.

The technology described represents a significant advance in measurement/monitoring of ship condition/performance capabilities. The system structure has been designed with a growth capability, and is common to all candidate ships, allowing, by the implementation and proper initialization of such a system, the simultaneous condition/performance measurements/analyses of all ships on which it is installed. This overcomes the economic and operational objection to existing techniques, e.g., (2,8-10,21), which require a lengthy processing time for condition/performance analysis and which, by the methods of analyses adopted, are directed to one particular ship at a time. As stated in (25), the condition-based maintenance concept recognizes that the correct time to perform maintenance should be determined by monitoring the condition and performance. Ideally, condition monitoring should be done in real-time, aboard ship to identify and isolate problems as they occur.

The system described has the potential to enable efficient maintenance management and so reduce maintenance costs; further it can provide the achievement of a high operational standard of the ship system. The adaptive filtering algorithms employed, together with the use of redundant sensor measurements (Section 3.2) implicit to the system design, enable sensor failure detection and a reasonable degree of failure diagnosis and fault compensation (32), and provide for a graceful degradation in system performance in the event of sensor failures. Given the modular design of the present microprocessor-based ship performance monitoring system, with its digital communications interface system between measurement sensors and the central signal processing computer-based system, and the implementation of recursive, sequential filter algorithms to process measurement data input to the system in the signal processor, it is straightforward to implement extensions to the system to enhances its capabilities.

The system implementation described is directed to ship performance monitoring. Condition/performance monitoring of the combined engine/ship system is achievable by an extension of the present system to include power plant measurements and relationships in the computer-based system. Accounting for the reasons for variations/degradation in power plant performance in the same manner as the ship performance monitoring system attributes speed/power losses to the various factors affecting its performance, as discussed in the paper, requires formulation of a machinery model within the online computer-based system and input of the necessary key machinery performance measurements.

The need and reasons for monitoring of machinery performance have been well documented, e.g., (1,4,25), as have been the various procedures implemented both to assess the machinery condition, and to attempt to correct deficiencies. The implementation of a rotating machinery condition/performance monitoring capability within the framework of the monitoring system described in the paper is a rather straightforward task. Modern machinery systems will employ a distributed computerized system for surveillance and online control purposes. The necessary basic computer system and related peripheral devices will therefore be already available, as well as most of the sensors, for an online machinery condition/performance monitoring system to be implemented. The combined engine/ship condition monitoring system software could be implemented either within an existing computer, or in an additional microprocessor of the distributed processing system.

We believe that the technology inherent to the performance monitoring system described in this paper has immediate application to merchant shipping goals for more efficient maintenance management to reduce maintenance costs, and for achievement of a higher operational standard of their ships in terms of both availability and performance together with a reduction in operating costs.

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JAPAN'S FIRST DEEP SUBMERGENCE RESCUE VEHICLE

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INTRODUCTION

The launching ceremony of the Japan's first Deep Submergence Rescue Vehicle (DSRV) for Japan Maritime Self Defence Force was took place at the Kobe Works of KAWASAKI HEAVY INDUSTRIES LTD. on October 15, 1984. The keel of the DSRV was laid on December 15, 1982 and its completion is set for March 1985.

FEATURES

The DSRV was developed for the purpose to rescue crew from the distressed submarine.
Once an accident happens the DSRV is transfered to the disaster point by the mother ship.

The DSRV leaves the mother ship through her center well and approaches to the distressed submarine following the guide system of the mother ship, and using its own many sonars, TVs and view ports. When the DSRV gets to the distressed submarine, it mates the transfer skirt on the hatch of the submarine using its trim/heel control system, maneuvering control system, automatic position keeping system and mating system. Then the crew is safely rescued into the DSRV through the hatch from the distressed submarine on the dark sea bottom.

Pressure hull of the DSRV is made of ultra high-tensile strength steel, and the construction is rather complicated one. Three spheres are connected to form a tri-spherical pressure hull in which a control room, a rescue room and a machinery room are arranged, and a hemispherical transfer skirt is attached on the bottom of the rescue room. Consequently very high grade techniques are necessary to build the pressure hull.

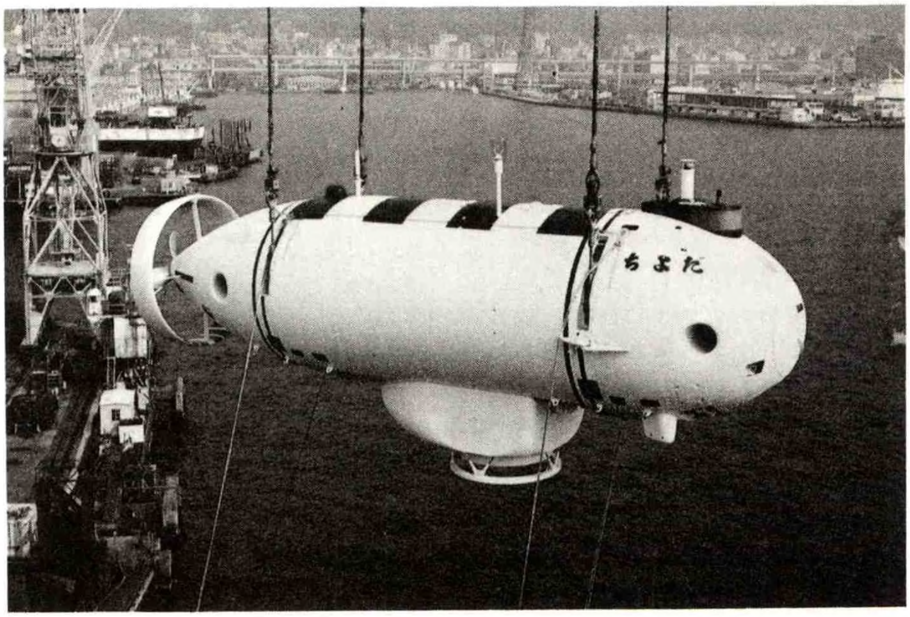
The outer hull is made of titanium alloy, pure titanium and FRP. Equipments are skillfully designed to have a high performance and to lighten the weight. And the equipments are well arranged outside the pressure hull as well as possible so as to utilize buoyancy and space to maximum.

In order to accomplish the urgent mission to save a life, main equipments are installed to be easy for quick maintenance and the reliability has been increased by adapting dual system.

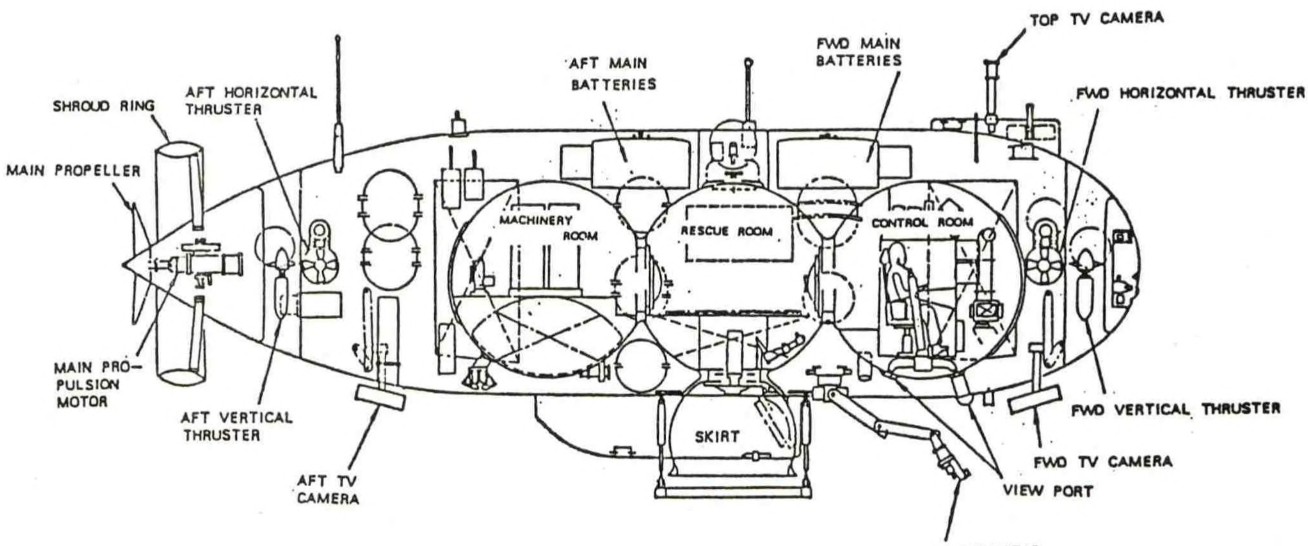
Thus the DSRV is a highly-advanced, complicated submergence vehicle, and very high-grade technologies are required for its construction. These technologies are believed to become a great help in building various submergence vehicles and under-the-sea equipments which are necessary for furthering ocean development, researching deep sea mineral resources such as manganese nodules and hydrothermal deposits or researching ocean trench for earthquake prediction.

PRINCIPAL PARTICULARS

Length o. a.	: 12.4m
Breadth	: 3.2m
Depth	: 4.3m
Displacement	: 40 t
Speed	: 4 knots
Pilot	: 2 men
Propulsion system	: Main forward propulsion is provided by a stern mounted reversible propeller, with an AC motor, oil-filled and pressure compensated. A shroud ring around the propeller can be tilted to provide pitch and yaw motion, 4 ducted thrusters, 2 vertical and 2 horizontal, each is driven by an AC motor, oil filled and pressure compensated.
Pressure hull	: Three spheres composed of ultra high-tensile strength steel.
Outer hull	: Titanium alloy and pure titanium framework FRP shell
Viewing port	: 2 ports made of methacrylic resin
TV camera	: 5 sets
Manipulator	: One, hydraulically-powered, 7 degrees-of-freedom



DEEP SUBMERGENCE RESCUE VEHICLE
GENERAL ARRANGEMENT



ON THE "NATSUSHIMA"'S LAUNCH AND RETRIEVAL SYSTEM

FOR 2000^{m} DEEP SUBMERGENCE RESEARCH VEHICLE

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ABSTRACT

Japan Marine Science and Technology Center (JAMSTEC) completed in October, 1981, the 2000 m Deep Submergence Research Vehicle "SHINKAI 2000" and the support ship "NATSUSHIMA" that carries this research vehicle on board to the destination sea area, carries out the sea surface investigation and supports the submersible during its diving operation. In this project Kawasaki Heavy Industries, Ltd. took charge of the coordination of the total system including the support ship and the research vehicle, and the construction of the support ship.

The launch and retrieval operation of the submersible in waves is very difficult. This is because of the point that, due to the substantial difference of the hull dimensions between the submersible and the support ship, their oscillation characteristics in waves differ from each other and the complex and large relative oscillation appears in irregular waves of the practical sea surface. For the support ship "NATSUSHIMA" this problem has been solved through the adoption of the shock decreasing method by using flexible nylon lift ropes, as well as the adoption of the self mating type lift devices in the stern A-frame crane system when retrieving the submersible from the wavy sea surface.

After about one year of the training, "NATSUSHIMA" is now engaged in the practical investigation work. Till now she has carried out 141 launch and retrieval operations satisfactorily. This paper outlines the launch and retrieval system of "NATSUSHIMA".

REQUIREMENTS

The principal particulars of the support ship and the research vehicle are shown in Table 1.

(1) SUPPORT SHIP

The general arrangement is shown in Fig. 1, and the external apperance in Photo 1.
In consideration of her good maneuverability in low speed condition during launching and retrieving the submersible, she is planned to be a twin-screw vessel with a bow thruster and controllable pitch propellers. She also adopts a wider breadth hull shape compared with conventional vessels in order to obtain the wide deck area as much as possible for handling the submersible on the deck.

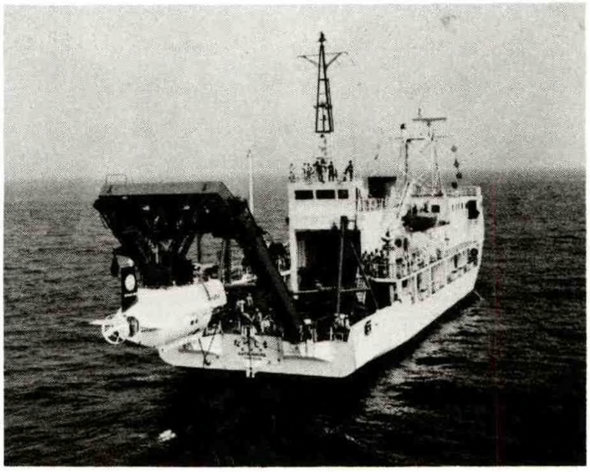

Photo 1. "NATSUSHIMA" RETRIEVING "SHINKAI 2000"

(2) SUBMERSIBLE

The outer hull is made of FRP and its hull shape is fat and short (L/B 3).
The submersible has two lifting points at fore side and aft side of the back and their lifting loads are abt. 13.5 ton and abt. 11 ton.

(3) SEA STATE CONDITIONS

The sea state conditions for the sumbersible operation including its launch and retrieval are determined as shown below. These are adopted, trying to obtain a reasonable working rate under the sea weather statistics around Japan.

(a) Normal launch and retrieval operation ... Up to Sea State 3.
 1/3 significant wave height : 1.25 m
 mean wave period : 5.5 sec.

(b) Emergency retrieval operation in case of sudden weather change during submergence operation ... Even at Sea State 4
 1/3 significant wave height : 2.5 m
 mean wave period : 6.0 sec.

PRINCIPAL COMPONENTS

The A-frame crane and hoisting winches for

launching and retrieving "SHINKAI 2000" are equipped at the after upper deck of "NATSUSHIMA" as in Photo 2 and illustrated in Fig. 2.
The specifications of the launching and retrieving system are shown in Table 2, and its principal components in Fig. 2. The system is composed of the A-frame crane with a pendant frame, 2 nylon lifting ropes, 2 ram tensioners, 2 hoisting winches, 2self-mating type lift devices, and a trolley.

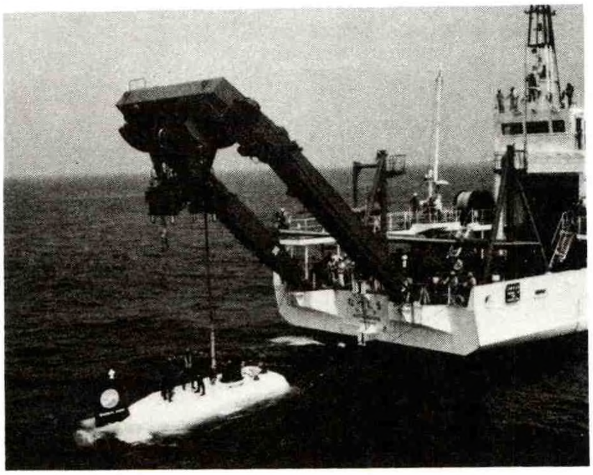

Photo 2. "NATSUSHIMA" HANDLING "SHINKAI 2000"

Table 1 Principal Particulars of Support Ship and Submersible

Support Ship		Submersible	
Length overall	: abt. 67 m	Length overall	: abt. 9.3 m
Breadth	: abt. 13 m	Breadth	: abt. 3.0 m
Depth	: abt. 6.3 m	Depth	: abt. 2.9 m
Designed draft	: abt. 3.55 m	Draft	: abt. 2.5 m
Desplacement	: abt. 1,700ton	Weight in air	: abt. 24.5 ton
Propeller	: CPP x 2 set	Displaced lines volume	: abt. 44.5 ton
Rudder	: 2		
Bow thruster	: 1 set		

PROCEDURE OF RETRIEVAL OPERATION

The procedure to retrieve the submersible is shown in the following (see Fig. 2). For its launching, reverse the retrieving procedure in almost the same sequence.

(a) The swimmers on a working boat approach to the submersible coming up on the surface and fit it with a steady line.
(b) The support ship starts in a slow speed (1-2 kts), taking in the steady line with a capstan, and brings the submersible near herself.
(c) The swimmers fit the guide lines to the lift pieces of the submersible and the automatic tension is applied to these guide lines
(d) The submersible is pulled further just under the A-frame.
(e) The hoist lines are let out, lowering the fore and aft lift devices along the respective guide lines to make the female devices fit automatically by their own weight to their counterpart male pieces of the submersible.

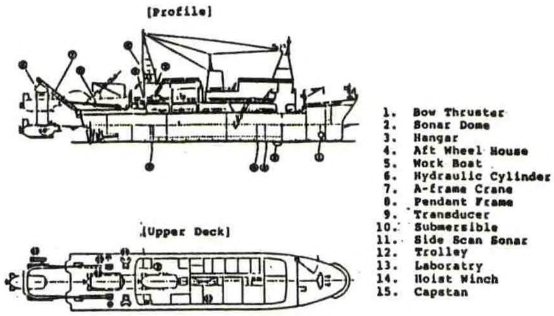

Fig. 1 ARRANGEMENT OF "NATSUSHIMA"

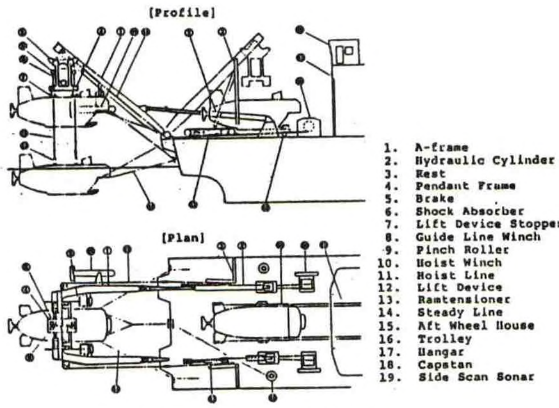

Fig. 2 LAUNCH AND RETRIEVAL SYSTEM

Table 2 Specification of A-Frame Crane and Trolley

Item	Q'ty	Specification
A-Frame Crane	1 set	Capacity : Max. 40 ton Lift : 6.5 m Out reach: 10.2 m
Pivotting Equipment	2 sets	Type : Hydraulic Cylinder
Hoist Line	2 sets	Type : ø85mm Nylon Rope (Double Braid)
Hoist Winch	2 sets	Type : Hydraulic Winch Capacity : 20tonx18m/min./set
Ram Tensioner	2 sets	Type : Hydraulic Ram Cylinder Tension Range : 2 to 10 ton/set Adjusting stroke: 4 m
Lift Device	2 sets	Type : Self-Mating Capacity : 20 ton/set
Guide Line	2 sets	Type : ø6 mm Wire Rope (Auto Tension)
Trolley	1 set	Type : Hydraulic Winch (Wire-Guided) Capacity : 25 ton x 6 m/min

(f) The swimmers confirm that the lift devices have fit securely.
(g) The hoist lines are let in to lift up the submersible out of the water surface.
(h) Having lifted the submersible, the load is transfered to the pendant frame, and then the A-frame is swung in and is returned to its stowing position.
(i) The submersible is lowered on to the trolley and tied fast to it. The lift devices and guide lines are removed.
(i) The hatch of the submersible is opened and the crew leaves the submersible.
(k) The submersible is washed with fresh water and the trolley is untied and pulled into the hangar.

A series of the retrieval operation is finished.

OUTLINE OF THE SYSTEM

(1) LIFTING METHOD

Usually, an A-frame crane system has one lifting point and one lifting rope method, but we have adopted two lifting points and two lifting ropes due to the following three reasons. Fitst, the weight of "SHINKAI 2000" was too great (abt. 24.5 tons). Secondly, the pitching and yawing motion could be decreased by using two lifting ropes. Thirdly, we have succeeded in developing a self-mating device to lift the submersible safely.

But unfortuately, we had no data to design the A-frame crane system in the areas of towing load, lifting load, and the relative motion during the recovery operation in waves. Therefore, we made the experiment of this system using a 1/10 scale model in the sea-keeping and maneuvering tank of the University of Tokyo. Through the result of this test and analyses we confirmed that the stern mounted A-frame crane with two lifting ropes was suitable for "SHINKAI 2000" launching and recovery system, and that this system could be operated even in Sea State 4. We have adopted this tank test result to the detail design of the launching/retrieving equipments, and it is shown in Table 3 as an example.

The A-frame is of the gate type with its upper beam a little narrower. Its lower ends are fitted on the extended stern end of the upper deck with hinges.
The strength of the A-frame is so designed that the maximum hoist load is 20 tons per hoist line and 40 tons in total in consideration of the dynamic load gained from the model basin test.

The pendant frame of the swing type is hung from the upper section of the A-frame. Two hoist lines are led at the outsides of both arms, enter into the middle section at the sheaves fitted at both shoulders, are separated fore and aft at the sheaves fitted at the upper section of the pendant frame, and run downward through holes provided at the lower section of the frame. The brakes for the pendant frame are provided at the inside of the upper sections of both arms.

(2) HOIST LINES

The hoist lines installed in the A-frame crane had to decrease the shock load and be suitable for smooth recovery.
Therefore, we selected nylon fiber rope for this system. However, we had no data on the large size Tetoron-Nylon double-braided rope concerning strength, spring constant, and other properties.
Thus, we designed an experiment of this rope to obtain its characteristics, and inverstigated the spring constant by using the simulated model rope which was the same length and which was installed in the same sheave arrangement as in the actual A-frame crane system.

Through this experiment, the strength, spring constant in the dynamic conditions, and other properties of the Tetoron-Nylon double-braided rope became clear. In this manner we confirmed that the rope was suitable for smooth recovery of the submersible, and decided the diameter of rope was 85ø (breaking strength: 165 tons).

The line having the rupture strength safety factor of 7 in the wet condition against the load of 20 tons considering the dynamic load is adopted.

Table 3 Characteristics Test Results in Waves

Item	Unit	Significant value (single amplitude) at Sea State 4				note 1)
		During towing		During lifting-up		Design Standard Value at =180°
		With sea anchor	Without sea anchor	With sea anchor	Without sea anchor	
Submersible motion						
Roll angle*	deg	4.3	3.8	15	16	16°
Pitch angle	deg	8.1	8.9	7.4	14	14°
Yaw angle*	deg	21	26	19	30	30°
Surge	m	0.9	1.1	1.5	2.2	2.2 m
Sway*	m	0.9	1.1	1.8	2.0	2.0 m
Heave	m	1.1	1.1	2.1	2.1	2.1 m
Surge acceleration	g	0.14	0.13	0.18	0.32	0.32 g
Sway acceleration*	g	0.04	0.05	0.26	0.21	0.26 g
Heave acceleration	g	0.13	0.12	0.24	0.31	0.31 g
Relative motion between support ship & submersible						
Surge relative motion	m	0.7	1.3	1.1	2.1	2.1 m
Sway relative motion*	m	0.9	1.1	1.8	2.0	2.0 m
Heavy relative motion	m	3.1	3.1	-	-	3.1 m
Lifting-up load — Fore rope		-	-	1.32	1.41	1.41
[Max. lifting-up load / Weight in air] Aft rope		-	-	1.26	1.26	
Towing load	ton	3.80	2.73	-	-	3.8ton

Note 1) Shall be the largest value at Sea State 4.

Note 2) (*) It is difficult to estimate the transverse motions in irregular waves, and the values shown in the table are only for reference.

The ram tensioners are arranged between the hoisting winches and the A-frame, follow the relative oscillation between the submersible and the support ship.

(3) MATING METHOD

The self-mating device provided at the end of the lifting rope was a part of the launching and retrieval system installed in the support ship.
This mating device was designed to slide down along the guide rope and mates with the male device installed on the top of the submersible. Hence, the swimmers can work easily and safely on the submersible.

However, since there was no data on this type of device, we have manufactured it in full-scale and carried out an experiment concerning its mating and handling performance using the simulated model which was composed of a launching and retrieval system. The simulated model was separately oscillated by the hydraulic cylinder. As a result of this test, we obtained data concerning the shape of the male device, suitable weight of the self-mating device and its handling method. Thus, we confirmed that this device was useful for the actual launching and retrieval system.

The main portion of the lift device is the welding construction of 6Al-4V-Ti for weight reduction and anti-corrosion. Each device weights about 55 kg. When the male type hoist piece of the submersible is come up into the hoisting device, it is engaged and checked with six claws arranged on the circumference. The section of the lift device is shown in Fig. 3.

The guide lines are handy stainless wire ropes of 6 mm in diameter. These run from the auto-tension winches on the pendant frame, and pass through the lift device stopper and the line end hooks are connected to the pins of the submersible lift pieces. Even when the submersible oscillates in wave, the winch can keep the guide line without slacking, and make the lift devices fall by their own weight along the guide lines and engage with the lift pieces.

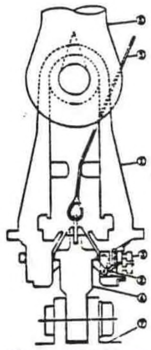

Fig. 3 LIFT DEVICE

(4) TROLLEY AND TROLLEY WINCH

The trolley and its winch are means of carrying "SHINKAI 2000" at a high degree of operating safety and assuredness between the launching/retrieval place at the aft upper deck and the maintenance/servicing place in the hangar.

They have also characteristically the functions of lashing "SHINKAI 2000" on the trolley, securing the trolley and submersible to the hull of "NATSUSHIMA" at the maintenance/servicing place and servicing as a work stand for the maintenance and servicing jobs. They comprise the trolley, trolley rails, winch, securing and lashing gears.

MANUFACTURING AND TEST

Having fully confirmed the performances and safety of various components through the development research, the final detail designing was carried out. Manufacture of the components were charged by their respective expert manufactures having sufficient experiences and carried out under the strict quality control.

The individual performance tests of the components in shop, the load tests after assembling on board, the operation test and sea trials were carried out. These tests were carried out under the cargo handling equipment regulation of Nippon Kaiji Kyokai and the inspections were carried out by its surveyor.

The operation tests in the mooring condition and at sea were carried out with a simulated submersible. This simulated submersible was manufactured with its external form, dimensions, weight, center of gravity, center of buoyancey, etc. nearly equal to those of the actual submersible. In addition, after the operation training had been carried out fully in the actual sea surface with the simulated submersible mentioned above, the sea trials were carried out with the actual submersible. More than 30 sea trials, including training, were carried out and all were satisfactory.

POSTSCRIPT

The 2000 m Deep Submergence Research Vehicle System was completed at the end of October, 1981, and after approximately one year of the training the system is now engaged in the practical investigation. Till now 141 launch and retrieval operation have been carried out satisfactorily.

Among the above operations the sea weather of 4 or higher in Beaufort wind scale were recorded in as many as 34 times, and even then the launch and retrieval operations could be carried out safely without any trouble. And the time length required for each operation was about 30 minutes on the average. So we are convinced that the System will also operate satisfactorily in future.

The authors wish to acknowledge the valuable advices given by the members of Japan Marine Science and Tecknology Center and the excellent operations carried out and the precious experience data given by those who operate the system.

TOWED UNMANNED SUBMERSIBLE (TUMS) SYSTEM

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ABSTRACT

A unique unmanned deep-sea submersible capable of operation in depths beyond the reach of conventional diving systems or ship sensors has been built by Sperry for the Royal Navy. The Sperry Towed Unmanned Submersible (TUMS) will perform a wide range of search, identification, classification, and recovery operations at full ocean depths using optic, acoustic, and magentic sensors and a manipulator arm.

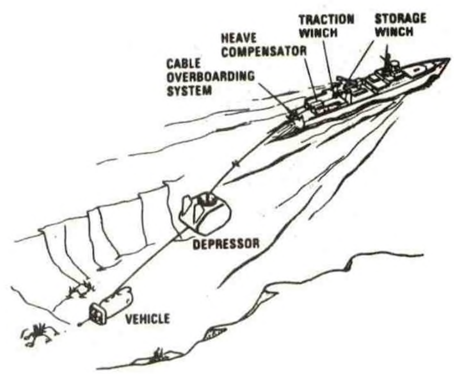
INTRODUCTION

The United Kingdom Ministry of Defence has launched H. M. S. Challenger, a Seabed Operations Vessel, whose missions involve seabed searching and working at full ocean depths. These functions are achieved by use of onboard saturation diving facilities and an unmanned underwater vehicle system. This vehicle system, supplied by Sperry to the Royal Navy, is called the TUMS (Towed Unmanned Submersible) system. The shipboard saturation diving facilities are limited to use at only shallow depths. The TUMS is required to obtain the searching and working functions beyond these depths, to 90% of full ocean depth.

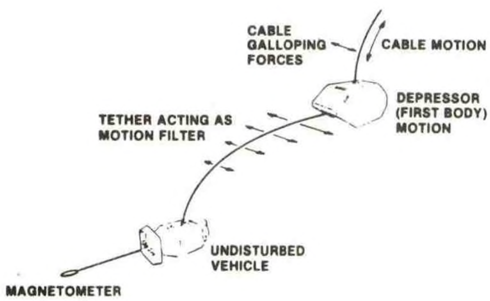
The TUMS contract was awarded, in a competitive procurement, to a team comprising two units of Sperry Corporation's Sperry Division: Gyroscope, U.K. in Bracknell (which is now Bracknell Division of the Dynamics Group of British Aerospace Ltd.) and Systems Management Group in Great Neck, New York. This teaming combined Gyroscope, U. K.'s experience supplying a wide range of equipments to the Royal Navy with Systems Management's 20 years of experience in underwater and deep submersible programs. As prime contractor, Gyroscope, U. K. assumed responsibility for overall program management, ship interfaces, system installation, harbor and sea trials, documentation and support. Systems Management was responsible for the development and test of the entire system, including procurement and supply of all equipments. Program authorization for the initial phase was received in May 1979; the development phase started in May 1980 and was completed in August 1982. Shipboard installation was completed in August 1983; preparations are being completed for ship trials in late 1984 continuing through 1985.

DESCRIPTION OF TUMS SYSTEM

A two-body underwater configuration, as illustrated in Figure 1, was selected for TUMS. The depressor is a heavy body which functions as a garage for the twelve-foot long instrumented vehicle. An advantage of this arrangement is that the depressor isolates the vehicle from ship's motion transmitted down the tow cable and from induced tow cable motions (see Figure 2).

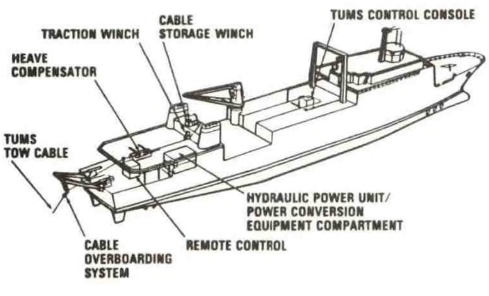


Unmanned Submersible System
Figure 1

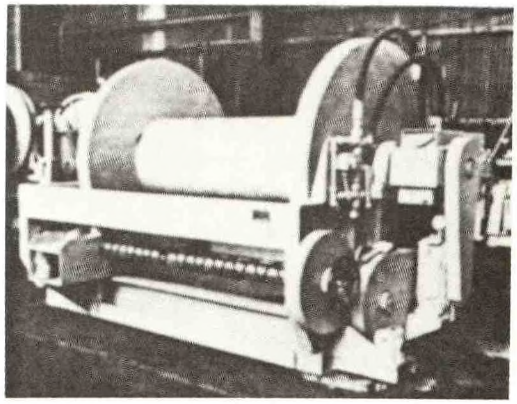


TUMS Tow Configuration
Figure 2

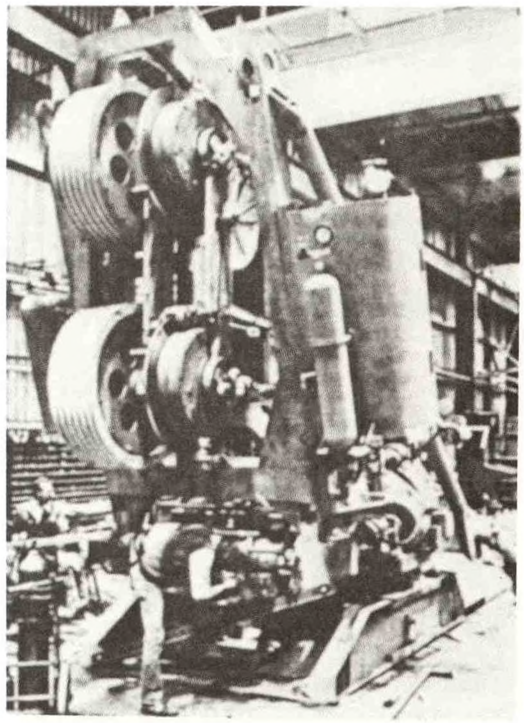
The vehicle is connected to the depressor by a neutrally-buoyant tether cable. A six-mile tow cable weighing 28,000 pounds couples the depressor with the ship. A single coaxial electrical cable core carries power of 30kVA at 3000 volts to the underwater bodies and carries signals in both directions. Mechanical strength is achieved by a steel armor sheath over the electrical core. The tow cable is wound on a storage winch located on the ship, as shown in Figure 3. Figure 4 is a photograph of the storage winch. The cable is hauled in and out by a traction winch (shown in Figure 5). A cable overboarding sheave hauls and supports the underwater bodies during launching and recovery. A heave compensator (shown in Figure 6) is provided to control cable motion which would otherwise induce high tensile loads in the cable through the ship and sea interaction. Two operator control stations are provided in the Ship's Operations Room. Remote ancillary electrical and hydraulic power equipments are included as part of the TUMS system.



Layout of Seabed Operations Vessel (S. O. V.)
Figure 3



Cable Storage Winch
Figure 4



Traction Winch
Figure 5

INSTRUMENTED VEHICLE

The instrumented vehicle (see Figure 7 and 8) is approximately neutrally buoyant and contains the sensor suite of the system. (The sensors are illustrated in Figure 9.) It can be deployed up to 1000 feet from the depressor body and is maneuverable using its thrusters in five axes -- surge, sway, heave, yaw, and pitch.

In addition to shelf-powered operation, the vehicle can be towed by the ship at speeds up to two knots. A vehicle autopilot enables automatic flight at constant heading and altitude. When searching, the vehicle employs side-looking and forward-looking sonars, low light level television and stereoscope photographic camera systems, and a magnetometer which trails behind the vehicle to isolate the magnetometer from magnetic fields. A six-function manipulator arm on the vehicle is used for working on objects near the seabed.

OPERATION OF TUMS

The instrumented vehicle is garaged in the depressor body before launching. The two bodies are launched as one unit from the aft of the ship under the control of an operator using a special console. They are lowered using the overboarding sheave through the air/water interface. Once underwater, the instrumented vehicle is separated from the depressor body, and control reverts to the TUMS control consoles in the Ship's Operations Room.

Two operator stations are provided for TUMS control as shown in Figure 10. A pilot at one operator station flies the instrumented vehicle using joy sticks, and monitors vehicle position computed by a special processor provided within the console. The Sperry-designed processor (shown in Figure 11) uses data telemetered from the vehicle, which acoustically measures distances to various bottom transponders. The Pilot also monitors sonar and television displays to detect obstacles in the vehicle's path, and to aid in search and work operations. An Observer at the other operator station monitors sensor displays during vehicle search operations. Either the Pilot or the Observer can control the manipulator arm during work operations.

Upon completion of an underwater mission, the instrumented vehicle is returned to the depressor body prior to recovery. Before lifting out of the water, control is transferred to the aft console. The bodies are lifted through the water/air interface, and securely latched by the cable overboarding sheave. Figure 12 shows the mated depressor and vehicle latched on the H.M.S. Challenger during installation testing. The bodies are then inboarded by the "M-Frame" shown in the figure and secured on the ship's deck.

The TUMS program required high technology and sophisticated management skills. The TUMS engineers on both sides of the Atlantic have combined their skills and resources to achieve the program's success and are working closely together to develop U. K. deep submergence technology for the future.

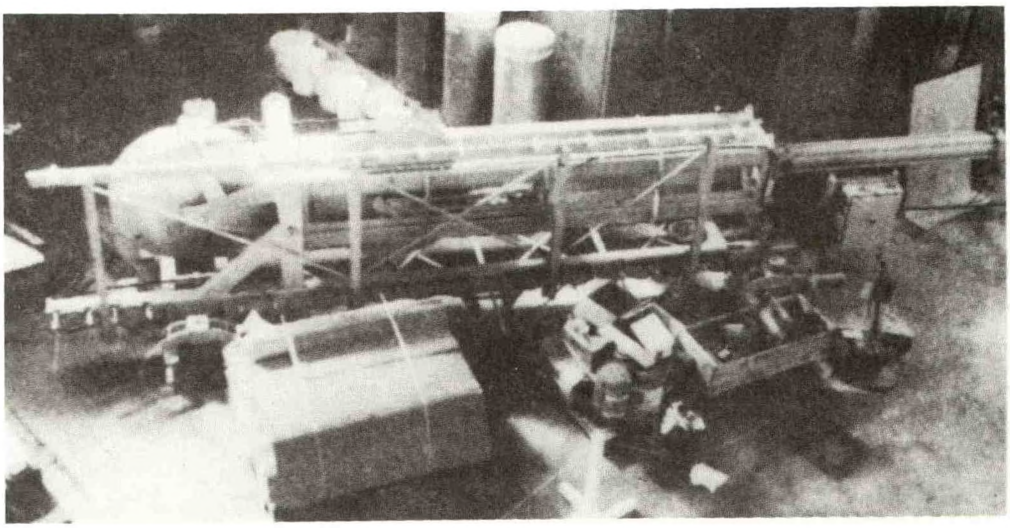


Figure 6

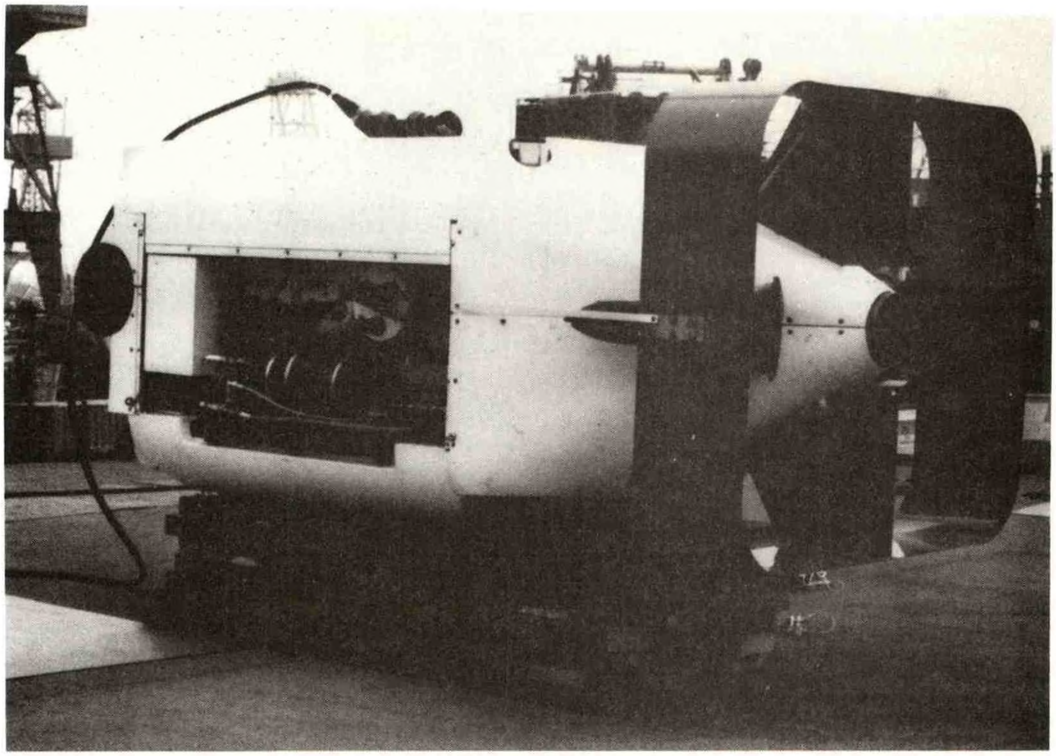


Figure 7

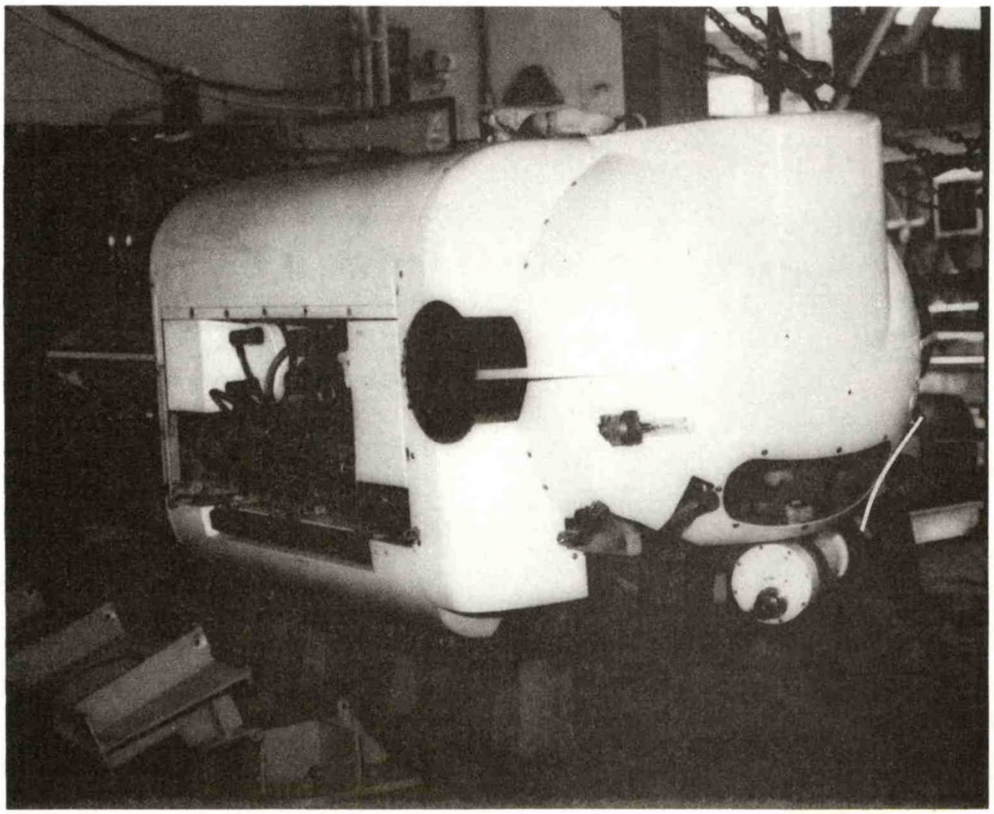
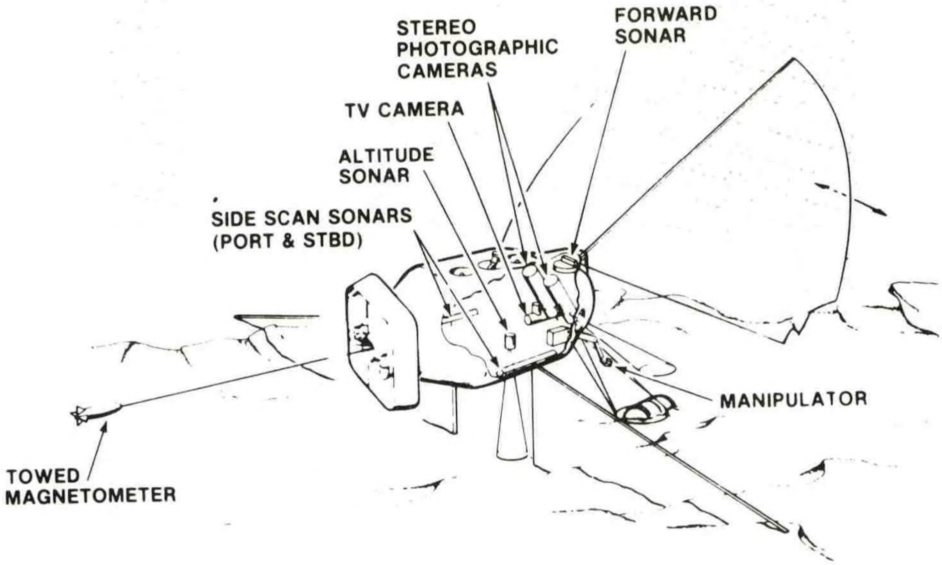


Figure 8



Major Vehicle Sensors
Figure 9

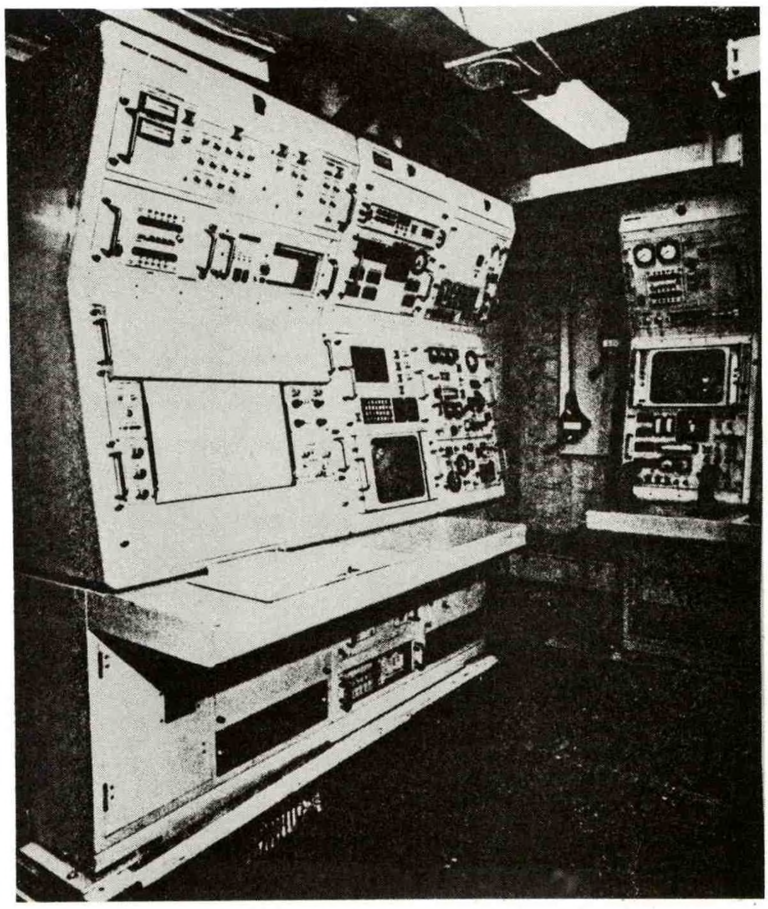


Figure 10

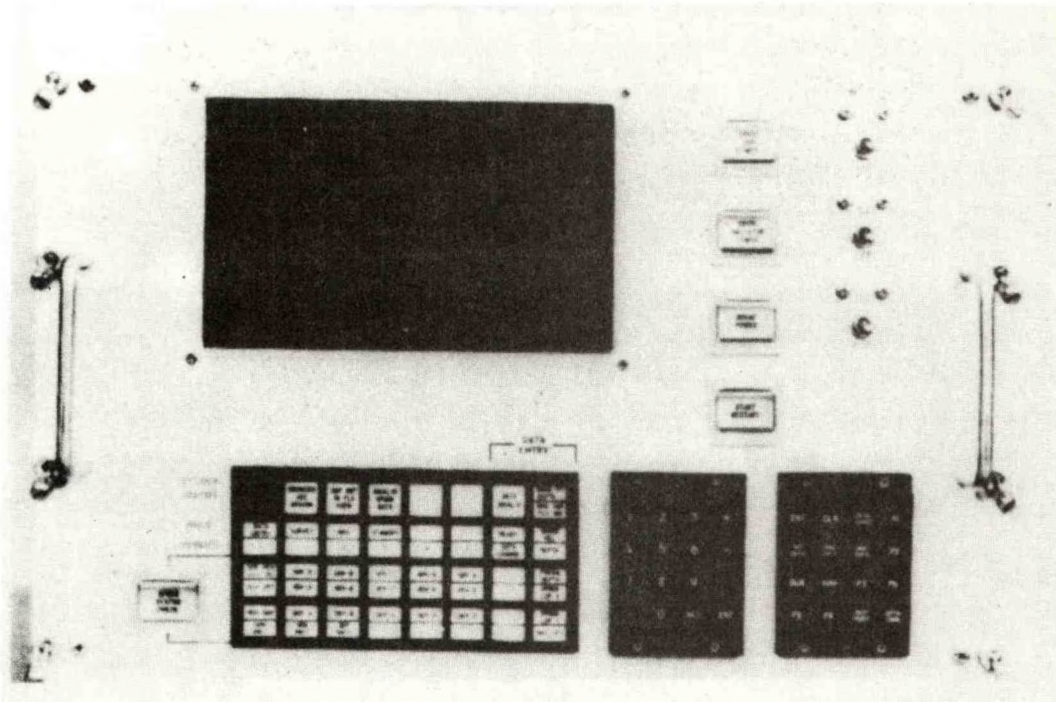


Figure 11

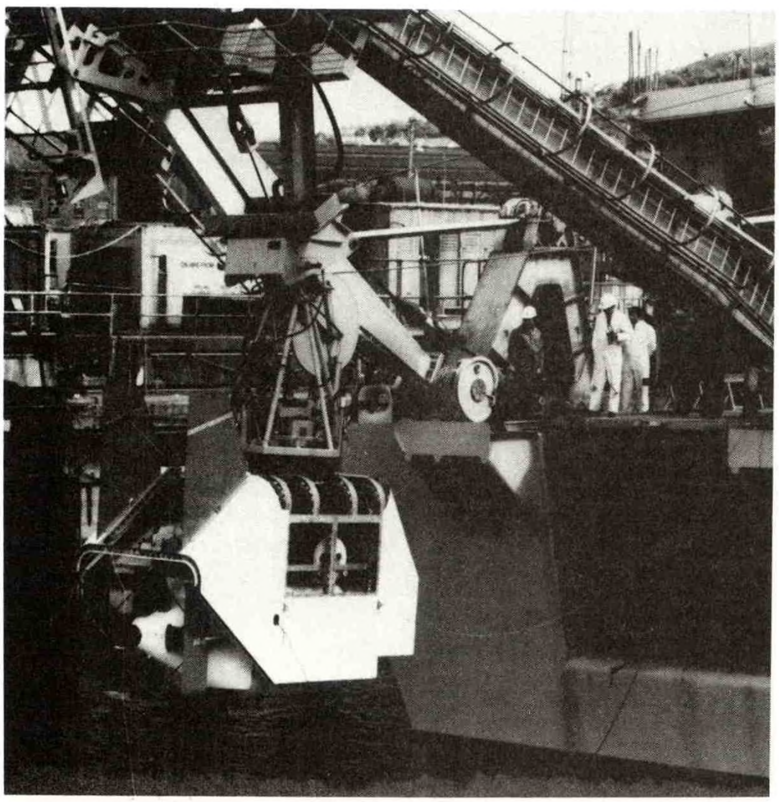


Figure 12

DESIGN OF ROV " DOLPHIN-3K "

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ABSTRACT

Dolphin-3K is a Remotely Operated Vehicle (ROV) developing in JAMSTEC. It is a largest and deepest ROV (3300 m of water) ever planned in Japan. The vehicle shall be completed in early 1987. The design of Dolphin-3K was started in 1982 and completed in 1983 and now under construction. The contractor for the system is Mitsui Engineering and Shipbuilding Co.,Ltd.(MES). The hydrodynamic test of 1/4 scale model and tests of components such as cable and buoyant materials were completed. The design of Dolphin-3K and static and dynamic consumptions of the suspension system are reported.

1.INTRODUCTION

Since 1978, 2 types of small ROVs were developed in JAMSTEC. The smallest one, JTY-1, for 200 m of water, was commercialized as DLT-300 by Q.I.Co.,Ltd.,Tokyo and 8 vehicles were delivered. The other vehicle HORNET-500, for 500 m of water, utilizes very thin fiber optic cable (o.d.7 mm) and successively tested up to 300 m of water in 1984, but lost by accident. HORNET-500-2 is under construction.

Dolphin-3K is planning to use for pre-site survey of the manned submersible "Shinkai 2000" and for scientific reconnaissance survey around Japan.

Dolphin-3K is planning to develope by 3 years schedule as follows.

a. 1982(FY): Conceptual design and test of prototype cable. Static hydrodynamic test of 1/4 scale model.

b. 1983(FY): Detail design. Hydrodynamic test of the revised scale model.

c. 1984(FY): Construction of the vehicle hydraulic system, a frame made of titanium, manipulator and grabber, pan and tilt units and TVs. Tests of new buoyant materials.

d. 1985(FY): Construction of the control console and the vehicle control software.

e. 1986(FY): Construction of the deck handling system, telemetry system, cable and acoustic navigation system (SSBL). Sea going test.

2. DESIGN OF DOLPHIN-3K

2.1. The System Operational Requirement

The vehicle is planned to use for pre-site survey of the manned submersible "Shinkai 2000" and scientific reconnaissance survey. The task required the above mentioned surveys are as follows.

- Pre-site survey of the "Shinkai 2000".
- After dive support survey of the "Shinkai 2000", depth up to 3300 m.
- Broad area scientific survey by tow mode.
- Installation and retreaval of scientific tools such as seismograph, tilt meter, current meter and transponder etc.
- Survey of dangerous areas such as very steep slopes, valley walls, submarine volcanoues and high current areas.
- Retreaval of lost object light than 2 tons with special tools.
- Entangling and cutting of ropes and wires.

2.2 Operational Conditions

Sea state:	under 4
Currents:	Surface 4 knots, decrease 1 knot at 500 m of water, 500 to 3300 m 1 knot.
Support Ships:	Natsushima, Kaiyo

2.3. Specifications of Dolphin-3K

The specifications of Dolphin-3K were determined by the detail design, total sytem of the vehicle is shown in Fig. 1.

Main specifications of Dolphin-3K are as follows.

1). Vehicle

(1) Dimensions: 285(L) x 194(W) x 190(H) in cm

(2) Weight in air: 3400 kg,in water -10 kg

(3) Operating depth: 3300 m

(4) Payload: Max. 150 kg

(5) Speed: Forward 3 knots, reverse 2 knots Port/stbd 1.5 knots, Up/down 1 knot. Rotation 30°/sec.

(6) Propulsion: A hydraulic pump provides power to 6 thrusters
2 x 15 HP each For/rev thrusters
2 x 9.5HP each Port/stbd thrusters
2 x 9 HP each Up/down thrusters

(7) Power unit: AC motor (3 phase 40 KW) and hydraulic piston pump

(8) Instrumentation: Color TV camera (broadcast grade) with pan and tilt, 5 x 500 W and 1 x 250 W light, two

manipulators, 1 x 7 d.f. master-slave, 1 x 5 d.f. rate control grabber, 2 x cutters, CTDV, still camera and strobe

(9) Navigation: Obstacle avoidance sonar, direction finding sonar, depth meter, fluxgate gyro, rate gyro, altimeter, current meter and trim sensor

2). Shipboard components

(1) Control/navigation Van
(2) Power generating equipments
(3) Deck handling system: Traction winch, cable storage winch, rum tensioner, zimbal shieve, servo hydraulic power unit
(4) Cable: 30 mm o.d. fiber optic electro-mechanical cable. L 5000 m. Breaking strength 16.5 tons
(5) Acoustic navigation system: Super short base line acoustic navigation
(6) Weight: 2.2 tons (in air), 2 tons (in water). This weight is used for tow/self-propelled mode operation

2.4. Main Characteristics of Dolphin-3K

Among the specifications mentioned above, the main characteristics of Dolphin-3K is as follows.

1). Dolphin-3K utilizes fiber optic electro-mechanical cable of proven performance and high speed PCM transmission system (400 MBPS) via one optical fiber of 5000 m length.
The transmission system is able to transmit 4 TV channels, 2 acoustic channels and 2 up/down data and control signals using 2 wave length division multiplex optical transmission together with high speed PCM mentioned above. The cable consists of 4 optical fibers and 7 power conductors and only one optical fiber is used, so there remains a great amounts of transmission capability.

2). Viewing system of Dolphin-3K utilizes 4 TV cameras, they are 1 news gathering grade color TV with remote zoom and focus, 1 stereo b/w LLL TV with remote focus and 1 b/w after TV. SIT and small color TVs shall be installed later. The main specifications of TVs are shown below.

	Color TV	b/w TV
Focus	6.3 to 21.9 mm	5.5 mm
Viewing angle		
Horizontal	53°(wide),16°(tele)	79°
Vertical	42°(wide),12°(tele)	63°
Resolution	400 lines	630 lines
Sensitivity	2000 lux	0.3 lux
Weight in air	23 kg	11.5 kg
Dimensions	ϕ186 x 635(L) mm	ϕ180x435(L)

Wide angle b/w TVs are designed to provide medium distance wide angle view and stereoscopic view. Color TV is designed to provide high resolution, high quality color pictures of broadcast grade.

3). Dolphin-3K is capable of two mode of operations, one is self propelled mode fine scale survey and the other is tow/self-propelled mode survey of broad area with simple attachable weight.

4). Dolphin-3K has 2 manipulators. They are 7 d.f. spacially correspondent manipulator and 5 d.f. rate control grabber. 4th to 7th arms of the manipulator are bilaterally controlled. The specifications of the manipulator and grabber are as follows.

	Manipulator	Grabber
Normal handling capacity	20 kg	20kg
Maximum lifting capacity	40 kg	40kg
Total length of the arm	1.5 m	1.5 m
Weight in air	100 kg	80kg

Both hands are normally stowed inside of the framework, they shall be stowed automatically by microcomputer control. Those arms are designed to perform variety of tasks. Main tasks shall be sampling of bottom rocks, sediments, creatures, cutting or entangling of ropes and wires and retreaval of object lighter than 2 tons with special tools.

3. HYDRODYNAMIC TESTS AND BEHAVIORS OF THE SUSPENSION SYSTEMS

Hydrodynamic tests of 1/4 scale model were carried out at Akishima Laboratory of MES in 1982 and 1983. The results were used for static and dynamic considerations of the suspension.
Main parameters except for hydrodymanic parameters are given below.

	Vehicle	Weight	Cable
Length			5000m
Diameters	4.54m	1.12m	0.03m
Weight	3500kg	2000kg	0.191kg/m
Drag coefficients	For/rev 0.7	1.0	1.2
	Port/stbd 1.0		0.01
	Up 0.8		
	Down 1.6		

As static considerations, cable catenary and foot print analysis of various conditions were carried out.
Fig.2 shows a cable catenary of the maximum current velocity. Fig.3 shows a foot print of the tow/self-propelled mode operation, tow speed is 1.6 and 1.7 knots, depth 3300 m.
The cable dynamics were calculated by the Lumped Mass Method and the results were used for dynamic considerations of suspension.
Three cases were calculated, they are:

1). ROV is fixed.
2). ROV is propelled.
3). Tow/self-propelled mode with weight.

They are shown in Table 1.

Static and dynamic considerations reveals that the vehicle has large stability and wide foot print and the maximum dynamic tension of the cable allows tow mode operation using 2 tons of weight or recovery of a object weight about 2 tons in the case of self-propelled mode of operation.

4. CONCLUDING REMARKS

The design and tests about main subsystems of Dolphin-3K were completed and the total system shall be completed and tested in early 1987.

The operation of Dolphin-3K shall play a important role concerning more sophisticated utilization and safety of the manned submersible " Shinkai 2000 " and scientific reconnaissance survey aroud Japan.

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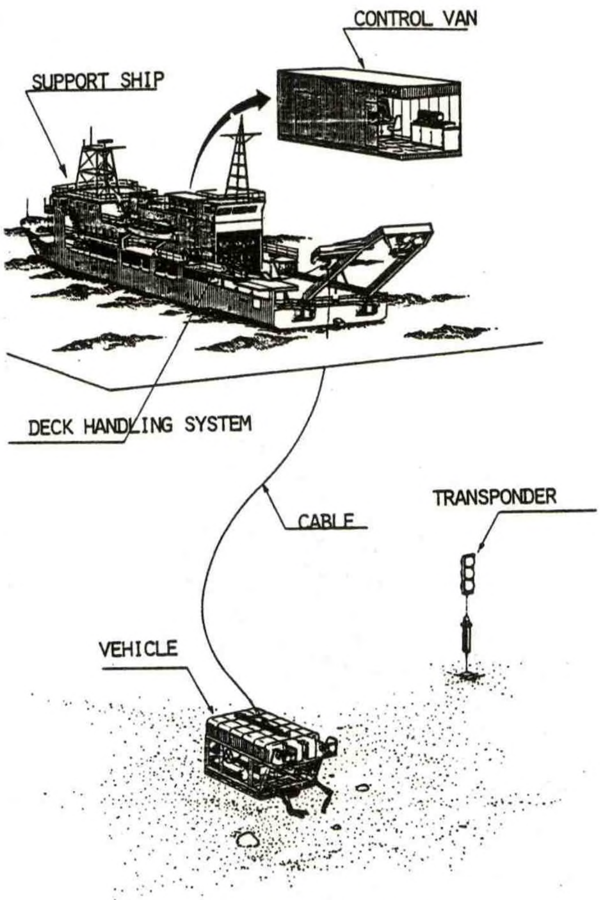

Fig.1. Dolphin-3K System

Ship's Motion T=6,Amp 2.5m		Maximum Tension		Minimum Tension		Tow/self-propelled
		Pitch	Heave	Pitch	Heave	Pitch
Static Tension	Ship side ROV side	1019 kg 312 kg	1019 kg 312 kg	980 kg 257 kg	980 kg 257 kg	2614 kg 51.3 kg
Ship side Dynamic tension	Max. Min.	1900 kg 495 kg	1380 kg 980 kg	1900 kg 490 kg	1370 kg 950 kg	3450 kg 2220 kg
ROV side dynamic tension (ROV fixed)	Max. Min.	400 kg 225 kg	355 kg 270 kg	345 kg 190 kg	275 kg 215 kg	--- ---
ROV side dynamic tension (self-propelled)	Max. Min.	395 kg 225 kg	350 kg 270 kg	340 kg 175 kg	270 kg 225 kg	57 kg 42 kg
Motions of ROV	X(m) Z(m) Pitch degree	0.25 0.16 4.1-16.1	0.065 0.045 8.5-11.8	0.23 0.18 4.0-13.9	0.045 0.037 7.8-10.3	0.01 0.01 1.3-3.3
Position of weight	X(m) Z(m)					0 0.24

Table 1. Dynamic suspension of Dolphin-3K system

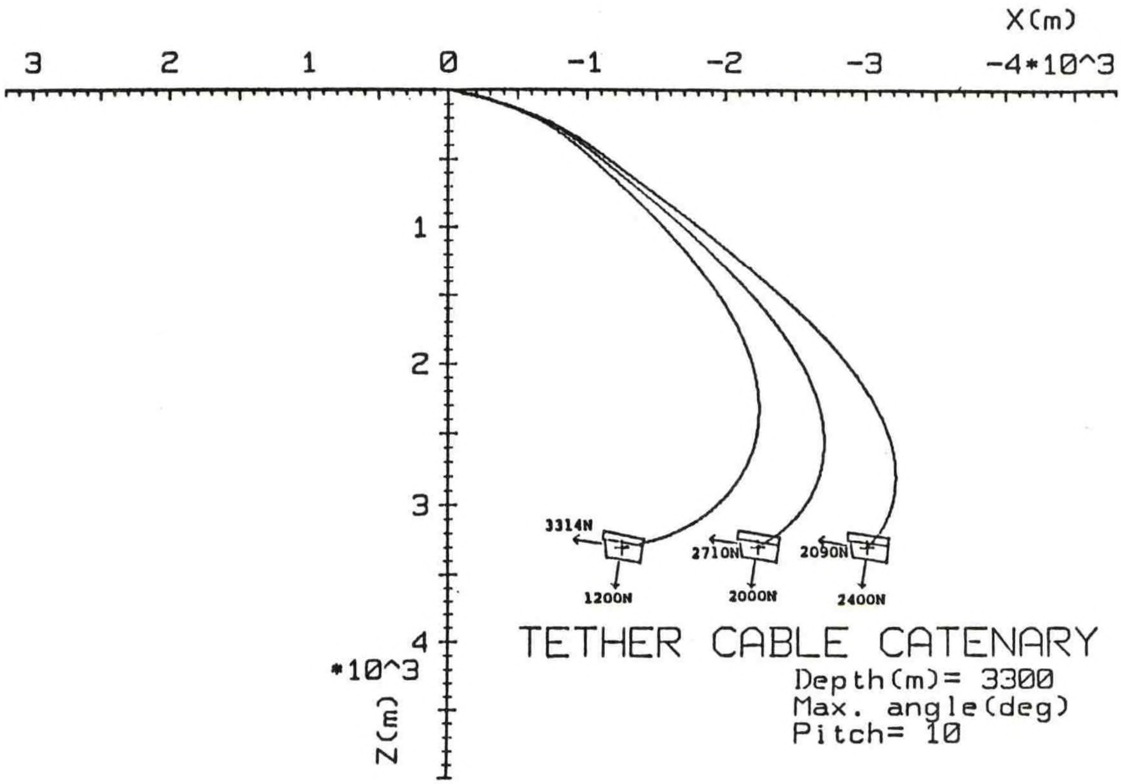

Fig.2. Cable catenary at the maximum current velocity

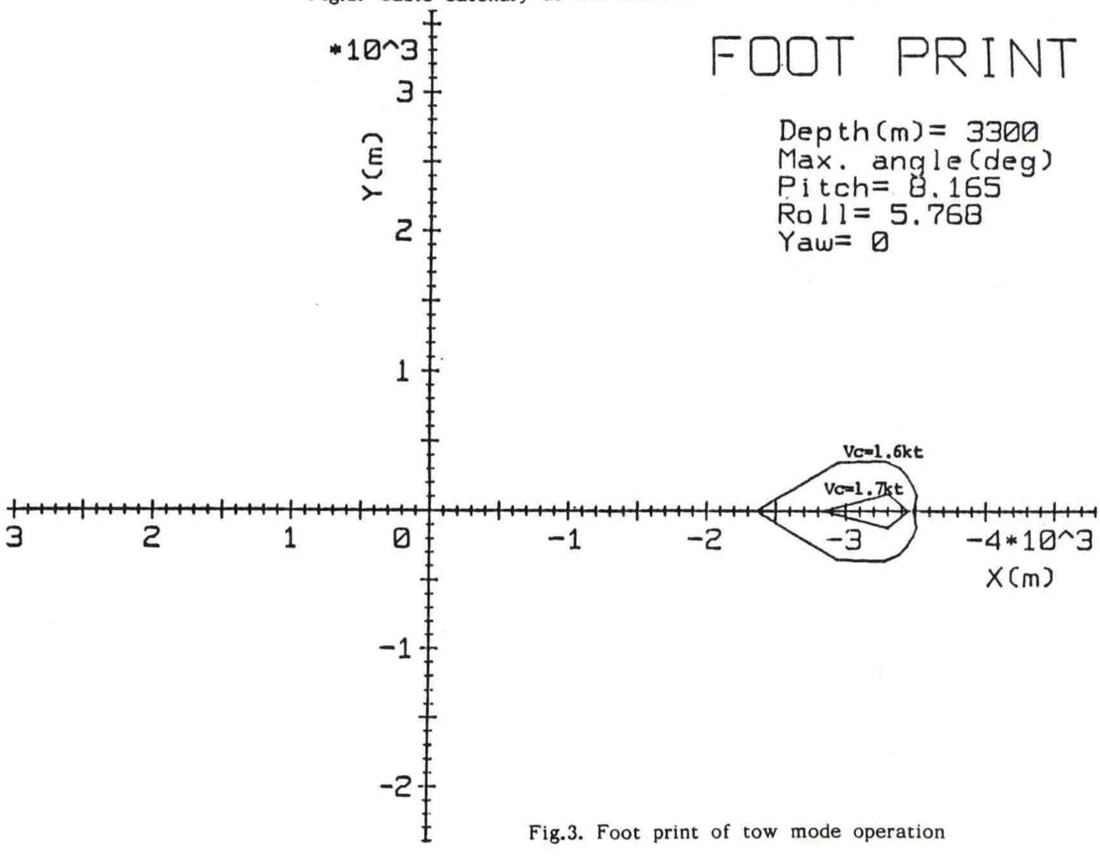

Fig.3. Foot print of tow mode operation

MANNED AND UNMANNED VEHICLE DEVELOPMENTS
IN THE UNITED STATES

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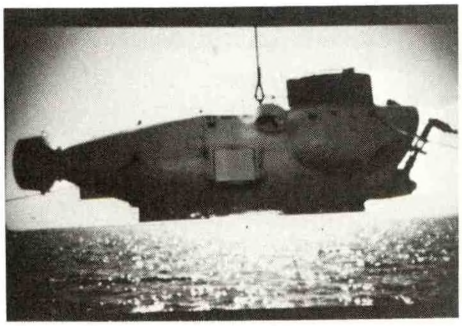
To start this discussion of the current status of manned and unmanned vehicles in the United States, I'll begin with an overview of manned vehicle activity and conclude with a summary of unmanned vehicle activity.

MANNED VEHICLES

One of the newest vehicles in the U.S. is the recently rebuilt SEA CLIFF operated by Submarine Development Group I of the U.S. Navy in San Diego, California.

Major characteristics of SEA CLIFF are:

Length 31 1/2 ft.	Displacement 58,000 lbs.
Width 11 1/2 ft.	Crew 3
Height 12 1/2 ft.	Operating Depth 20,000 ft.



DSV SEA CLIFF

Of particular interest is the methodology used by the Navy to achieve operational readiness of the vehicle and its crew. This rigorous and documented sea trial procedure has two phases. Phase 1 consists of several parts. First is the certification of the crew in their administrative positions (i.e., do they have the correct background and experience for their new assignment).

Second, is the certification of the training course to be used for each of the different positions. Third is the production (or hardware) test and checkout of each part of the vehicle, by component, subsystem, and system.

The vehicle and the crew are now ready to begin interactive checkout. This consists of actually doing such items as: vehicle system and subsystem maintenance checks. (This trains the people involved and validates the written procedures used to maintain the vehicle. Changes to procedures are made as required to reduce design and written theory to actual practice.)Pre dive checkouts are run as well as the vehicle air and water inclining experiments.

Thethered dock trials and certification of the launch and recovery handling systems are then conducted prior to entering the second phase of the sea trial procedure.

Phase 2 begins with the official certification of the crew in their assigned watch station. Vehicle operational checkout is next; with the vehicle in the water, but on the surface, a "fast cruise" cycle is started. This is a realistic dive simulation where all systems are operated in normal sequence with the exception that the vehicle does not dive.

After a successful fast cruise, the vehicle and operational procedures are certified for dives to progressively deeper depths. In SEA CLIFF's case, 500 feet, 5000 feet, and 15,000 feet.

The success of the sea trial methodology is measured in terms of successful future operations not really in terms of how smoothly the sea trials went. In fact, it is the object of the Navy's sea trial procedure to force things such that problems and discrepancies are exposed and corrected. The more problems that are discovered during sea trials, the fewer that will come up during future operations.

Deep Ocean Engineering of Oakland, California has recently completed its first Deep Rover vehicle.

This one person craft has a 5 inch thick acrylic plastic sphere 63 inches in diameter. The overall vehicle size is 8.2 feet long, 7.8 feet high and 6.3 feet wide. The two plastic hemispheres mate to a central aluminum structural ring that contains all of the pressure sphere's penetrations for power and control wiring. Deep Rover displaces 6800 pounds and has a current depth capability of 3200 feet. Four 1 1/2 HP thrusters provide vertical and horizontal mobility. The two heavy duty work manipulators have a lift capacity of 200 pounds when fully extended.

Operator safety is obtained through jettisoning of the battery, frame, thrusters and manipulators. The 1400 buoyancy of the hull brings it to the surface . An acoustic pinger, strobe light and radio provide the means to locate the sphere. A 150 hour life support system has a 6 day emergency capability beyond a normal 6 hour dive.

DEEP ROVER

The Perry Offshore Company of Riviera Beach, Florida, has had a number of Perry names and produces a variety of undersea products. They have built 28 manned submersibles over their 25 year history. Thus making them the leading submersible manufacturer in the United States and the World. Table I lists all of the Perry submersibles as to designation, year built, depth capability and original owner.

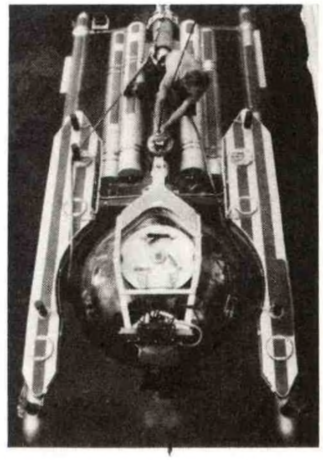
TABLE I

PERRY SUBMERSIBLES

DESIGNATION	YEAR BUILT	DEPTH (FEET OF SEAWATER)	OWNER (ORIGINAL)
PC-3A-1	1964	300	U.S. Army
PC-3A-2	1966	300	U.S. Army
PC-3A-2	1963	600	I.U.C.
PC-3X	1960	150	U.S. Navy
PC-5C	1968	1200	Sub Sea Oil, Italy
PC-8B	1971	800	Intersub, France
PC-8C	1972	1200	Sub Sea Oil, Italy
OPSUB	1972	2000	Phillips Petroleum, UK
PC-9	1970	1350	Merpro, UK
PC-1201	1975	1000	Intersub, France
PC-1203	1976	1000	Intersub, France
PC-1204	1976	1000	Intersub, France
PC-1205	1976	1200	Intersub, France
PC-14-C1	1974	1200	Texas A&M University
PC-14-C2	1975	600	U.S. Army
PC-1601	1976	3000	Intersub, France
PC-1602	1980	3000	Saipem, Italy
PLC-4	1968	1350	Ocean Systems, Inc.
PLC-4B	1968	800	Oceanographic Institute, France
PC-1202	1975	1000	Intersub, France
PC-15-LI	1973	1200	Vickers Oceanics, UK
PC-15-LIII	1977	1500	Vickers Oceanics, UK
PC-15-LIV	1977	1500	Vickers Oceanics, UK
PC-1801	1977	984	Intersub, France
PC-1802	1977	984	Intersub, France
PC-1803	1977	984	Superpesa, South America
PC-1804	1978	984	Intersub, France
PC-1805	1982	984	Shell, UK

Harbor Branch Foundation of Fort Pierce, Florida operates two Johnson Sea Link (JSL) submersibles. At the end of 1984, these two vehicles will have completed over 2500 dives during their careers. In 1984 150 dives were made for fisheries research, baseline ecology documentations in offshore oil lease areas, mid-water science studies, and marine organism enzyme collection for possible development as pharmaceutical agents.

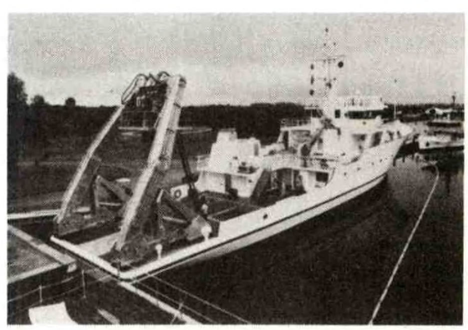
The JSL submersibles are four man 12 ton vehicles with a two man acrylic pilots sphere and a two man aluminum observation/diver lockout chamber. They are certified by the American Bureau of Shipping for operations to 2640 feet.



JOHNSON SEA LINK I

Harbor Branch has developed a new support ship the Seward Johnson. With its ultra modern 18 ton aluminum A-frame on the stern, their vessel can carry two submersibles or one submersible and a deck mounted diver living and decompression chamber for use when saturated lock out diving is done from the submersible.

The Seward Johnson is 276 ft. long, has a beam of 36 ft. and a draft of 12 ft. She carries a crew of 8 and has additional space for a 22 person submersible and scientific team.

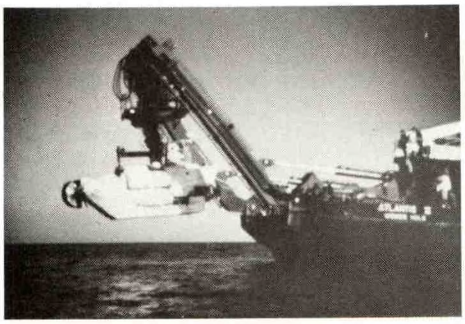


RV SEWARD JOHNSON

The Woodshole Oceanography Institution (WHOI) of Woodshole, Massachusetts, operates perhaps the best known submersible in the United States, ALVIN. Since commissioning in 1963, ALVIN has made 1460 dives. With the addition of a titanium hull her current depth capability is 4000 meters

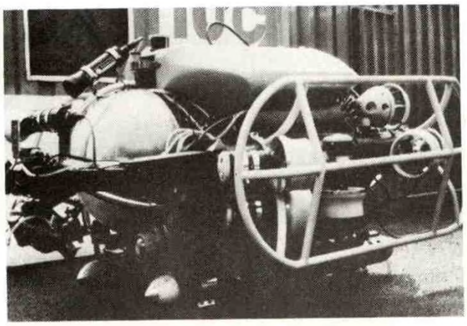
ALVIN has been somewhat limited in her dive activities by the lack of mobility of her 6 knot catamaran support ship LULU.

In 1984 the WHOI oceanographic research ship ATLANTIS II was reconfigured to support ALVIN with the addition of a stern mounted 28 ton A-frame. Hanger space for ALVIN and a vehicle control room were also added. To use the A-frame launch and recovery system, ALVIN had to be rebuilt to incorporate a single point lift point on her titanium frame.



ALVIN AND ATLANTIS II

The International Underwater Contractors (IUC) vehicle, ROV MANTIS, is the final submersible to be discussed in this overview of U.S. manned submersible activity. It is fitting to use this vehicle as a bridge between manned and unmanned vehicles for ROV MANTIS is in fact, both types of vehicles. It can be used as an on board operator controlled manned submersible. It can be used as a surface operator controlled manned craft when the occupant is a particular technical observer or work specialist. Fastly, the vehicle can be used as a completely unmanned ROV.



ROV MANTIS

An interesting and perhaps significant point reported by IUC at the Oceans '84 Marine Technology Society Conference was that when operators were made aware of the dual roll of ROV MANTIS and a choice was available for use as a remotely operated vehicle or a manned vehicle, in every case the manned capability of MANTIS was selected.

UNMANNED VEHICLES

This summary of unmanned vehicles starts with a review of the vehicles produced by International Submarine Engineering (ISE) of Port Moody, Canada. While not a U.S. activity it is close to the U.S. and does have a major U.S. subsidiary; ISE Gulf of Houston, Texas.

ISE is the most diversified and largest producer of a variety of ROV craft. Since 1974 they have produced 124 ROV type craft. One, Wrangler, has both ROV and manned capabilities similar to the ROV MANTIS. Table II shows the various types of vehicles that they have produced.

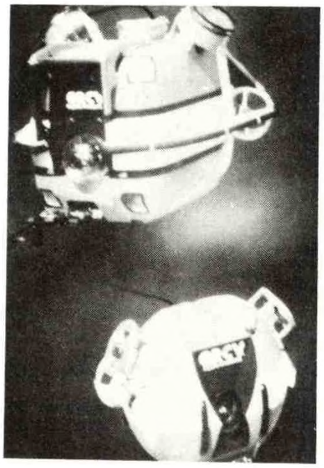
TABLE II

I.S.E. BUILT VEHICLES

1974-1979	8 TROV
1975-1980	19 TREC
1977-1982	26 DART
1981	6 TREC MARK II
1981	1 SUPER DART
1982	1 WRANGLER
1982-Present	6 RASCL
1982-Present	8 HYSUB 10
1982-Present	34 HYSUB 20/30
1982-Present	8 HYSUB 40/60
1983-Present	1 DOLPHIN
1983-Present	1 MAXI-DART
1984-Present	1 ROSS Type 6
1984-Present	1 ARCS
1984-Present	1 TRAILBLAZER
1984-Present	1 F.M.V.
1984-Present	1 INSPECTOR

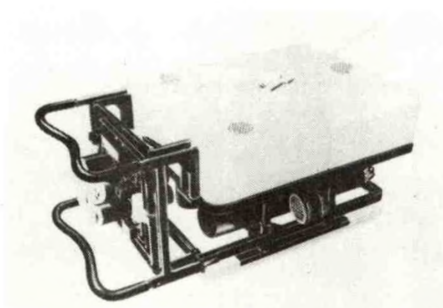
In the U.S. proper, the largest producer of unmanned vehicles is Hydro Products of San Diego, California. They have produced 96 RCV 225 vehicles, and 10 RCV 150 vehicles.

They are currently working on a U.S. Navy contract to produce eight mine neutralization vehicles and they have recently introduced a new low cost vehicle the LCRCV. As a result, their total count is currently (Dec 1984) 115 vehicles.



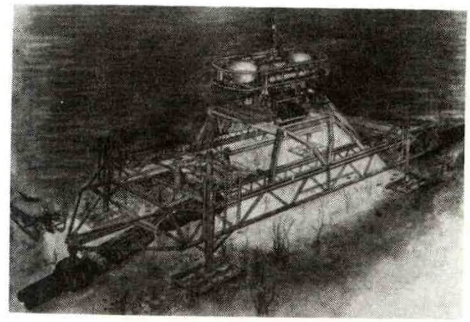
RCV 225 AND RCV 150

Also in San Diego is the Ametek Straza Company which has produced 75 remotely operated vehicles. These include their large SCORPIO work vehicle (51); the smaller inspection vehicle SCORPI (15); and a redesigned SCORPI vehicle designated the ASD 620 (5).They also produce a number of other vehicles; a new modular work package vehicle GEMINI (1); a new special purpose underwater structure cleaning vehicle PROS (1). Earlier they produced two older cable work vehicles SCARB and the Deep Drone vehicle built for the U.S. Navy.



ADS 620

Perry Offshore entered the ROV business in 1977 with their first remotely operated vehicle RECON II. Since that time, they have built some 35 of the RECON series of vehicle including RECON III's, IV's and one RECON V (see Table III).In addition Perry has built a number of special purpose remotely operated devices. These include: a large remotely operated pipeline repair system for operation to 3000 feet. A thruster module for the Deepwater Pipe Repair System also contains two remotely deployed RECON IV systems to monitor the progress of the pipe repair work.



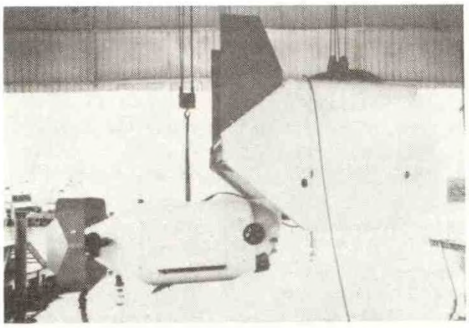
DEEP WATER PIPE REPAIR SYSTEM

TABLE III

PERRY RECON SERVICE HISTORY

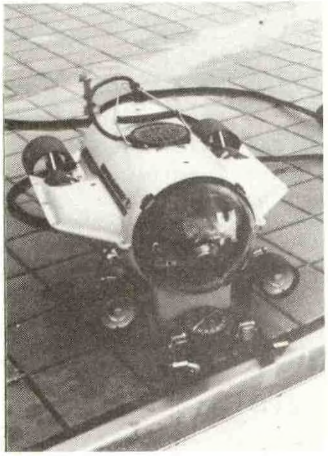
MODEL NUMBER & NAME	YEAR BUILT	OWNER
RECON II	1977	Shell Expro (out of service)
RECON III-1	1978	Oceanics (out of service)
RECON III-2	1978	Oceanics (destroyed)
RECON III-2 (spare)	1979	Replacement (out of service)
RECON III-3	1978	POI (lost at sea)
RECON V-1	1979	Prototype - MIT
RECON III A-1	1980	International Underwater Contractors
RECON III B-1	1980	International Underwater Contractors
RECON III B-2	1980	Constructora Subaquatica Diavaz
RECON III B-3	1981	International Underwater Contractors
RECON III B-4	1981	Jered J-1 (now Oceaneering)
RECON III B-5	1981	Jered J-2 (now Oceaneering)
RECON III B-6	1981	Jered J-3 (now Oceaneering)
RECON III B-6	1982	Replacement (destroyed)
RECON III B-7	1981	Jered J-4 (now Oceaneering)
RECON III B-8	1982	McDermott, Inc.
RECON III B-8 (spare)	1982	McDermott, Inc.
RECON III B-9	1982	Solus Ocean Systems (now OI)
RECON III B-9 (spare)	1982	Solus Ocean Systems (now OI)
RECON III B-9	1982	Solus Ocean Systems (now OI)
RECON III A-2	1981	German Navy
RECON IV-1 - 1500	1982	Jered J-5 (now Oceaneering)
RECON III C-10	1982	Jered J-6 (now Oceaneering)
RECON IV-2 - 1500	1982	Jered J-6 (now Oceaneering)
RECON IV-3 - 1500	1983	Jered J-7 (now Oceaneering)
RECON IV-4 - 1500	1983	Solus Ocean Systems (now OI)
RECON III B-11	1983	McDermott
RECON IV-5 - 2300	1983	International Underwater Contractors
RECON IV-6 - 3000	1984	Snamprogetti (summer delivery)
RECON IV-7 - 3000	1984	Snamprogetti (summer delivery)
RECON IV-8 - 1000	1984	USN (summer delivery)
RECON IV-9 - 1000	1984	USN (summer delivery)
RECON IV-10 - 1500	1984	Sonat
RECON IV-11 - 1500	1984	Sonat (June 1984 delivery)
RECON IV-12 - 1500	1984	RECON T Taylor Diving

The Towed Unmanned Submersible (TUMS) search and survey system was delivered to the British Royal Navy by Perry. It has an operating capability down to 6000 meters.



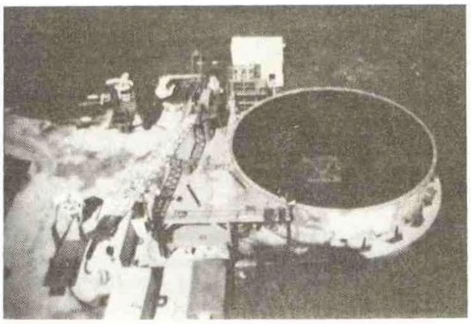
TUMS

A new very small ROV is the MINI ROVER by Deep Sea Systems International of Falmouth, Massachusetts. This vehicle is so small that it can be lifted by one hand (50 lbs) and carried as passenger luggage on board airplanes.



MINI ROVER

In the area of ROV operations, both SONAT Subsea Services and International Underwater Contractors, in Houston, Texas are offering ROV operator training courses. The SONAT facility is at Belle Chase, Louisiana and includes a large (55' diam. x 24' deep) training tank with typical offshore oil hardware on the bottom. ROV's are then deployed in the tank by trainees to familiarize them with wet vehicle operations on real equipment.



SONAT SUBSEA SERVICES ROV TEST AND TRAINING TANK

CONCLUSION

Manned and unmanned vehicle activity in the U.S. is continuing at a reasonable, market based pace. Manned submersible usage is essentially limited to scientific activities with ALVIN and the two Johnson Sea Link vehicles; offshore oil support involving IUC and their MERMAID, BEAVER, PISCES and ROV MANTIS vehicles and the search and salvage work done by the U.S. Navy with SEA CLIFF and TURTLE.

Unmanned vehicle activity is growing in the area of offshore oil support with inspection, maintenance tasks, repair and support of drilling and production.

UNMANNED REMOTE-CONTROLLED SUBMERSIBLE

MURS-300 MKII

I. Mutoh
Mitsui Ocean Development & Engineering Co., Ltd.

1. INTRODUCTION

In co-operation with Tokyo Electric Power Co., Ltd., MODEC has developed MURS-300 MKII (MODEC Unmanned Remote-Controlled Submersible for 300 meter water depth) and carried out first trial successfully at Midono Dam in December, 1984.

The MKII is a highly mobile and remotely controlled submersible which is used for inspection of the facilities of Hydraulic Power Plants such as dam wall, water intake, Penstock, etc, as shown on Table-1.

Table-1 Objects of Inspection

Object	Detail
Dam	. Deterioration, cracks, joints of the concrete wall . Piling condition of sand
Discharge gate	. Corrosion, wear, damage and rust of the gate . Piling condition of sand around the gate
Water intake Water outlet	. Corrosion, wear, damage and rust of screens . Deterioration and cracks of concrete . Piling condition of sand around intake and outlet
Headrace Surgetank Trail race	. Deterioration and cracks of concrete
Penstock	. Corrosion, wear, paint condition and rust of pipe inner surface . Joints of pipes

2. PRINCIPAL FEATURES

For the above mission, some improvements or enhancements have been done on the component or subsystem of MK II.

1) Compactness

Considering its transportation in hilly terrain or carrying into narrow areas, the MKII was made in compact as far as possible in both size and weight.

2) Improvements of Tether Cable

A kevler armored composit cable using optical fiber for communication has been newly developed so as to conform with the following requirements.

a) Ample strength to lift up the vehicle
b) Small diameter
c) Positive bouyancy

3) Underwater DC Motor

A new brushless DC Motor for the vehicle thruster was develped to get higher reliability of DC motor.

4) Others

a) Pitching lens was developed for TV camera to make the vehicle compact.

b) Vehicle control system was enhanced to achieve high maneuverability.

c) A gyro system was adopted to detect the direction of the vehicle especially in case of pipe inside inspection.

3. SYSTEM SPECIFICATION

1) System Configulation

The MKII system consists of the following major modules (see Fig-1).

- Vehicle with TV camera, still camera
- Control van with a control console and power supply panel
- Handling system with cable winch

The vehicle is electrically and optically connected to the cable winch with 600m tether cable and it can be operated by one man.

The vehicle is capable of longitudinal, vertical and lateral translation as well as turning by four (4) electric thrusters.

Heading and depth of the vehicle can be maintained manually and also automatically.

The navigational informations of the vehicle such as relative position to base point, direction and depth are displayed in digital on the TV monitor and recorded by a video tape recorder.

2) Principal Particulars

a) System

Type : Tethered Remotely operated vehicle
Maximum Operating Depth : 300m
Operating Extent : max. 500m
Function : Real time observation by TV camera
: Recording by VTR
: Photographing by still camera

b) Vehicle (Fig 2)

Type : Open frame
Size : 950mm(L) x 750mm(B) x600mm(H)
Weight in Air : abt. 200kg
Maximum Speed : 1.8 kts (ahead)
Payload : abt. 40 kgs
Thruster : 4-300W eletric DC brush-less motor
(2 sets for forward and aft)
(2 sets for lateral and vertical)
TV Camera : 1-SIT TV camera with lens pitching mechanism
Still Camera : 1-35m/m x 250 exposures
Light : 2-75W halogen lamp
Sensor : Acoustic transponder
Depth sensor
Angular rate sensor
Directional gyro
Telemetry Unit : PCM using optical fiber

c) Control Van (Fig 3)

Size : 3m(L) x 2m(B) x 2.4m(H)
Weight : abt. 1,600 kgs
Equipment : Control console
VTR
Thruster Control Unit
Power Supply Panel

d) Handling System (Fig 4)

Truck Size: 7.9m(L) x 2.2m(W) x 2.93m(H)
Weight : abt. 8,000 kgs
Equipment : 1) Crane 300kgs x 15m
2) Cable winch & power sheave
3) Tethercable 17.5ϕ x 600m
4) Gyro compass

4. TEST

This MURS-300 MKII was completed in Nov. 1984 and first trial test has been carried out successfully on 19th Dec. 1984 to inspect damwall and waterintake where the depth was abt. 20 - 60m, water temperature was abt. 6°C and transparency was 1.5m. (see photo-1)

After the test, it is expected that the MKII inspection is much convenient and better than the conventional inspection system by divers.

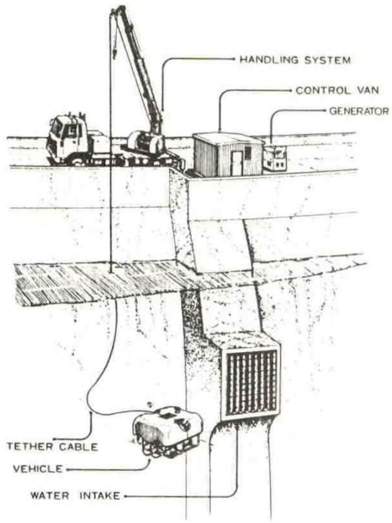


FIG. 1 SYSTEM CONFIGURATION

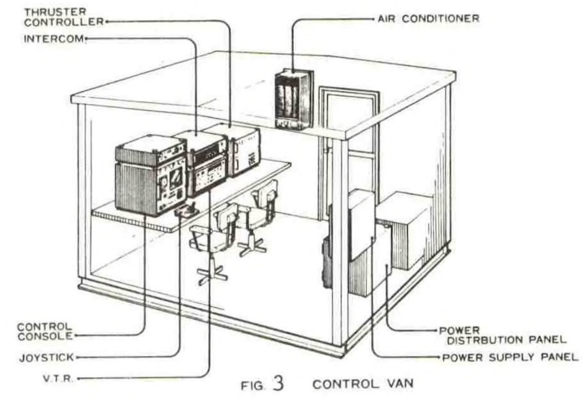


FIG. 3 CONTROL VAN

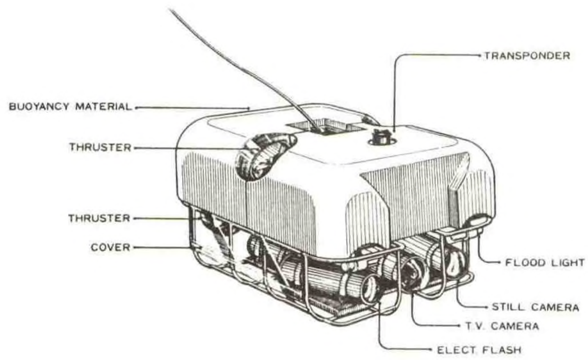


FIG. 2 VEHICLE

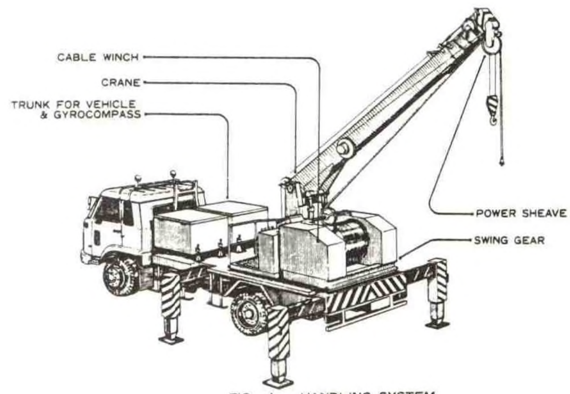


FIG. 4 HANDLING SYSTEM

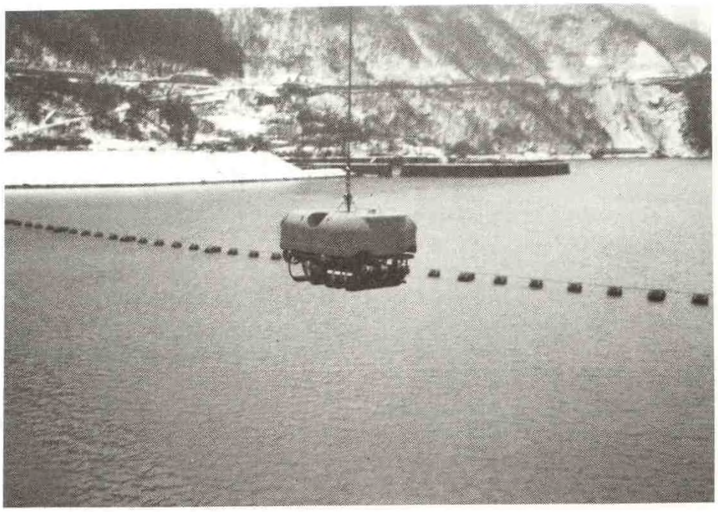


PHOTO 1 TEST

VOICE CONTROLLED MANIPULATORS

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Research Performed by:
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INTRODUCTION

The objective of the research effort is to investigate the use of voice control of undersea teleoperator systems. This initial investigation was concerned with voice recognition technology as applied to an existing supervisory controlled underwater manipulator. To investigate the potential of applying this technology to specific Navy applications, a laboratory demonstration of voice actuation of both analogic and symbolic commands was conducted. It is anticipated that voice control of an underwater manipulator or teleoperator system will eliminate the necessity of providing an operator with a complex computer keyboard at sea. This will allow the operator to issue verbal commands (or obtain data) when his hands or eyes are already occupied by other necessary functions.

BACKGROUND

During the past several years the Naval Ocean Systems Center (NOSC) has developed an untethered, unmanned submersible testbed for demonstrating, testing, and evaluating advanced concepts in underwater robotic systems, teleoperators, and remote manipulation. Under the Office of Naval Research (ONR) sponsorship and in cooperation with Dr. Tom Sheridan at Massachusetts Institute of Technology (MIT), an advanced underwater manipulator has also been developed to demonstrate advanced concepts in supervisory control of teleoperators. A review of the general concepts arising from Dr. Sheridan's work is provided in reference 1. A description of how the supervisory command language functions is provided by Yoerger and Sheridan (reference 2). The manipulator developed for this effort is an oil-filled, pressure compensated, electrically-driven unit having five degrees of freedom, harmonic drive gearing and position control feedback. The entire configuration is operated in a supervisory controlled fashion using two Digital Equipment Corporation (DEC) LSI-11/23 computers; one contained in an underwater housing on the submersible and one located at the surface operating console. It is this topside computer working under the DEC RSX-11M operating system that acts as the host computer for voice controlled manipulation. This single computer should allow interaction between existing resolved position control software generated by MIT and external voice recognition circuitry actuated by the console operator.

As the research effort progressed, it was found useful to add voice response for verification of input commands from the voice recognition hardware. In addition, voice recognition input was added to the NOSC Free Swimming Submersible to allow investigations into the voice control of planning operations as well as unmanned submersible control.

LITERATURE REVIEW

During the past decade, there has been a growing interest in the use of supervisory control of remote teleoperator systems. Supervisory control means that a human being plans the actions and directions the computer should take, "teaches" it how to achieve the desired function, and monitors its performance, but always retains the ability to intervene whenever necessary. Supervisory control has been shown to be more effective than manual control, with the exception of master/slave with force feedback (reference 3). Various environments have been examined for possible use of these remote systems (references 4, and 5). One such environment is the ocean depths. Computer controlled systems may increase the effectiveness of remote manipulation. One big advantage with the use of supervisory control in undersea projects would be cost savings. Brooks (reference 3) presents data for cost comparisons for underwater welding based on a model developed by Moore (reference 6). Brooks cautions, however, that the length of time needed to complete the task is another critical factor that must be taken into consideration.

Vadus (reference 7) and Pesch, Hill, and Klepser (reference 8) both discuss the issue of cost effectiveness of using divers versus manned or unmanned teleoperators.

In another investigation, commercial airline pilots preferred synthesized speech providing the callouts of approach to landing data (reference 9). Improvements in flight performance were noted when there was a high manual and visual workload on the pilots and synthesized speech was employed. The interface between the human being and the computer might improve operations in terms of accuracy, speed of performance, and user satisfaction. Several input devices might be used, including handprinting, touch sensors, keyboards, or voice.

Numerous investigations have been conducted to evaluate the use of voice versus other input or output. Some questions that should be asked in evaluating potential systems are:

- Are the operator's hands and eyes busy with other functions?

- Must the operator frequently move from the input station?

- Must the operator deal with various or confusing computer languages?

- Will the operators be untrained?

- Are speed and accuracy important factors when transmitting the commands?

- Can a small input vocabulary be utilized?

If these questions can be answered, "yes," then voice input should be seriously considered as a method of improving the functioning of the system. In addition, Bejczy (reference 10) found that voice input was beneficial for man-machine integration. Taggart and Wolfe (reference 11) explored the use of a voice recognition unit in performing two data processing tasks, and found that subjects who had prior voice input experience were able to work faster when using voice input, rather than keyboard data entry. They believe speech is convenient and natural and that artificial syntax should be avoided. Speech allows the user to be more mobile and have freedom to do other tasks. Another aspect is security. The voice recognition unit could use the voice pattern to identify the operator. The subjects they tested reported, on a questionnaire, that they generally preferred to enter data using the voice mode because it was less fatiguing. Taggart and Wolfe also point out that even though more errors were made using voice input, this result may have been an artifact of the vocabulary being used. Operators would often say, "Two-two," instead of "Twenty-two," for example. The fact that there were no recognition errors possible in the typing mode, thus, total errors equal operator errors, whereas for voice input, total errors truly equal operator errors plus recognition errors. Also, for total errors, there were no significant differences for either experience level or task type. Experienced subjects were faster than inexperienced subjects in all three entry methods, especially in the unbuffered voice condition. One possible side benefit of using voice input is that others can hear what commands are being given, whereas typewritten commands are usually known only to the operator. This would keep supervisors (or others) informed and would also be a check on improper or incorrect commands being given.

Previous research in the use of voice controlled systems and the personal observations gained while performing preliminary investigations have indicated possible directions in which we might proceed in the development of a workable system for use in the field. Because of the large number of variables that might be considered when devising a research project in voice recognition, the following guidelines have been developed in an attempt to logically measure what conditions will lead to optimal human performance.

First, creation of a command vocabulary which will best allow the operator to perform a variety of tasks using a remote manipulator with optimum efficiency. Thus we should attempt to develop a vocabulary that:

a. Has a minimum of errors

b. Is easy to remember

c. Is sufficiently flexible to accomplish a variety of tasks.

It appears that longer terms result in the best performance of the voice recognition component of the hardware.

Keeping the list of commands as short as possible will aid memorization, but it should be large enough to allow the operator to complete the task efficiently. One should include those terms which would naturally express the operation of the manipulator. We always keep in mind, however, the problem of word recognition by the hardware. The authors of this document, for example, assumed that the words, "open" and "close" would be the best terms to describe the operation of the jaws of the manipulator. A major problem arose, though, because the voice recognition equipment cannot differentiate between these two commands due to the long "oh" sound in both words. Syntax nodes, too, seem to create problems in memorization. The modes are confusing to the operator and prove to be frustrating, especially for the novice who may not completely understand how they function. It may be beneficial to have several words available to the operator which will bring about the same result. For example, having the words "grasp" and "grab" as commands to make the jaws close.

Secondly, there should be some means of verification feedback to the operator to indicate that the command has been received and correctly interpreted by the computer before it is executed by the manipulator. Command verification aids the operator in his/her ability to quickly correct mistakes which result in a mis-recognition or non-recognition of the command. It also makes the operator feel more relaxed using the system and builds operator confidence in the system. It appears on cursory examination that auditory (voice) verification is an excellent means of providing a command verification. Voice response is better than a visual (CRT) alpha-numeric response because it is less distracting and does not require complete concentration on the CRT. The operator is freed to be more mobile, or to divide his attention between necessary tasks. Also, if keyboard input is sometimes used, typing errors are often hard to detect (if a word is misspelled, for example) and, therefore, can be pointed out to the operator via voice response.

Thirdly, as indicated by the literature, the optimal number of training passes to establish a very high degree of voice recognition (98%) should be approximately seven.

Fourthly, research has determined, in general, that ambient noise is not a serious problem when the following procedures are employed:

a. The operator training takes place with some noise in the background.

b. Loud, intermittent "banging" type noise can be eliminated.

c. A noise cancelling microphone is used, and

d. The operators receive proper instruction in how to wear the microphone (consistent placement approximately one inch from the mouth) and how to speak in a consistent manner.

SYSTEM DESCRIPTION

The primary components of the hardware system used in our investigation are the underwater manipulator itself, a DEC LSI-11/23 computer, and a computer terminal CRT. An Interstate Electronics Corporation (IEC) Voice Recognition Unit, Model VRT-200, and an IEC Voice Response System, Model VTM-150, have been added for evaluation of voice input and output commands, respectively. Two LSI-11/23 computers are used for operator interface topside, and one is packaged in an underwater housing to be installed on an unmanned submersible, such as the NOSC Free Swimmer. This latter version of the hardware architecture allows incorporation of the vehicle related routines, such as joint space coordinate transformations, within the vehicle hardware. Such an allocation of computer resources has the inherent advantage of reducing the bandwidth of control communications to the vehicle, anticipating control of such advanced teleoperators by acoustic control in the not too distant future.

During the initial stage of this investigation a cursory study was performed addressing the suitability of various commercial hardware which might be incorporated into the present hardware and software configuration. In general, there were two overriding criteria involved in the choice of hardware for this investigation: (1) Cost versus Equipment Performance; and, (2) Software Configuration. The approximate cost range of the voice recognition equipment falls into three categories: (a) $200-$500; (b) $2,000-$5,000; and (c) $12,000 and above. Category (a) was found to be hobby quality and market oriented hardware. Category (c) was found to address technology such as connected speech and 98% reliability designs. These were deemed to be quite expensive and somewhat more advanced than the state-of-the-art which we were considering. Thus, the main area of consideration was category (b), which addressed commercial quality hardware and single utterance, operator dependent operation.

The second criterion involved in the selection of suitable voice input hardware was the ease of incorporation of that hardware into the existing equipment and software configuration. It happened that two of the voice recognition cards manufactured by IEC easily plugged into this equipment; one, the VRT-200 plugged directly into the existing Lear Siegler, Model ADM-3A, "dumb" terminal. Another, the VRQ-400 board, worked from the DEC LSI-11 "q" bus. Since this latter board required considerable software support, it was not adopted for this investigative effort. In order to allow detailed evaluation of the hardware circuitry involved in the VRT-200 system, the VRT-103 voice recognition system was used. This system included a means of sorting voice patterns and vocabulary on mini-floppy disks.

EQUIPMENT DESCRIPTION

The VRT-200 provides voice data entry capability for Model ADM-3A or Model ADM-5 of the Lear Siegler Interactive Display Terminals. The ADM-3A or ADM-5 retains its standard terminal keyboard and display capabilities while adding the following voice recognition capabilities:

a. A user-defined vocabulary of as many as 100 words and/or phrases.

b. Trainable for any vocabulary in any spoken language.

c. Reject threshold level control.

d. User control of recognition parameters.

e. Real-time performance.

f. Accuracy of over 99% (claimed by manufacturer) on 50 word subsets.

g. User programmable automatic gain control (3 ranges).

h. Word length: 80 milliseconds minimum; 1.25 seconds maximum.

i. Response time: 25 + N milliseconds following end of word detection, where: N = active vocabulary size.

j. Required pause between words: 160 milliseconds minimum.

k. Power consumption: 60 watts (115 volts, 60 Hz).

l. Audio input bandwidth: 200 to 7,000 Hz.

m. Input impedance: 10 kilohms, a.c. coupled.

The VRT-200 is a speaker dependent, discrete word recognition system. Speaker dependence requires each speaker to provide it with a sample of how that speaker enunciates each item in the chosen vocabulary. This sample is recorded by the recognizer as a reference pattern stored in random access memory. The reference pattern is produced during a training session wherein the speaker recites the vocabulary one or more times. Usually, five to seven training passes are required to produce an optimum set of reference patterns. A battery backup power supply on the VRT-200 board allows retention of the reference patterns in the CMOS RAM on board, while the a.c. power is turned off or lost.

In the beginning of this investigation it was deemed that computerized voice response would be incorporated as an added bonus to the study simply because it was reasonably cost effective. In view of the fact that existing systems were available at a fairly low cost, and since we already had a host computer in the system to support it, we felt it would be easy to include an evaluation of voice response and at the same time add to the novelty of the system. Unexpectedly, however, the voice response system was found to be a very natural and effective means of verifying the validity of input speech commands without causing the operator an excessive amount of distraction from his command task with the manipulator.

The underwater manipulator arm is basically controlled by an LSI-11/23 minicomputer and has the option of being controlled in a supervisory manner using this single computer. In this single computer configuration, the computer is assumed to be at the surface, while in a two computer configuration, a second computer is installed in an underwater bottle, close to the manipulator. Despite the number of computers used, there are several different ways in which the operator can maneuver the arm. These are:

a. Master-Slave operation

b. Joystick control

c. Incremental movement control

d. Rate control (i.e., on/off discrete command).

Perhaps even more important is the choice of coordinates for the work space reference frame, since we have to distinguish between two different ways of movement: absolute and relative. The absolute movement is a movement in which the set of joint angles of the arm is unique for a certain position relative to a base-frame. The base-frame is defined as the coordinate frame attached to the base of the arm. Relative movement, on the other hand, is a movement in which the spatial hand positions always are the same but require different sets of joint angles, depending on the relationship of hand movement and the base-frame.

The components described above were assembled into a demonstration system. Many experiments were conducted with several different operators, including multilingual commands. It operated satisfactorily, and successfully demonstrated the concept of voice control of dexterous manipulators.

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UNDERWATER WORK SYSTEMS DEVELOPMENT

John F. Freund

U.S. NAVAL SEA SYSTEMS COMMAND

ABSTRACT

Two interrelated areas are being given attention in the development of underwater work systems. The first concerns tool packages for use either by saturation divers or by deep ocean vehicles. The other is seawater hydraulics, which promises not only to simplify the operation of such tool systems but is finding use in submersible pumps and motors for many other applications.

UNDERWATER TOOLS

Depending on depth, underwater work is done either by divers or by submersible vehicles equipped with work packages. Diver tools for shallow water can usually be adapted from their dry-land counterparts, but tools for use by saturation divers operating at depths of 600-800 feet (180-250m) must be specially designed. Vehicle work packages are even more complex because the tools must be integrated with manipulators which are operated wither from within the vehicle or from the surface.

A work package developed for U.S. Navy submersibles consists of an array of tools arranged in a series of bins (Figure 1). The package also includes a set of manipulators, two for holding the work stationary, and one, more dexterous, for selecting and operating the tools. The tools themselves are hydraulically driven and designed for a variety of tasks. They include a high speed rotary saw, wrench, velocity stud driver, jack, and spreader. The manipulator arm can exert a wrist torque of 1,200 lb-in (135 N-m) and multiplication can be achieved by gearing in the tool itslef. The arm can lift a set of TV cameras to provide the necessary visual inputs to the operator.

A somewhat similar tool package is being developed for saturation divers. For such work a power module is lowered to the work site near the Personnel Transfer Capsule (PTC) which provides life support and transport for the diver (Figure 2). The power module is battery operated and contains the necessary pumps and controls to provide hydraulic power to a tool head carried by the diver. The head can then be fitted with any one of a set of tools to perform tasks similar to those done in deeper water by a vehicle. The tools so far proposed include an abrasive saw, a grinder, an impact wrench, a rope cutter, a wire brush, drills, a small winch for moving heavy objects, and a water eductor for pumping or trenching. The tool head contains reduction gears to step down the input speed (3,000 rpm) in one or possibly two steps. Power levels at the head are about 4.5 hp (3.3 kw) and an endurance time of 3 hours can be expected.

The major advantage to this approach is that tools may be interchanged without breaking the hydraulic lines. This not only avoids contamination of the fluid by seawater but also prevents the fluid from escaping into the sea. Such pollution can be dangerous not only to the diver but also to other occupants of the PTC. For oil-based hydraulic fluids, contact with the oxygen-rich atmosphere of the PTC can result in a violent reaction.

With this hazard in mind, a water-based hydraulic fluid has been adopted for use in the system. This fluid has significantly less lubricating ability than conventional fluids and the motors and pumps in the system have had to be modified to some degree. Such a development has brought the system closer to one which can operate on seawater alone, and the technology of seawater hydraulics, itself under intensive development, is being applied to these systems.

SEAWATER HYDRAULICS

Hydraulic power systems of any kind are the most adaptable and versatile systems for safely providing controlled forces and functions for use at all depths in the ocean. Systems which can use seawater as the working fluid have many advantages:

(1) they use the surrounding environment as the working fluid; (2) they are insensitive to contamination due to leakage; (3) they are non-polluting; (4) they can be used without reaction hazards in hyperbaric environments; (5) they require only one supply hose; (6) they do not require the use of pressure compensation in heat exchangers or reservoirs; and (7) they are compact, light-weight, and easy to maintain.

The original problem in the development of such systems was a materials one. There was only limited information available on materials suitable for use for close tolerance, heavily loaded bearing surfaces operating in a seawater medium. Materials studies conducted since 1977 have indicated that certain Inconel and titanium alloys are sufficiently resistant to seawater corrosion to be used for pump and motor bodies. Thermoplastics with fibre fillers can be used for parts which move in sliding contact with the metal surfaces. These materials were used to build a 3 hp (2.2 kw) spring-loaded vane motor from which it was discovered that spring fatigue appeared to be a more serious problem than wear. An improved version was then constructed and run for 250 hours, with spring renewal necessary at 100 hours (Figure 3). This motor weighed less than 7 lbs. (3 kg), occupied a volume of 23 cu. in. (375 cc) and operated at 1,370 rpm with an overall efficiency of 70%. Its performance demonstrated the feasibility of seawater hydraulic machinery and development was accelerated.

A few commercially available hydraulic components such as valves and filters need only small modifications to work with seawater. However, motors and pumps are not available off-shelf and specific development efforts are called for. Pumps are of particular interest at present. Two types, fixed and variable displacement, are required. The fixed-displacement type is suitable for surface applications where energy supplies are ample. A typical size is 15 gpm (57 l/m) at a pressure of 1,500 psi (10,200 kPa). The variable displacement type is needed for portable systems where small size and high efficiency are important, as in diver-carried tool systems. Flow rates and pressures run somewhat higher, being in the 20 gpm (75 l/m) at 2,000 psi (13,800 kPa) range.

One application of seawater hydraulic technology is already in place. This is the seawater pump used in the variable ballast system for the modified SEA CLIFF submersible. This pump is a double-acting piston type designed to operate at 9,000 psi (62,000 kPa) at a flow rate of 1 gallon (3.78 liters) per minute. It is driven by a 10 hp (7.5 kw) motor. Titanium and ceramic components are used to resist corrosion and abrasion.

The vane-type motor already described has been modified to operate as a pump and is being evaluated for use in variable ballast systems for smaller vehicles. A major question exists as to the limits to which simple dimensional multiplication can go to upscale the power capabilities of the vane motor/pump design. A study effort is currently in progress to establish guidelines; 10 hp (7.5 kw) seems to be readily attainable with little sacrifice in efficiency.

WORK IN PROGRESS

Work in both the tool and seawater hydraulic areas is continuing. Higher powered tools are being designed, including a rock drill and a low-speed, high torque drill press. This is for drilling large holes in metal objects where the torques needed are too large for a diver to control.

Other hydraulic devices being adapted to the seawater medium include linear and rotary actuators. When fully developed they will complete the array of seawater tools available to underwater workers and the tasks of both repair and recovery will be made much easier.

VEHICLE WORK PACKAGE CONCEPT

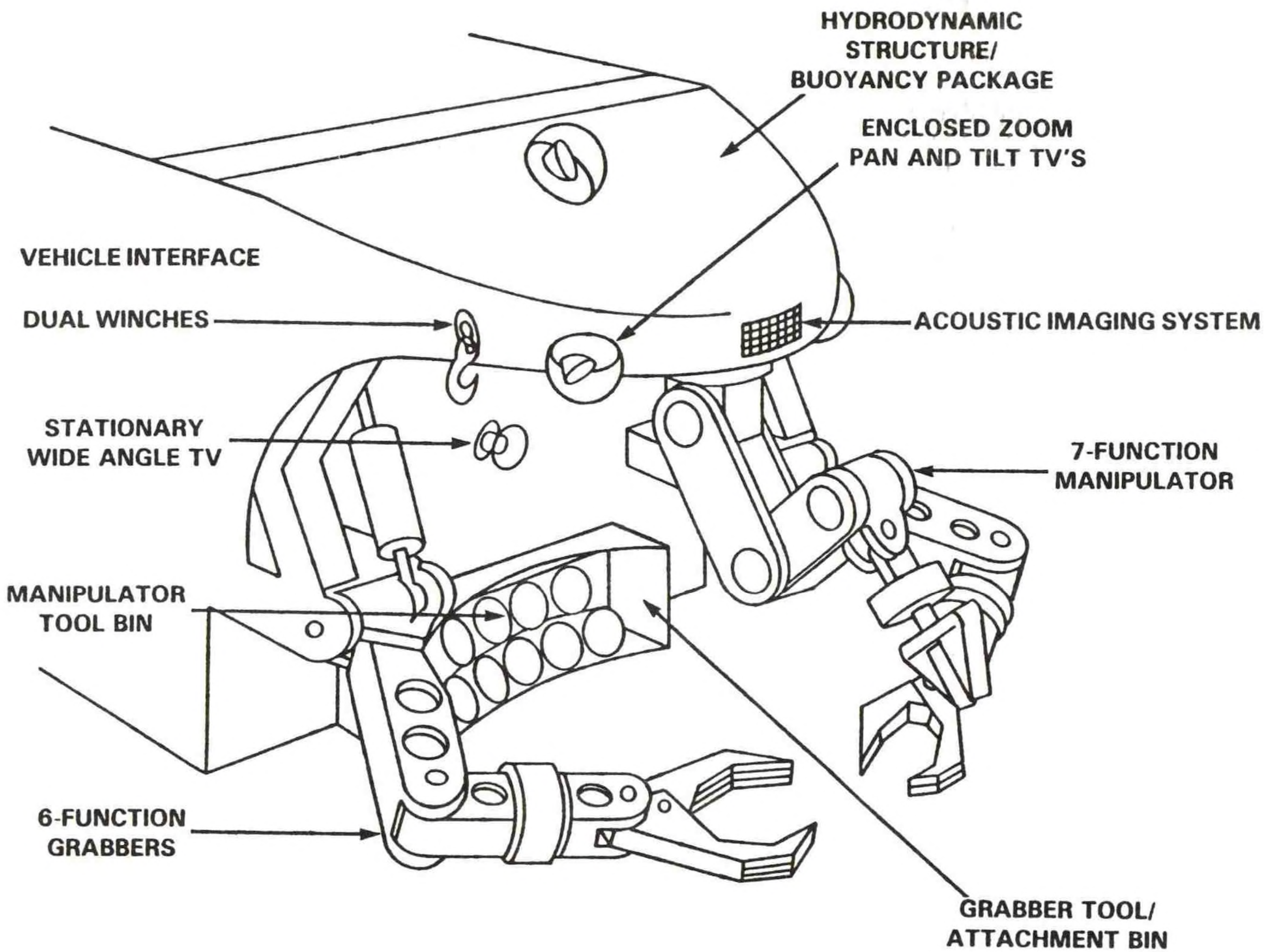
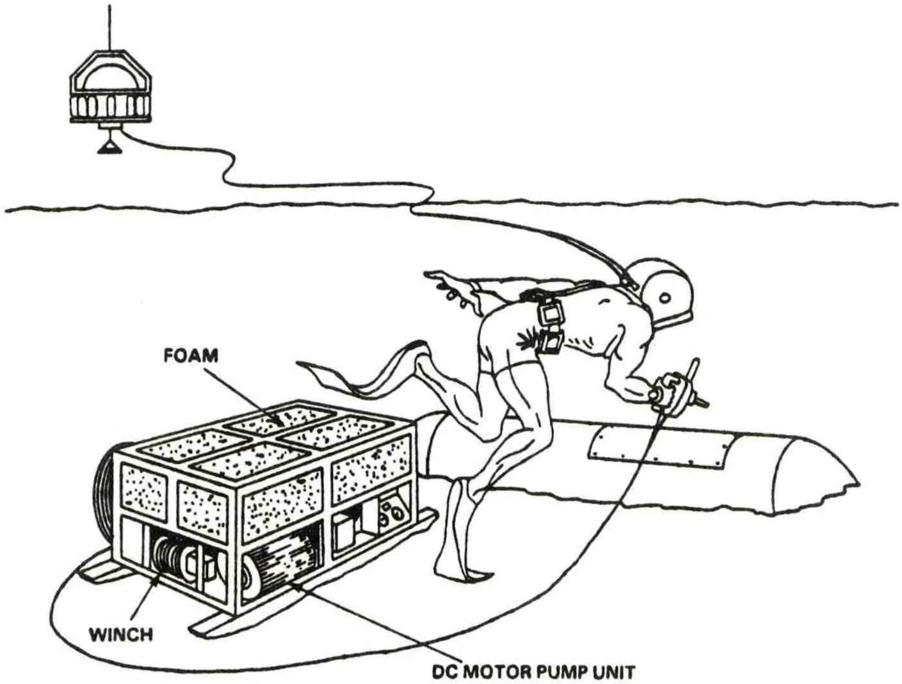


Figure 1

SATURATION DIVER TOOL PACKAGE



Saturation Diver Tool System

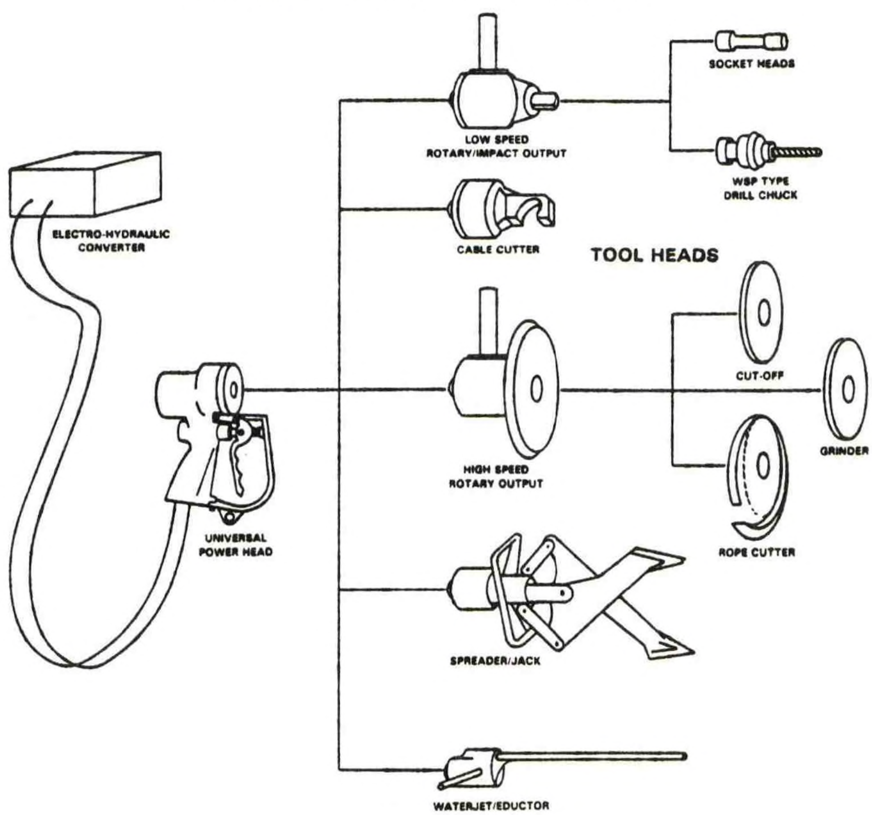
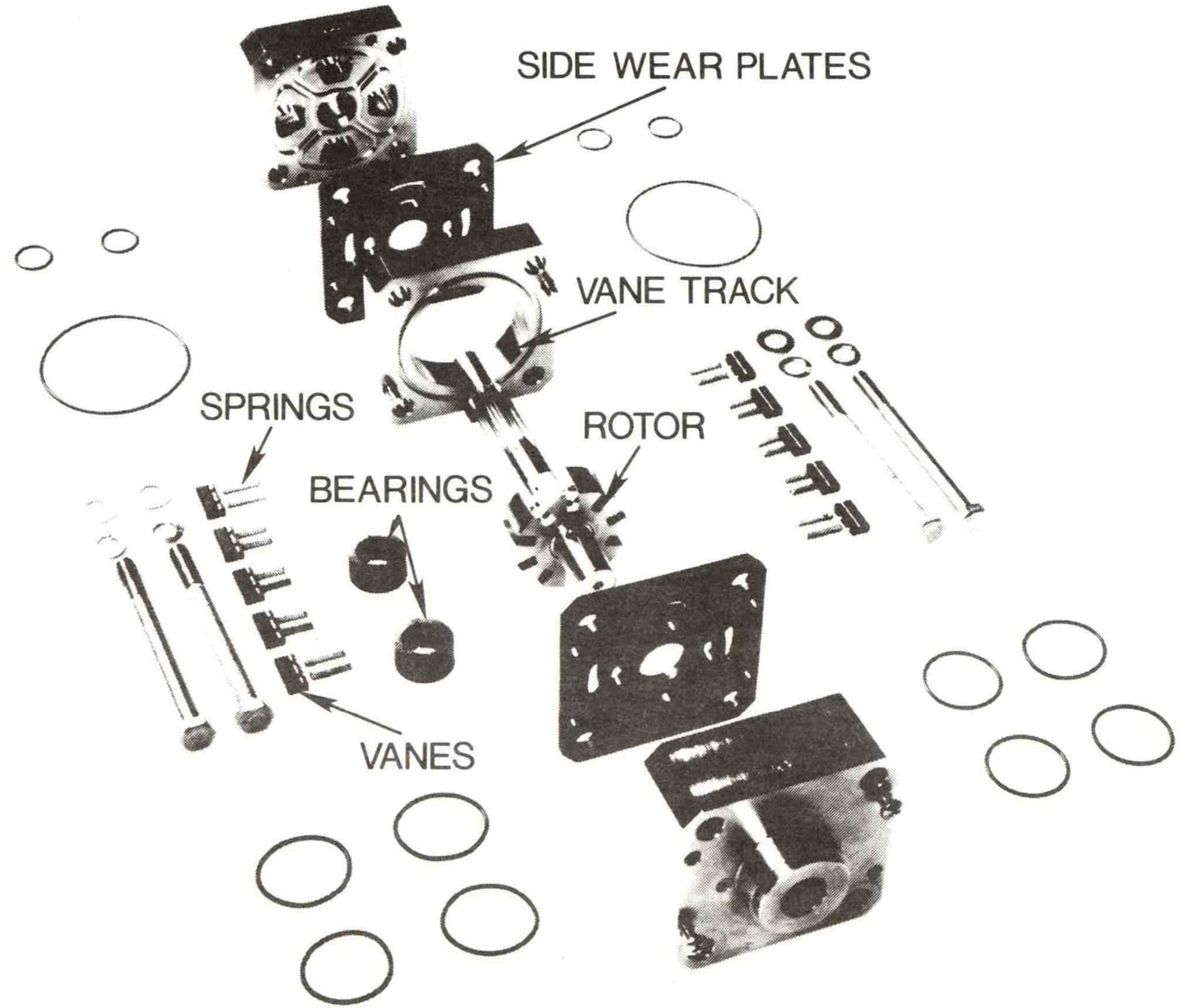


Figure 2



EXPERIMENTAL 3HP SEAWATER HYDRAULIC VANE MOTOR
3.0HP AT 1370RPM 70% EFFICIENCY WITH 6GPM

Figure 3

DEVELOPMENT OF AN ELECTRIC POWER CONTROL SYSTEM FOR 6,000M CLASS DEEP SUBMERSIBLES

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ABSTRACT

An oil-filled and pressure-compensated transistor inverter, which is suitable for installation on 6,000m class deep submersibles, has been developed for the first time in the world, its main features being small size, light weight, and high efficiency.

The particulars of the inverter unit trially manufactured are as follows.

- Rated input voltage 108V DC
- Output power more than 8KVA,3ø
- Rated output voltage more than 80V AC
- Rated output frequency 120Hz
- Maximum operating pressure 625kgf/cm^2

This unit has been tested under pressure conditions of 0 to 938kgf/cm^2 (1.5 times the pressure at 6,000m depth), and its satisfactory performance has been confirmed.

1. Introduction

World-wide interest in the scientific research and the development and utilization of ocean has remarkably increased in recent years. Under these conditions, the deep-sea surveys by SHINKAI 2000(maximum operating depth: 2,000m) have marked the beginning of a new era of ocean development in Japan, and now the development of a 6,000m class deep submergence research vehicle is being planned for wider and deeper ocean research.

The purpose of this study is to realize a compact power control system for 6,000m class submersibles by adopting an oil-filled and pressure-compensated system for a transistor inverter, the satisfactory performance of which was confirmed on SHINKAI 2000.

The study has been carried out for two years from 1982. In the first year, the principal parts such as power transistors(250V, 300A) and large electrolytic capacitors (160VAC, 6,800μF) which are capable of functioning in high-pressure oil, were developed.
In the second year, the transistor inverter was trially manufactured, assembling these parts in an oil-filled and pressure-compensated container instead of a pressure vessel. Various tests were then carried out under the pressure conditions from 0 to 938kgf/cm^2.

As satisfactory results have been obtained both electrically and mechanically, they will be reported in this paper.

2. Power Control System for Submersible

The main purpose of a manned deep submergence research vehicle is that the man on board is able to observe and investigate objects directly with his own eyes. In order to make accurate, delicate and free maneuvers possible, the submersible must be compact.

Batteries are used for the power source of such a submersible and the power is mainly consumed by electric motors which drive the thrusters, hydraulic pumps, and so on.

Two types of motors are used in a submersible: DC motors and AC motors. DC motors are used in many submersibles because they can be operated directly by batteries. However, DC motors require more frequent maintenance because they have commutator bars and brushes, and comtamination caused by clinker formation decreases the insulation resistance of the encapsulated oil especially under high pressures.

AC motors, on the other hand, are small, light, and simple in construction, and have no such problems. AC motors, however, require the power control equipment to convert DC to AC. The transistor inverters which were developed for SHINKAI 2000 using large power transistors are excellent both in controllability and efficiency.

Six transistor inverters, which are housed in three pressure vessels made of titanium alloy

(Ti-6Aℓ4V ELI), were installed outside the pressure hull of SHINKAI 2000. If these pressure vessels are adopted for a 6,000m class deep submersible, the weight of the total inverter system will be more than 2.5 times as heavy as that for SHINKAI 2000, which will cause serious problems in a submersible design.
Figure 1 shows the difference in weight.

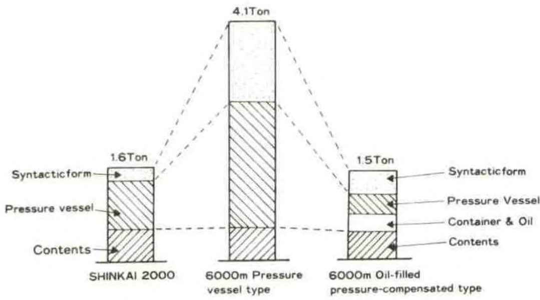

Fig-1 Comparison of weight of inverter system

The aim of this study is to make the weight of the total inverter system equal to or less than that of SHINKAI 2000 system by using an oil-filled and pressure-compensated method for the main circuit of the transistor inverter.

The electric system for the 6,000m submersible is shown in Figure 2 and the basic circuit of the PWM (Pulse Width Modulation) transistor inverter is shown in Figure 3.

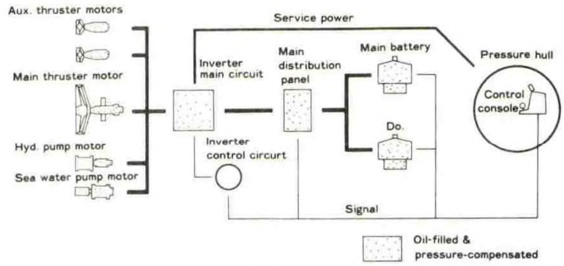

Fig-2 Diagram of electric system

3. Development of Main Circuit Parts

As shown in Figure 3, the main circuit of the transistor inverter consists of power transistors, power diodes, large electrolytic capacitors, reactors, and so on.

When conventional parts are assembled in an oil-filled and pressure-compensated container, they will be crushed and broken by the high pressure of the surrounding deep-sea water, because they have empty space inside their casing.
Therefore it becomes necessary to develop parts that can maintain their electrical characteristics and mechanical performance even in high-pressure oil.

As for reactors, it is possible to make them withstand high pressures by hardening with epoxy resin.
Transistors, diodes and capacitors, however, have empty space inside their casing.
Accordingly they must be filled with insulation oil or electrolyte and be housed in a pressure-compensated case.

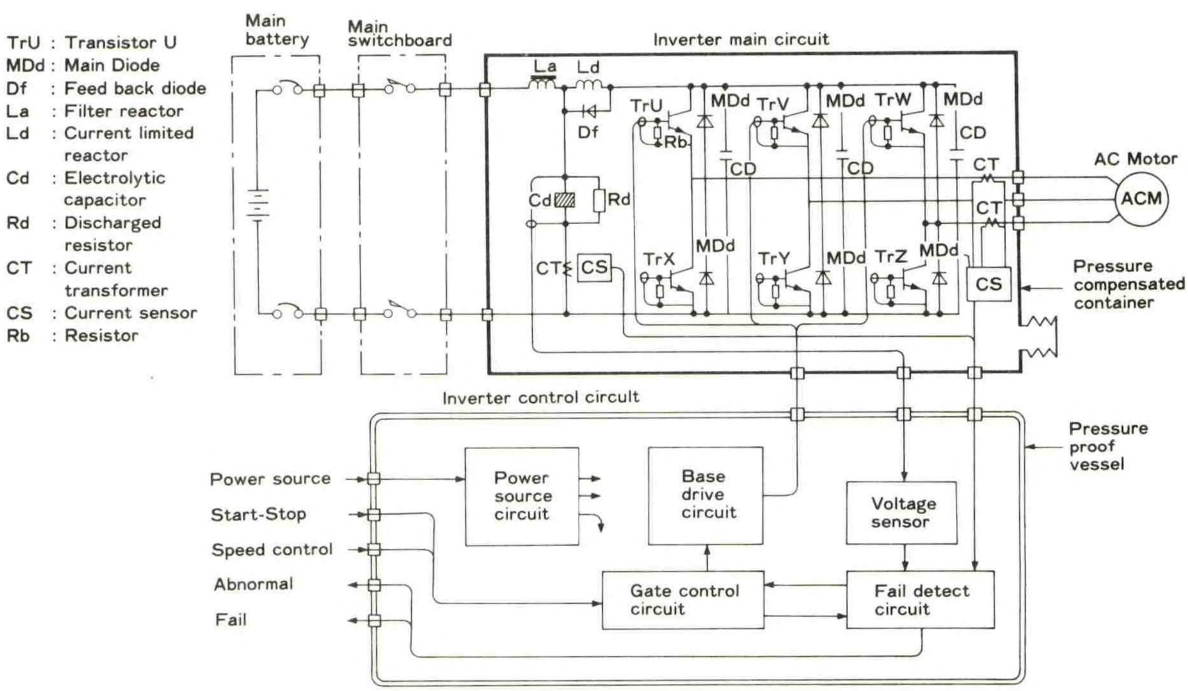

Fig-3 Basic circuit of PWM transistor inverter

Figure 4 shows an example of a power transistor. The empty space is minimized and filled with silicone oil. The flanges are so designed as to serve as pressure-compensating bellows. Figure 5 shows an example of an electrolytic capacitor. This capacitor has a rubber bladder and is filled with electrolytic fluid.

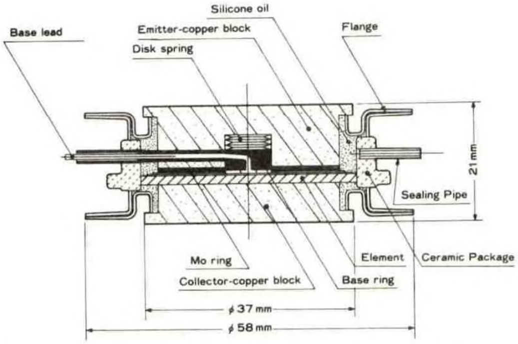

Fig-4 Oil-filled and pressure-compensated power transistor

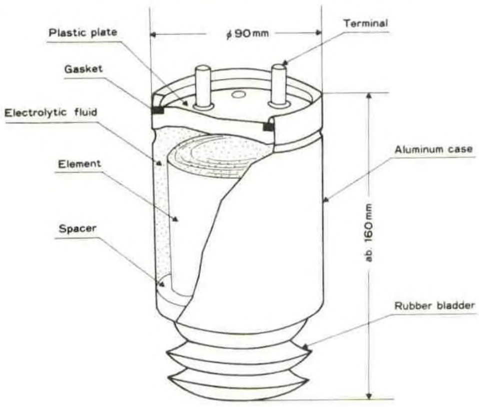

Fig-5 Electrolytic capacitor with rubber bladder

The electrical characteristic tests of each part were first carried out in insulation oil under atmospheric pressure and in high pressure test tank from 0 to 688kgf/cm^2. Then pressure-proof tests, were carried out at a static pressure of 938kgf/cm^2 and 1,000 cyclic pressure from 0 to 625kgf/cm^2 under supplying voltage to each part. Satisfactory results were obtained.

4. Manufacture and Tests for Evaluation

Using the parts described above, an oil-filled and pressure-compensated transistor inverter was designed and manufactured for evaluation. The target specifications of the newly developed inverter are shown in Table 1.

Table 1. Particulars of oil-filled and pressure-compensated transistor inverter

Control system	PWM wave control system
Rated input voltage	108V DC
Output power	More than 8KVA
Output phase	3ϕ
Rated output voltage	More than 80V
Rated frequency	120Hz
Storage temp.	−10∼50℃
Operating temp.	−5∼35℃
Sea water temp.	0∼28℃
Inclining angle	±15°(Heel) ±30°(Trim)
Rolling angle	±60°
Max. operating pressure	625kgf/cm²
Test pressure	688kgf/cm²
Proof pressure	Over 938kgf/cm²
Pressure compensating oil	Silicone oil

PWM control was chosen in order to achieve high efficiency and compactness. The input voltage was decided, assuming that the power supply was from the battery system consisted of 72 silver-zinc alkaline cells.
The output power was decided, assuming that the main thruster would require a 4kW AC motor.

The main circuit of the inverter was enclosed in an oil-filled and pressure-compensated container, and underwent various electrical charactaristic tests in an atmospheric-pressure water tank. After that, pressure tests were carried out as shown in Figure 6.

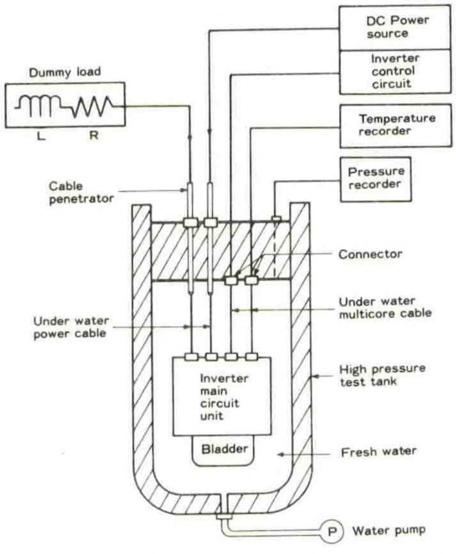

Fig-6 Schematic diagram of high pressure test

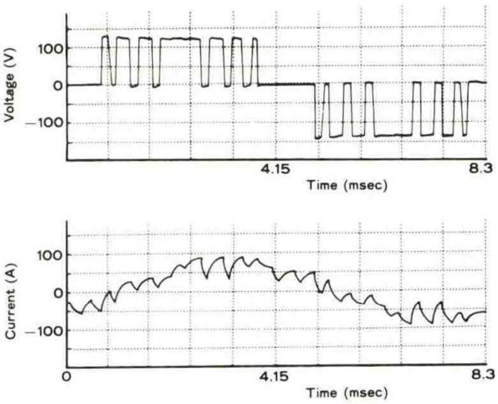

Fig-7 Output waveform
(input 135 V DC, output frequency 120 Hz)

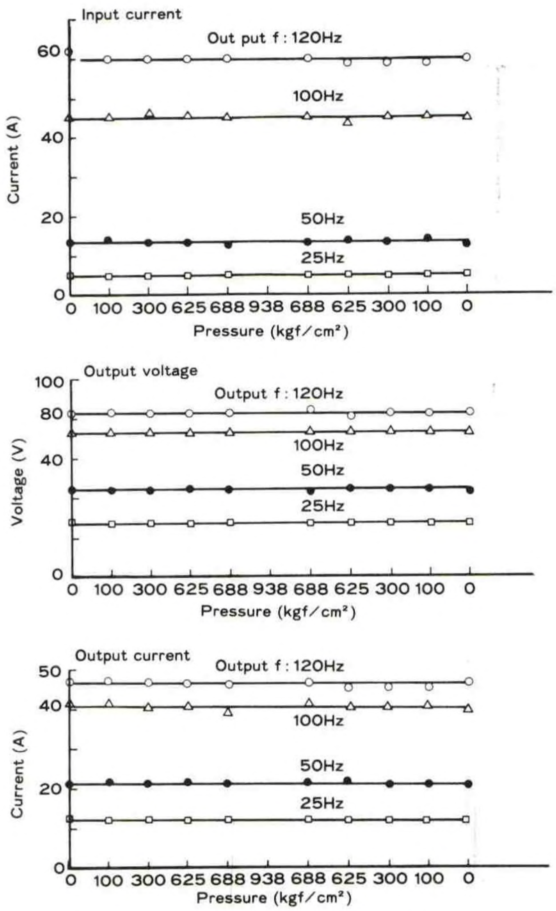

Fig-8 Input and output characteristics
(input voltage 108 V DC)

The electrical charactaristics were confirmed under pressure from 0 to 688kgf/cm^2 and the mechanical performance was confirmed at 938kgf/cm^2. Continuous operation tests were carried out at pressures of 625kgf/cm^2 and 688kgf/cm^2.

Figure 7 shows an example of output waveform of 120Hz for an input voltage of 135V. The input-output characteristics under various pressures are given in Figure 8.
By monitoring the output waveforms on oscilloscopes throughout these tests, the inverter was confirmed to have enough performance both electrically and mechanically.

5. Conclusions

An electric power control system for a 6,000m class deep submergence research vehicle has thus been developed after two years of research and development.

(1) The main circuit parts of the transistor inverter withstanding the maximum pressure of 938kgf/cm^2 and an operating pressure of 625kgf/cm^2 have been developed.

(2) Various kinds of data for the design and manufacture of a practical oil-filled and pressure-compensated transistor inverter have been obtained.

Now it is possible to apply an oil-filled and pressure-compensated method for all electric power equipment such as batteries, distribution panels, motors, and inverters, so that it will be possible for a 6,000m class deep submergence research vehicle of the same size and weight as SHINKAI 2000 with an equally satisfactory performance.

This study has been conducted under the subsidy from the Technology Development Fund of the Japan Foundation for Shipbuilding Advancement.

The author acknowledges the technical guidance of Japan Marine Science and Technology Center (JAMSTEC) and The Shipbuilding Research Association of Japan.

OXYGEN EXTRACTION FROM SEAWATER, A MAJOR ADVANCEMENT FOR SUBSEA SYSTEMS

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ABSTRACT

The ability of man to operate underwater is severely limited by his oxygen supply which he must carry in a pressure container or receive via a lifeline tether. A promising new patented process, capable of extracting oxygen directly from sea water in sufficient quantities to support a diver or provide oxygen for operating underwater power systems is currently under development by the Aquanautics Corporation.

INTRODUCTION

Biotechnology, like microelectronics technology two decades ago, is now emerging from the basic research laboratory and entering the marketplace. Aquanautics Corporation, a San Francisco-based small business firm founded to develop business opportunities associated with man's interaction with the sea, is looking toward biotechnology in diversifying its business base. Aquanautics, in 1984, obtained the patent rights from Duke University to an invention (U.S. Patent 4,427,416) by two biochemists, Drs. Joseph and Celia Bonaventura. The invention relates to a material for, and a process of extracting oxygen from fluids, such as seawater, in which oxygen is dissolved.

The commercial potential of this invention in marine applications is obvious. A device that will allow direct extraction and recovery of oxygen from seawater would not only enable man to operate undersea with a degree of freedom and mobility not now possible, but would also permit development of a new generation of non-nuclear, undersea power supply systems that can operate electrochemical fuel cells or conventional internal combustion engines.

Currently, man's capability to operate underwater is limited by his oxygen supply. Present power supply systems for undersea work and for submersible vehicles, e.g., manned and remotely operated vehicles (ROVs), also have severe limitations. The submersible power-generation systems which use batteries have limited operating time and low power-to-weight ratios. The surface-based systems which generate power by conventional means and supply it underwater via power cables impose undesirable restrictions on operating depth and mobility.

Devices capable of extracting the oxygen that is disolved in seawater, which are called artificial gills, could supply breathing oxygen for divers, or oxygen for power systems, an exciting potential.

HISTORICAL BACKGROUND

The work that led to the invention of the biologically-based oxygen-extraction process was essentially the result of a natural progression in the basic research activities of Drs. Joseph and Celia Bonaventura, a husband and wife team of internationally known biochemists. The Bonaventura team pondered the fact that fish not only extract oxygen from a low oxygen content fluid, but are capable of storing it at pressures up to 500 pounds per square inch in sacs called "swim bladders",and are apparently able to adust the amounts at will to provide buoyancy control. The Bonaventuras had long been interested in proteins that are involved in respiration, especially hemoglobin, which in our blood and in the blood of fish provides the proper environment for reversible oxygen binding. They thought they might be able to simulate in the Lab what happens in a fish.

Reversible is the key word in describing the process in which iron atoms resident in each molecule of hemoglobin will first load oxygen while passing through a lung or gill, later to unload it, after entering a cell, and returning again to reload. In the lung or gill, the iron, properly protected by the protein (globin) that surrounds it, has an affinity for oxygen, an almost magnetic kind of attachment, which decreases under the chemical condition of slightly lower pH that is natural within each cell. Without this loss of affinity, you have what is called irreversible oxidation, where the iron in losing an electron becomes, as a result, much more like iron oxide, better known as rust. For humans and for fish, reversibility, in this process is synonymous with life.

Joe Bonaventura reasoned that hemoglobin and other heme-like molecules could be made to bind oxygen outside of the body and that, if they could somehow be contained, enough of them concentrated would allow a diver or a submersible to mimic fish and extract oxygen from water. Dr. Bonaventura extracted his own blood from a vein, separated the serum, immobilized the remainder in a polyurethane sponge and then passed seawater through the sponge. He noted with sensors that most of the available oxygen had been extracted in passage. It was this immobilization effort that led to their invention of a now patented process for the extraction of dissolved oxygen from fluids.

With this proof of principle behind them, the Bonaventuras obtained modest financial backing from the Office of Naval Research and from the Naval Sea Command to explore the concept on a lab scale. By the summer of 1983, they were certain enough of the reliability of the technique to seek a commercial partner to both assist in future funding and to focus on practical applications.

Aquanautics Corporation, in the Fall of 1983, acquired the patent rights to this process and began a program for the commercialization of this technology under the direction of Mr. Taylor A. Pryor, the Aquanautics Director of Research. In an effort to expedite the execution of this program and to assemble a strong technical team, Aquanautics set up a branch of its operations in Beaufort, N.C., and formed a joint venture with Duke University.

The initial phase of the Aquanautics' development program was directed mainly at designing a small-scale device to demonstrate the integrated operation of the various process elements and to develop information for the construction of prototype devices. Research efforts, carried out with the support of Makai Ocean Engineering, Inc., have focused on the fabrication of a small-scale device capable of extracting sufficient oxygen from seawater to operate a small internal combustion engine that has been modified for shallow underwater operation.

SYSTEM DESCRIPTION

The system as it emerged by June, 1984, consisted of five major components: (1) a set of hollow fibre membranes which is exposed to seawater and which contains an oxygen carrier fluid, (2) the carrier fluid itself which is a solution that supports, not hemoglobin, but heme-like molecules with active metal sites, (3) a pump to move the fluid through the membrane to other parts of the system, and back again, (4) an electrochemical cell which acts to extract an electron from an active metal carrier causing the carrier to lose its affinity for oxygen, and later to donate an electron causing it to regain its affinity, and (5) a second set of membranes which act to separate the now free oxygen from the carrier fluid so that it can be taken off in a very pure gaseous form for breathing or combustion. Four of these items, that is all but the pump, are a result of relatively new technology developments in membrane science, biochemistry and electrochemistry which have come together to make possible a man-made gill.

A schematic block diagram of the system, combined with an internal combustion engine is shown in Figure 1. The gill subsystem incorporates

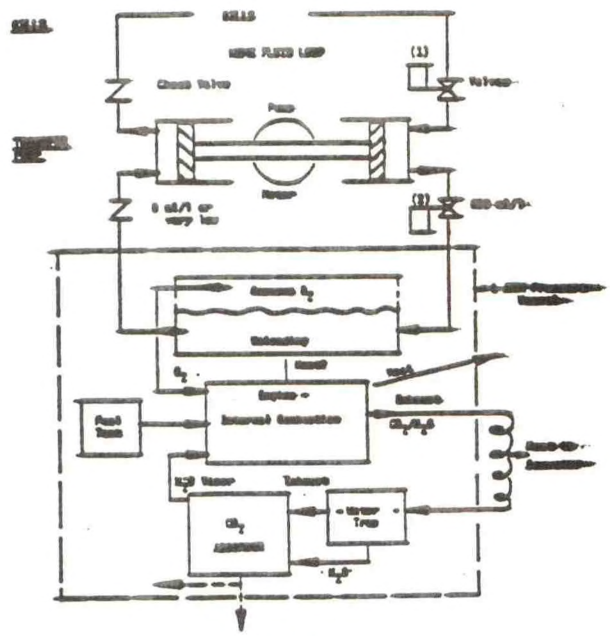

Figure 1.

hollow fibre membranes which mimic the fish's gill tissue. The carrier fluid passes through the membranes and seawater flows over the outside. Oxygen molecules, contained in the seawater, pass through tiny pores that exist in the membrane skin and are molecularly absorbed and carried away by the carrier fluid. The oxygen tension gradient between the two fluids, across the membrane, permits concentration of the oxygen to take place in the carrier fluid, up to 500-600 ml/l.

The carrier fluid then passes through a pump which isolates the higher pressure ambient carrier fluid from the 1-atmosphere carrier fluid loop within the pressure vessel. Currently, in the development effort, the technical team has dropped hemoglobin, substituted cobalt for the iron, and are now working with essentially a heme analog. While it is only an echo of the carrier fluids founding father, hemoglobin, the cobalt fluid is simple and compact, low in cost, man made, and durable.

Inside the pressure vessel, the carrier fluid is electrically unloaded and yields gaseous oxygen which can be used for a wide variety of energy converters. This component of the system is a new method for unloading the oxygen, a patented electrochemical unit which substitutes for cell tissue, but does the same job.

Cobalt has a very high affinity for oxygen but has a low affinity if one electron is removed. By simply pumping the carrier fluid to the anode of the electrochemical cell, and producing the correct potential and current, an electron is removed so that the oxygen is released. This allows the oxygen to exit out through the second set of hollow fiber membranes, and into a bladder where it is available for divers to breathe or to be used in support of a suitable power system. The carrier fluid is now moved into the cathode side of the electrochemical cell where the missing electron is restored, so that it can emerge once again with a high affinity for oxygen, and returned to the gill.

In November, 1984, the project team was able to bring all of these components together into a simple system. A unit was made to operate successfully, extracting oxygen from tap water, and demonstrating that the Aquanautics/Duke University team had successfully substituted an electrochemical shift for the chemical shift that occurs in biological tissue. A major milestone! The task ahead is a breadboard unit and a prototype capable of supporting a 5KW diesel engine. This will be completed before the end of the year.

APPLICATIONS

Scanning over the possible applications of the oxygen extractor, one can readily predict where the priorities will be in the commercial world. One use is for divers, to provide a backpack which will substitute for scuba tanks. When Aquanautics first announced in 1983 that it would develop the gill, there was indeed an amazing rush of worldwide interest.

Another application, however, looks more highly attractive. Just as the petroleum industry and the automobile boomed in tandem after the turn of the century, so should underwater robots and oxygen extractors in the undersea world at the end of the century. Such "robots" are simply unmanned submersibles with sensors, perhaps manipulators, and some artificial intelligence. They are called remote operating vehicles (ROVs). In 1975, an explosive growth in this field began and by the end of 1983, over 600 of such vehicles had been built.

The reason for this fast growth was that ROVs were accepted by the offshore oil and gas industry as a viable alternative to providing underwater services in the offshore fields. Divers, manned submersibles and manned 1-atmosphere work systems were previously used for such jobs, but ROVs offered major advantages over all of these. To list a few, they offered unlimited operational duration, can work in a wide range of environments without human risk, are less costly to maintain and operate, and are compact for flexibility and air transportability.

Tethered free-swimming vehicles account for most of the fast growth. Originally demonstrating their efficiency in performing observation tasks, their design has now advanced to incorporate capabilities for both observational and limited work tasks. Advancements in ROV technology have made this type of underwater work system very useful for a large variety of systems down to 7,500 feet of water. In only 10 years, ROVs have proven that man's place in the system is on the surface.

Currently, man's role is still a very active one in that he continuously monitors and controls the movements of the vehicle. Increasingly, however, man is taking a less active supervisory control, where he intervenes in vehicle actions only when necessary. The final step will be when man is totally removed from any function and one has the unmanned, tetherless system.

Practically all ROVs operating now receive their electric power through an umbilical cable on the vehicle. The electric power drives thrusters and hydraulic pumps and is transformed for driving electronic equipment and instruments. Power requirements vary vastly, depending on vehicle size, drag, speed, equipment on board, and umbilical length and diameter. Control data can be easily transmitted over light-weight, fine fiber-optic tethers, but this gain is limited by electric power requirements.

A few tetherless ROVs have been built and

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have performed well in special tasks, e.g. bottom surveys and oceanographic data gathering. The data collected by the ROV are stored on board until it returns to shore or to the support ship. These vehicles are powered by batteries which limit the operational endurance to a few hours without the tether. One recent study of tetherless vehicles concluded: "The major problem area in the development of the tetherless ROV is the vehicle power source."

A most promising concept for a ROV power source is the oxygen-extraction/heme system coupled with a fuel cell or an internal combustion engine. The development of the heme/engine concept culminating in successful demonstration tests of a prototype power pack would remove the greatest hurdle in the path towards autonomous ROVs. It would make the electrical power umbilical obsolete for many work systems.

For commercial and scientific purposes, the trend seems clear. Divers are being replaced by robots and robots are going deeper and doing more. The impact of severing them from the constraints of umbilical power cables and batteries first, and later from all tether requirements, can only be surmised in todays commercial market. However, it will not be long before the first heme-powered ROV will be free swimming in Hawaiian waters, undergoing evaluation by both government and civilian engineers. A great day for the undersea world!

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RESCUE BUOY SYSTEM FOR MANNED SUBMERSIBLE "SHINKAI 2000" SYSTEM

by

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ABSTRACT

2,000m deep research submersible "SHINKAI 2000" constructed by JAMSTEC has a marker buoy and cable for emergency. In this investigation, theoretical and experimental studies of rescue system using this marker buoy and cable actively are carried out.

Outline of this rescue system is as follows. The cable of the retrieved buoy is stretched between the sunken submersible and the surface ship, then keeping the position of the surface ship adequately using underwater acoustic navigation system, a go-getter connected with strong retrieval rope is launched down to the submersible by its own weight along the buoy cable. After the go-getter mates with her, she is pulled upward and then retrieved on the deck of the surface ship.

Theoretical study showed that it is not necessary for the surface ship to stay just upward of the submersible but she has a wide operational region when materials of ropes, weight of go-getter and others are appropriately designed. Ocean experiment also showed good results retrieving a dummy sinker from the depth of 2,000m which is equal to the maximum operating depth of "SHINKAI 2000".

I. INTRODUCTION

Manned submersible should be designed as safely as possible. However, underwater operations are accompanied with many and serious dangers, so operators should always consider the possibilities of accidents which oblige the submersible unable to ascend to the surface.

In case a submersible has a misfortune to have such a fatal accident at the bottom of the ocean, the crew should be rescued by the other vessels. This rescue procedure usually consists of 1)ascertainment of the sunken position and 2)retrieve of the submersible to the surface of the ocean.

There are several methods to ascertain the sunken position, such as underwater acoustic method. However, the marker buoy method will be the most simple way. Outline of this method is that the sunken submersible releases the marker buoy which contains a thin and long cable, then the surface ship catches it and stretches the cable. At the other end of the cable there sits the sunken submersible. This marker buoy method is adopted by several manned submersibles(Ref.1), and also "SHINKAI 2000" adopts this method(Ref.2).

Next stage is to retrieve the sunken submersible. One method for this stage is to use another manned or unmanned submersible. But it is usually not certain whether these submersibles can be utilized to this rescue operation during the very limited residual life support time.

The rescue buoy method is the most simple and prompt way using actively the marker buoy method although it can be applied only for submersible's weight increase. Outline of this method is that a go-getter connected with a strong retrieval rope is launched down to the sunken submersible along the thin cable(guide rope) and she is pulled up to the surface. There are several submersibles adopting this method(Ref.1).

However, effectiveness of this method is highly affected by current, properties of ropes and go-getter etc., and the effects of these factors were not found clearly yet.

In this investigation, theoretical study on these effects was carried out and then the ocean experiments were carried out to the depth of 2,000m, the maximum operating depth of "SHINKAI 2000".

Fig.1 shows the concept drawing of the rescue buoy method.

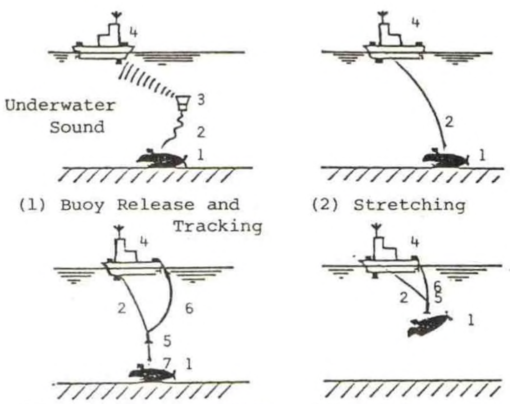

Fig.1 Concept Drawing of Rescue Buoy Method
1:Sunken Submersible 2:Guide Rope
3:Buoy 4:Surface Ship 5:Go-Getter
6:Retrieval Rope 7:Male Mating Device

II. THEORETICAL STUDY

In this theoretical study, underwater double catenary problem was treated. And in order to simplify the problem, theoretical calculation was carried out under static hypothesis.

(1) Operational Region

In case of no current, it is easily imagined that the guide rope and the retrieval rope are stretched straightly between the sunken submersible and the surface ship when the latter is just upward of the former, and a go-getter mates with the submersible without difficulty(Fig.2-A). However,

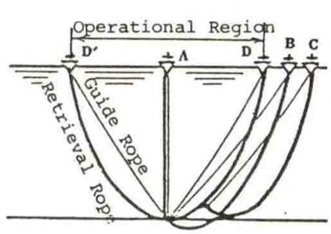

Fig.2 Double Catenaries and Operational Region under No Current

when the surface ship is some distance off from the point just upward of the submersible, the retrieval rope may droop lower than the go-getter, and the drooped rope may crowl the ocean bottom. This situation may become some problem such as friction or entanglement(Fig.2-B). Moreover, when the distance becomes longer, the go-getter may be stopped by the friction with the guide rope(Fig.2-C). Therefore the positions may exist where the retrieval rope never droops down and goes forth to the sunken submersible. The mathematical definition of these points is given as 0(or horizontal) gradient of the retrieval rope end at the ocean bottom(Fig.2-D and D'). The retrieval operation is considered to be carried out successfully when the surface ship stays between these D and D'. So this region was defined as "Operational Region" in this study.

When there is any current, the points D and D' may drift. So one of this theoretical study is to find out the relation between the current and the operational region.

Moreover, the guide rope is stretched between the surface ship and the sunken submersible by a constant tension at the surface ship and when the current is very strong, the hydrodynamic force on the guide rope may become stronger than the tension exerted at the surface ship, so there may exist some position upstream from where the guide rope cannot be stretched. This point also gives the limitation to the operational region.

Therefore, the operational region was calculated using the conditions that;

1) The guide rope can be stretched between the surface ship and the sunken submersible,
2) The go-getter can go forth and mates with the sunken submersible, and
3) The gradient of the retrieval rope at the bottom is larger than 0(or horizontal).

(2) Optimum Solution Condition

When the operational region is very narrow, any drift of the surface ship or any fluctuation of the current may bring the surface ship away from the operational region very often, and the rescue operation including the position keeping of the surface ship becomes very difficult. Therefore the operational region should be as wide as possible, and such region is optimum. So, in this study, optimum solution of the rope sizes, rope diameters, rope materials, guide rope tension and size and weight of the go-getter etc. were calculated in order to make the operational region the widest.

(3) Parameters on Operational Region

Operational region is determined by the following 9 parameters.

1) Depth
2) Current pattern
3) Guide rope tension
4) Material of the guide rope
5) Diameter of the guide rope
6) Material of the retrieval rope
7) Diameter of the retrieval rope
8) Weight of the go-getter
9) Frictional coefficient between the guide rope and the go-getter

In this calculation, the depth was selected mainly as 2,000m and the current pattern was hypothesized as no current between 500m and 2,000m deep and triangular increase from 500m deep to the surface.

(4) Tank Test

Beforehand of the above mentioned parametric studies, tank test using a circulating test tank of JAMSTEC was carried out in order to confirm the calculation method, and the results showed good agreements.

(5) Effect of Each Parameter

In order to optimize the operational region, the effect of each parameter was calculated. This calculation shows that,

1) When the tension of the guide rope becomes stronger, the operational region becomes a little wider, but the effect is not so significant. However, the tension affects the maximum operational surface current velocity, so the tension should be as strong as possible.
2) The diameter of the guide rope has no significant effect on the operational region.
3) The density of the guide rope should be as small as possible.
4) The diameter of the retrieval rope should be as small as possible.
5) The density of the retrieval rope should be as small as possible. If it is large like steel wire, the operational region becomes very narrow.
6) The frictional coefficient between the guide rope and the go-getter should be as small as possible. This means that usual rope of rough surface should be avoided as the guide rope but the rope sheathed with smooth surface material should be preferred instead. Also the inner surface of the go-getter should be smooth and rounded.
7) About the weightof the go-getter, the calculation shows that the weight should not be too light or too heavy, but be about 50-70% of the guide rope tension.

III. ROPES AND GO-GETTER

In order to specify the ropes and the go-getter the type of accident should be defined. This rescue buoy system is designed to rescue the submersible sunken by weight increase. In case of SHINKAI 2000, her maximum weight increase is presumed as about 1.2ton by the seawater flood-in to the pressure vessels and the exchange of oil of the oil-filled devices with seawater. So the breaking strength of the retrieval rope is determined as more than 12ton adopting the safety factor as more than 10.

The candidates of the retrieval rope are Nylon rope of 26mm Dia.(Breaking strength; 12.6ton) and Kevlar rope of 14.8mm Dia.(Do.; 12.6ton), but wire rope is excluded because of its heavy density.

The calculation for selection from these two candidates shows no significant difference on the operational region, so Nylon rope was selected because of the easy handling and low cost. The length was decided as 3,300m following to the catenary calculations.

The guide rope should be as light, thin and strong as possible. And also its surface should be smooth. So the Nylon sheathed Kevlar 29 rope of 3.4mm Dia.(Do.; 880kg) was selected. From its breaking strength, the tension exerted to the guide rope was determined as about 100kg by taking the safety factor more than 6. The length was also determined as 3,300m.

The weight of the go-getter was determined as 50kg in order to get 50% of the tension of the guide rope.

In Fig.3, The calculation result on the operational region using these ropes, tension and the go-getter is shown.

IV. DEVICES

The rescue buoy consists of the buoy, reel, pinger and the cable, and is installed in SHINKAI 2000. The pinger indicates the release of the buoy and also indicates the bearing of its position relative to the surface ship by its underwater acoustic pinging so that its tracking becomes

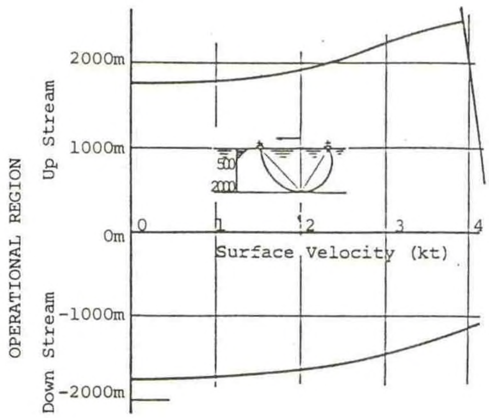

Fig.3 Relation between Operational Region and Surface Current Velocity of Model Current Pattern

very easy. The real is fixed in the buoy and when ascending, the buoy itself rotates so that the cable is dragged out smoothly without kink. The ascending velocity is calculated to be about 70-80m/min. The rescue buoy is connected with SHINKAI 2000 through a cut-off device.

(2) Go-Getter

Fig. 4 shows the configuration of the go-getter and the outline of mating sensor. Gravity cen-er of the go-getter is located as rear as possible in order to make the mating attitude straight forward. The principle of the mating sensor is the obstruction of ray. When the photo transistor doesn't receive the light emitted from the LED, the underwater acoustic pinger begins to ping. However, the light obstruction may occur not only by the mating but also by the guide rope. In order to distinguish them, the circuit is so designed as to ping after 30 seconds continuous light obstruction because the guide rope cannot obstruct the light such long time. The LED and photo transistor are usual commercial ones and are directly pressurized by seawater. They were selected from many candidates through the pressure test(water and seawater) and the temperature test of 0°C 20°C. The performance test at the sedimental environment was also carried out and this system showed good performance even at the usual worst conditions.

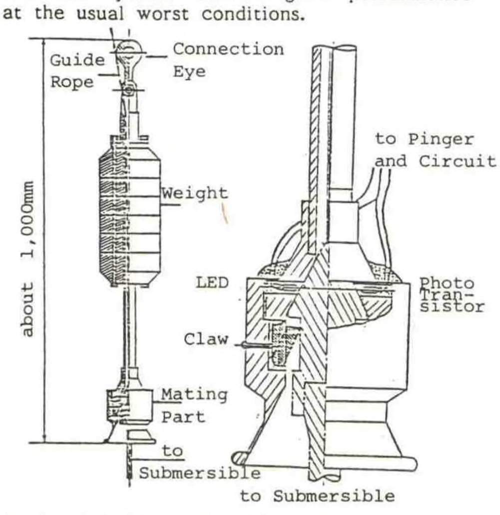

Fig.4 Go-Getter and Mating Sensor

(3) On-Board Devices

As is already mentioned, the surface ship should keep her position. "NATSUSHIMA", the support ship of SHINKAI 2000, has a splendid underwater acoustic navigation system and maneuvering system. However, these are not dynamically positioning system, so she is manually controlled. At the rescue operation, the relative position to the sunken submersible is measured by the underwater acoustic navigation system. And using these data the crew controls each machinery such as two controllable pitch propellers, two rudders and bow thruster. The ocean experiments showed that even in the very rough sea of more than 15m/sec wind speed, NATSUSHIMA could keep her position precisely with error of only 30m.

In order to exert the constant tension to the guide rope, "Constant Tension Winch" is settled on the forecastle deck. The guide rope is wound in this winch through the handy davit.

The retrieval rope is wound in "Retrieval Rope Reel". This is hydraulically driven and the retrieval rope is wound up/off. However, this reel has no such capacity as to retrieve the sunken submersible by itself. The force required to retrieve is exerted to the retrieval rope by capstan through blocks fitted on the A-frame crane and on the poop deck.

V. RESCUE PROCEDURE

In case of a fatal accident of SHINKAI 2000, the pilot pushes the button of the rescue buoy and it ascends to the surface pinging and dragging out the guide rope. The surface ship tracks the ascending buoy using underwater acoustic navigation system and make work boat stand-by to retrieve the buoy.

Just after when the buoy emerges on the surface, the work boat catches it, and it is picked up on the forecastle deck. Then the residual guide rope in the buoy is dragged out manually and is cut at an appropriate length. The rope is put through the go-getter and is wound in the constant tension winch through the pendant block on the handy davit. The go-getter is hanged outboard on the davit. After the adjustment of the position of the surface ship, the go-getter is launched down to the sunken submersible dragging the retrieval rope. Also the retrieval rope reel is driven precisely so that the rope is wound off with neither slacking or tight-stretching in order to avoid kink or to make the time for retrieval short.

Some time after the go-getter launching, it mates with the male mating device of the sunken submersible. The mating is found at the surface ship by sensing the mating shock transitted through the guide rope or by the underwater acoustic navigation system catching the underwater acoustic pinging of the pinger.

After the mating, the winding off of the retrieval rope is stopped and fixed at a cross bit temporally and then the retrieval rope is brought to the stern and the preparation for retrieval is accomplished. Then, releasing the fixation of the retrieval rope at the cross bit and driving the capstan, the retrieval work starts. During this work, the retrieval rope reel and the constant tension winch are also driven so as to avoid the entanglement of the ropes.

As is already mentioned above, this retrieval rope reel has no capability to retrieve the submersible onto the deck. Therefore, the submersible is retrieved up to 5-20m beneath the surface, and after then A-frame crame system is driven for the retrieve onto the deck as usual.

VI. OCEAN EXPERIMENTS

As can be easily imagined, this rescue operation is highly influenced by the training level of the operators who are crew of the support ship NATSUSHIMA. Therefore, the ocean experiments of this rescue buoy system were carried out in order not only to confirm the capabilities of this system but also to train the operators.

In the experiments, it was very difficult to use the actual submersible SHINKAI 2000 as a sunken submersible, so specially designed Dummy Sinker was used instead.

As is shown in chapter V(Rescue Procedure), the rescue operation is divided into two phase. One is the releasing and catching of the rescue buoy and the other is the mating and retrieving. In case of the experiment also, it is divided into the same two phase.

The experiments were carried out by three periods. The first period was January 1982 at the depth of 100-500m for the first and the second phase at SAGAMI Bay, the second was July 1982 at the depth of 1300-2000m for the second phase at SURUGA Bay and the third was January 1983 at the depth of 2,000m for the first and second phases at KUMANO-NADA.

VII. TEST RESULTS

The experimental results on the relation between the depth and the horizontal distance are shown in Fig.5. Because we had no method to measure the current pattern at this time, the experimental results are compared with the static theoretical limit for no current as shown in solid line in this figure.

The time for retrieving concerns mainly with the depth, however, it concerns directly with the length of the retrieval rope wound-off. The comparison of the 2,000m deep retrieval tests at the second and the third period showed the effectiveness of the mating sensor, that means, the retrieval at the second period of 2,000m depth took about 2 hours but it was only 1 hour at the third period when the mating sensor was introduced. The reason is that the too much longer rope was wound-off at the second phase because the mating could not be sensed.

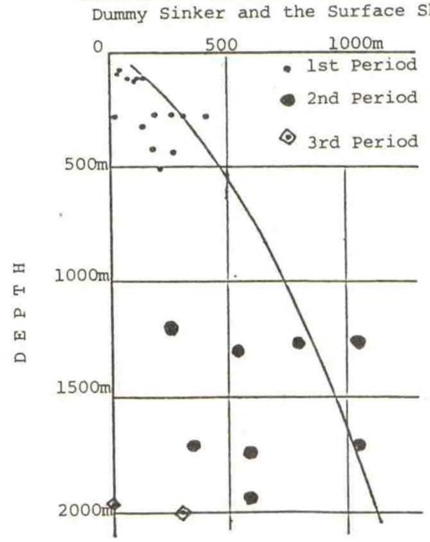

Fig.5 Experimental Results for Second Phase (Launching, Mating and Retrieving)
Remark: Calculation was carried out with Frictional Coef.;0.3

VIII. CONCLUSIONS AND PROVISIONS

By these experiments, the following results were obtained.

1) It was confirmed that this rescue buoy system had a good performance to mate even at the very deep ocean of the depth of 2,000m. The operational region had a fairly wide region and this means that the operation becomes very easy. This system is a cheep, small and light one compared with other manned or unmanned submersible system. Of course its capability is restricted, however, it will be an effective system as an instant rescue method.
2) Test results showed that the mating could be done even beyond the theoretical limit. This reason is presumed as the dynamic effect at descending. And this situation means that the rescue operation becomes easier than can be given by the static theory.
3) The mating sensor worked well even at the depth of 2,000m. This method will be applied to any area of deepsea activity. But also it is important that LED and photo transistor are used under the condition of direct pressurization by seawater. This result shows the near future feasibility of electronic parts application under pressurized condition, and of small and light weight design of manned and unmanned submersible.
4) This rescue buoy system is originally developed for the rescue of manned submersible. However, as is easily seen, this method can be applied to another recovery area of any objects from the deepsea. We hope this system utilized to such recovery operations.

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MANAGING ENERGY WASTES IN THE OCEAN

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ABSTRACT

The exploitation of the ocean as a practical source of energy as well as a safe disposal site for energy wastes becomes reality as our knowledge of ocean technology increases. Presently the ocean is used as a sink for CO_2 in the atmosphere. The ocean also receives drilling fluids and cuttings, brine effluents (produced water) arising from offshore platform operations, and coal wastes (fly ash and colliery wastes). In 1983 and 1984 no nuclear wastes were disposed of in the ocean. As our nonrenewable energy reserves become smaller, the renewable energy in the marine environment should be exploited.

INTRODUCTION

Recently we (including Dr. Bostwick H. Ketchum, 1912-1982) edited a series of books entitled "Wastes in the Ocean", issued by Wiley-Interscience, New York City. As its volume 4 we edited "Energy Wastes in the Ocean" that is published in 1985. While editing we noted that both the production and the consumption of fuel and energy create considerable wastes. We believe that both scientific understanding of the fate and effects of the disposed wastes and technical knowledge of how to dispose of the wastes safely in the marine environment must be considered simultaneously to insure the future growth of mankind. The ocean, as a large energy source as well as a vast disposal site, is intrinsically coupled with our future energy demand.

ENERGY DEMAND

The demand for energy by us has accelerated faster than has population growth. In 1900 the rate of energy consumption per person was about 4000 kilowatt-hour per year (kWh y^{-1}); in 1980 it was 20,000 kWh y^{-1}. Sustained economic growth needs more electricity (energy) since mechanization and automation depend on electricity rather than human labor. In general, the gross national product (GNP) is proportional to energy consumption.

However, there is an upper limit to the amount of energy we can extract safely from the Earth[1]. Beyond that, climate and weather patterns could be affected for the energy we spend may eventually be returned to the atmosphere as heat. The Earth presently receives 10^{17} joules per second (J s^{-1}) of solar radiation. The maximum energy use safely allowed is estimated to be 10^{15} J s^{-1}[1]. The present global energy demand by humans is about 10^{13} J s^{-1}. When our energy demand increases to 10^{14} joules per second or more in the 21st century, we will be approaching the upper limit of the global capacity to consume energy safely. Even for that reason alone, it is prudent for us to conserve energy.

ENERGY RESOURCES

In the United States of America we mainly use petroleum liquids, natural gas, coal, hydropower and nuclear power to produce enrgy. Hydropower is renewable; a limited increase in hydropower production is seen for the future.

Nonrenewable energy reserves in the United States are shown in Table 1. Within several hundred years many of these reserves will be depleted. Effective and safe use of nuclear power, such as breeder reactors, will give us an energy sufficiency in the order of 1000 years. Other countries, including Japan, are not as fortunate as the U.S. is. We believe that renewable energy sources should be tapped as much as possible.

Table 1. Energy Reserves in the United States

Material	Energy Reserve (joules)	Estimated time of Depletion(yrs)
Natural gas	9×10^{20}	50
Petroleum liquids	8×10^{20}	50
Oil shale	5×10^{20}	50
Coal	3×10^{22}	400
Uranium(nonbreeder)	10^{21}	30
Uranium(breeder)	10^{24}	1000
Thorium	2×10^{24}	1000

ENERGY WASTES

Energy wastes come from exploration and mining operations, and from all the steps of the fuel cycles ranging from combustion to dismantlement; the four main fuel cycles are that of natural gas, oil, coal and atomic energy. When fuels are burned, they produce solid, gaseous (air-pollutant) and heat wastes. Notable ones include fly ash (mainly from coal burning), CO_2, CO, hydrocarbons, nitrogen oxides and sulfur oxides. Large quantities of solid wastes produced by coal combustion must be collected and disposed of or utilized properly as a resource in order to prevent air, land, and water pollution. For nuclear wastes, care must be taken to prevent any radiation damage to man as well as irresponsible proliferation of nuclear weapons (atomic bombs can be fabricated from nuclear wastes).

Carbon dioxide is the major waste product of fossil-fuel burning. In 1980 five billion metric tons of carbon were produced as carbon dioxide; per capita we ejected 1.2 metric tons of carbon (4.4 metric tons of carbon dioxide) into the atmosphere. Approximately one half of the CO_2 produced may have entered the ocean.

When coal is burned, fly ash and bottom ash are produced as solid wastes. In the United States they are usually dumped into disposal ponds, landfills, or in the ocean. Flue-gas desulfurization (FGD) sludge is also produced as a coal waste; the U.S. may produce two million metric tons of 50%-solid FGD sludge in 1985. In Japan FGD waste is utilized for wallboard fabrication and as an additive in cement production.

MARINE DISPOSAL OF ENERGY WASTES

Recently, drilling fluids and other discharges from offshore oil and gas operations came under scientific scrutiny[2]. Drilling fluids and cuttings are discharged continually into surrounding waters during the drilling operation and are discharged in bulk at the completion of drilling. Drilling fluids discharged into the ocean can be as much as 33,000 metric tons per platform. During the production phase of oil and gas, brine effluents (produced water) become the major discharge.

Coal wastes are disposed of into the ocean as loose fly ash and as consolidated coal waste. The Blythe Power Station in the United Kingdom dumps about one million metric tons annually of loose fly ash into the North Sea[3]. Colliery wastes (the solid material remaining after coal is washed; they are mainly shale and sandstone particles) are also dumped into the North Sea[3].

In the United States several experiments have been carried out to use coal ash wastes for artificial fish reef construction. Fly ash and FGD were stabilized with lime and Portland cement; the wastes thus became bricks with which to build the fish reefs. The blocks were then placed in the New York Bight apex (Atlantic Ocean), the Chesapeake Bay and Lake Ontario as artificial reefs to improve sportsfisheries.

No marine disposal of nuclear wastes has occurred in 1983 and 1984. The wastes have been stored on land awaiting an international decision on its marine disposal.

RECOMMENDATIONS

Two recommendations we wish to advocate here are 1) control of energy consumption rate so that no adverse climatic and weather change occurs rapidly[1], and 2) exploration of renewable forms of ocean energy. The upper limit of energy consumption may be 1% of the incoming solar radiation as deduced by von Arx[1]. For the renewable forms of ocean energy, much technological development is needed to convert diffuse, renewable energy into readily useable forms. With advanced technology the ocean will play a major role in man's quest for renewable energy (Table 2).

Table 2. Renewable Energy in the Marine Environment [1,4]

Source	Total Power (joules per second)
Photosynthesis	10^{14}
Thermocline(OTEC)	10^{13}
Steady surface wind	10^{12}
Variable surface wind	10^{12}
Potential(osmotic pressure)	10^{12}
Damming of evaporative sinks	10^{11}
Surface waves	10^{10}
Geothermal power	10^{10}
Tidal flow	10^{9}
Great oceanic currents	10^{8}

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COAL WASTE ARTIFICIAL REEFS IN THE UNITED STATES

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ABSTRACT

Fly ash and flue-gas desulfurization sludge can be mixed with hydrated lime, cement, and water to form coal-waste blocks for disposal into the ocean as an aritifical reef. Two blocks are produced every 6 to 8 s at a concrete block-making factory using conventional equipment. Accelerated curing of the blocks using 70°C steam quickly produces block strengths exceeding 2000 kPa, which allowed automated handling of the blocks for transport and disposal at sea. Fifteen thousand blocks (450 t) were disposed of in the sea to form an artificial reef in the Atlantic Ocean south of Long Island, New York, the United States of America. The reef has a relief of about 1 m, and a length of about 70 m, and covers about 1200 m^2 of seabed. The reef blocks have maintained their physical stability and are being examined for their biological and chemical acceptability as a means of disposal into the ocean.

INTRODUCTION

Many countries are converting to increased coal usage for electricity generation because of the rapidly rising cost of oil and the uncertainty in the oil market. In coal combustion, fly ash and flue-gas desulfurization (FGD) sludge are the main soild wastes produced; several hundred tons of coal waste are generated daily from a 500-MW power plant. Fly ash is a finely divided mineral byproduct with high concentrations of silica, alumina, and iron oxide. Flue-gas desulfurization sludge is the solid residue remaining after SO_2 is removed from stack emissions; it is primarily a mixture of $CaSO_3 \cdot \frac{1}{2}H_2O$ and $CaSO_4 \cdot 2H_2O$, the relative amounts depending upon whether the SO_2 scrubbing system uses lime, limestone, or forced oxidation.

In the United States of America most of the fly ash is disposed of in landfills, with less than 20% utilized as a resource, mainly by the concrete industry. FGD sludge is disposed of entirely in landfills.

In their shift to coal, many power plants will be faced with a very serious waste-disposal problem because of the large volumes of coal waste; thus the need is growing for new solutions to the coal-waste disposal problem. Because of the scarcity of land and environmental problems associated with disposal of coal wastes on land, the ocean could become a possible site for disposal.

The chemical stabilization of fly ash and FGD sludge to form a stabilized power-plant coal waste composite has led to some success in decreasing the amount of leached toxic metals entering the groundwater flowing near a disposal site. Chemical stabilization of fly ash and FGD sludge is made possible by the formation of cementitious compounds after the wastes are mixed with lime. Two kinds of cementing products are formed when coal waste reacts with lime (Table 1): (1) hydrated compounds from the chemical reactions occurring between silica, alumina, and lime; and (2) aluminosulfate compounds, which are formed when the FGD sludge components $CaSO_3 \cdot \frac{1}{2}H_2O$ and $CaSO_4 \cdot 2H_2O$ react in the presence of water and the added lime with the alumina present in fly ash.

Stabilized, power-plant coal wastes in the form of solid blocks were tested in a pilot study to determine their effects on an estuarine system and their potential as reef-building material (Duedall et al., 1981; Roethel et al., 1983). This study led to a larger project involving machine production of coal waste blocks and the subsequent placement of these blocks into the ocean to form a reef (Parker et al., 1981, 1982). This present paper reports on the research required for the successful machine fabrication of approximately 15,000 of coal waste blocks, each 20 cm x 20 cm x 40 cm, and their disposal into the Atlantic Ocean as an artificial reef. Other smaller reefs or oyster bars have been constructed in Chesapeake Bay, in Lake Ontario, and in Long Island Sound.

Table 1. Composition of Reactants and Cementing Products in Stablizied, Power-Plant Coal Wastes

Reactants	Cementing Products
Fly Ash	
SiO_2	$3CaO \cdot 2SiO_2 \cdot 3H_2O$
Al_2O_3	$3CaO \cdot Al_2O_3 \cdot H_2O$
Flue-gas Desulfurization Sludge	
$CaSO_4 \cdot 2H_2O$	$3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O$
$CaSO_3 \cdot \frac{1}{2}H_2O$	$3CaO \cdot Al_2O_3 \cdot CaSO_3 \cdot 7H_2O$

FABRICATION OF COAL WASTE-BLOCKS

The coal waste blocks were made using conventional concrete block-making technology (Figure 1). The block-making plant was equipped with a Besser block-making machine. The batches were stored in a hopper above the block-making machine and transferred to the mold via a feed box. Feed time allows the feed box to pick up material at the bottom of the hopper and transfer it to the mold; the compression shoes press the material into the vibrating mold during the finishing time. The feed time was approximately 5-7 s, and the finish time averaged about 2-3 s. At both plants, batches with low solids content needed longer feed times and shorter finishing times; while dry batches needed less feed time and longer finish time. Adjustment of the feed box height is important because the compression shoes are lowered into the mold to a predetermined depth; if enough material does not fill the mold, the blocks will not receive sufficient compaction. Two blocks were produced per cycle.

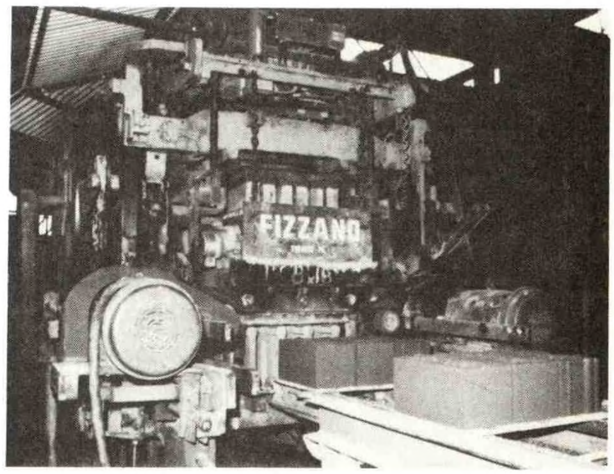
The additives used were hydrated lime (6% by wt) and Type II Portland cement (3% by wt). Moisture content of the coal-waste mix was the most critical factor in processing the coal waste with block-making machinery. The steam kilns operated at 70°C with a 24-h curing period repeated one or more times depending on the experiment. This became important in the development of initial block strength. After the cured blocks were tested for strength, other blocks from the same batch were fed through a conventional block cuber to determine how well blocks stood up to handling by the cuber and the conveyor system.

The compressive strength of the blocks provided the best index of performance for block handling and for block stability in the sea (Figure 2). Blocks with strengths of 2000 kPa held up well during mechanical handling by automated factory machine, including stacking in interlocking layers by the cubing machine. Due to their shapes, blocks that had slumped were more difficult to interlock. The strength of 2000 kPa was adopted as the criterion for long-term survival of the blocks in the sea (Duedall et al., 1981).

BLOCK CURING

Once the blocks were formed, they were transferred to an underground circular steam-curing chamber where they remained for 0.5 to 3 d, since it was found that a longer curing time produced a stronger block. The freshly cured blocks averaged 29.5 kg each, although block weight decreased to 28.6 kg when the blocks remained outside for a few days. The temperature in the steam kiln ranged between 60 and 70°C.

FIGURE 1. Block-Production Facility



BLOCK CUBING

Cubing, the automatic stacking of individual blocks into interlocking layers to form a stable, easily portable cube, held the greatest potential for damage to the blocks. The blocks were pushed off their pallet and loaded into the front of the cuber, where the blocks were turned so that they would interlock. An armature then pushes rows of blocks together into layers onto a cart for transport. The total weight of the cubes ranged between 2.3 t and 3.2 t depending upon the cubing configuration. In order to avoid the use of wooden pallets, the first layer of the cube was made of conventional hollow concrete blocks (20 cm x 20 xm x 40 cm) to allow fork lifting. The concrete blocks also served as a reference material for comparison with the coal waste blocks in the ocean.

REEF CONSTRUCTION

The cubes of coal waste blocks were taken on flat-bed trailers to Port Kearney, New Jersey. There the cubes were placed in large skip buckets and placed into a 180-m-long bottom dumping barge, with 8 pockets and a capacity of 1500 m^3. The barge was towed to the disposal site by tug boat. The reef site was located 3.7 km off Fire Island, Long Island, near an existing artificial reef made of construction rubble. Once the barge was positioned over the reef site, the bottom doors were opened in sequence, and the coal waste blocks fell to the seabed. The entire disposal operation took 15 min to complete.

BATHYMETRIC SURVEYS

Bathymetric surveys to map the position and relief of the coal waste reef were carried out once before and once immediately after construction of the reef. The work was conducted using a specially developed computerized data acquisition system designed to provide maximum precision between successive surveys over the same area (Morton, 1983). A trisponder system was used to obtain continuous and accurate (± 1 m) ship positions for the bathymetric surveys. Measurements of the water depth during the surveys were made using a precision fathometer system consisting of a digital graphic recorder, a transciever, a digital tracking system, and a 200 kHz narrow beam (4^0) transducer; depth measurements were accurate to ± 20 cm.

The general bottom topography of the region reflects a gentle northeast southwest bottom slope with depths ranging between 18 and 20 m. The bottom in the vicinity of the reef is flat and nearly featureless, with a slight slope to the southwest. The total depth difference over the 300 m x 300 m area is less than 1 m. A probable outcrop in the southwest corner of the survey area is the only discernable feature found at the site.

The result of the contouring of all post disposal data showed an irregular elliptical mound of coal waste blocks oriented in a northeast-southeast direction. The highest point of this mound was 0.4 m.

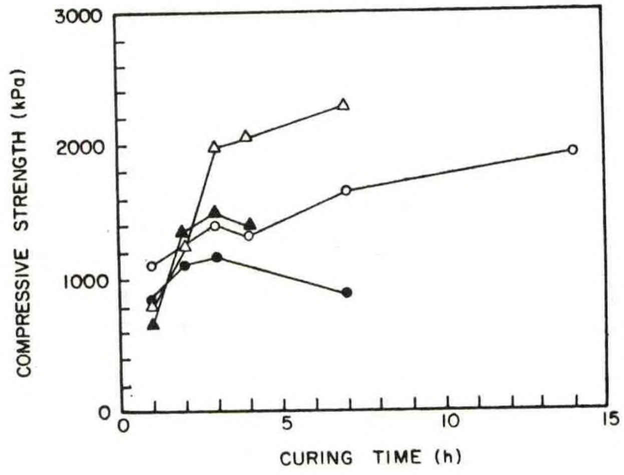


FIGURE 2. Compressive Strength of Blocks. Additives: △ hydrated lime, ▲ quicklime, o hydrated lime and 3% Type II Portland Cement, and ● hydrated lime and 6% Type II Portland cement.

CONCLUSIONS

Our work has shown that coal waste can be converted to blocks that are useful in the production of reef substrate. After our coal waste reef was established, colonies of marine organisms began to appear on the blocks and numbers of fish increased in and around the reef site. Work is underway to determine the extent of colonization (Woodhead et al., 1984). For the artificial reef to be successful, the coal waste blocks must survive in the sea for long periods of time. Consequently, research is also underway to determine the physical and chemical stability of the blocks in the ocean. To date, we have discovered that block strengths have increased with time and also that the leaching of major components has been steadily decreasing (Woodhead et al., 1984).

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OCEAN WAVE SPECTRA MEASUREMENT AND HINDCASTING*

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ABSTRACT

The rapid evolution of marine vehicle design technology during recent years has emphasized the need for quantification of systems performance. This in turn has resulted in the need for better quantification of the prevailing environments in which vehicles must operate. The remote sensing community may eventually provide substantial marine environment data bases, but at least for the near future, only sparse measurements will be available to engineers. Hence, in 1975 the U.S. Navy examined the possiblity of utilizing computer based models to estimate wave and wind climatologies for large open ocean, deep water areas. This paper highlights the resulting Hindcast Climatology (HCC) and briefly previews the application of buoy measurements to its verification.

WAVE HINDCASTING

A complete history, including a list of related publications, of the Hindcast Climatology (HCC) is provided elsewhere [1], so that only highlights of its development, validation, and application are summarized here.

The Spectral Ocean Wave Model (SOWM) [2], operational at the Fleet Numerical Oceanography Center (FNOC) in Monterey, California, routinely provides twice daily forecasts of directional wave spectra for about 1500 open ocean, deep water locations or grid points throughout the Northern Hemisphere. The SOWM is based on the earlier work of Pierson and his associates [3]. While total validation of the SOWM was not complete in 1975 (nor is it now), some correlations with full-scale measurements indicated that the forecasts provided representative wave spectra, particularly in the statistical sense (e.g., at a given location over long periods of time).

The SOWM was thus selected to produce the HCC. In brief, surface pressure fields for much of the years 1955 to 1975, archived at the U.S. National Climatic Center, were converted to wind fields which were, in turn, the required input to the SOWM. The input winds were updated every 6 hours. Hence, the directional wave spectra were hindcast at 6 hour intervals. The term "hindcasting" is used here because the events predicted are historical, or in the past, as opposed to forecasting where events in the future are predicted.

A typical hindcast directional spectrum is illustrated in Figure 1. Clearly, with a sufficiently large data base of these spectra, many useful statistics can be derived. A variety of wave height, period, and direction, and wind speed and direction statistics, derived from the hindcasts, are now available for the North Atlantic and North Pacific Oceans [1]. Table 1 illustrates a Sea State probability chart, based on the World Meteorological Organization (WMO) definition of Sea State, now widely used in the U.S.A.

Other wave parameters associated with the directional spread of the hindcast spectra as well as their skewness have been developed by Cummins and are summarized in [1]. Cummins has also developed a "stratified" sample of the spectra for both the North Atlantic and North Pacific. The development and application of this small but unbiased sample were summarized in [4] and a more detailed description will be published at a later date.

Due to the temporal and spatial grids of 6 hours and up to 180 nautical miles, respectively, the hindcasts may not necessarily account for waves in the case of severe storms of small extent. However, some extreme value analyses can be conducted. Figure 2 illustrates the occurrence of significant wave heights of 10 m or greater over a 10 year period in the North Atlantic. Clearly, the band between about 55 to 60° N is the area of most severity. And, by Figure 3, 10 to 12 m waves can persist in the North Atlantic for as long as 42 hours, 12 to 14 m for 36 hours, 14 to 16 m for 30 hours, and 16 to 20 m for 18 hours.

Additionally, if a Weibull distribution is assumed, extremes can be estimated for long return periods [4].

WAVE MEASUREMENT

Since the days of the Tucker meter, many advances have been made in both in-situ and remote

* Presented by Dr. Alan Powell.

** This paper is the sole responsibility of the authors. It does not necessarily reflect official U.S. Navy policy.

wave measurements. For purposes of evaluating the applicability of the HCC, some data bases, though sparse, have been available for comparison of point spectra and overall statistical parameters such as significant wave height and modal wave period. In general, the comparison of these parameters has been favorable, even though individual point spectra may sometimes vary from measurements due to temporal or spatial shifts in the wind fields input into the SOWM. This is not considered particularly important, however, because what is lost at one time step or grid point, will be picked up at another.

The verification of the hindcast directional components has been more difficult due to a great sparsity of measured directional wave data, particularly for times and locations spanned by the hindcasts. Most directional data have been collected to support more shallow water (e.g., offshore) applications. Another problem associated with the directionality evaluation was the difficulty of deploying a measuring system from small naval vessels. It was correctly anticipated early on that most measurements would be made during trials of opportunity. The deployment and retrieval of high resolution sensors, such as cloverleaf buoys, arrays of sensors, and/or large discus buoys, appeared to be difficult for routine use aboard ships.

After some deliberation, it was decided that, for the time being, it would be sufficient to evaluate only the overall directionality characteristics of the SOWM spectra. Their coarse 30 degree directional bands together with limits in the directional propagation techniques employed by the model, make more refined comparisons difficult.

Thus, a simple directional wave measuring system was sought and found in the ENDECO Wave Track™ buoy, originally developed at the University of Rhode Island [5]. Figure 4 illustrates this accelerometer buoy which tilts with wave orbital velocities to provide directional information. A good description of the buoy has been given previously [6], and it clearly provides representative point spectra comparable to those from conventional heave accelerometer buoys. Measurements with this so-called pitch-roll-heave buoy can be taken with relative ease. The calculation of a truncated Fourier expansion using the first five Fourier coefficients results in a smoothed directional spectrum. This follows the well-known theories of Longuet-Higgins and his associates [7].

Figure 5 provides a sample comparison of the mean wave directions vice wave frequencies for a location in the North Atlantic. The measurements were taken in cooperation with the Royal Dutch Navy aboard the HNLMS TYDEMAN during May 1982. The mean direction from the buoy is the solid line. The approximate mean direction from the forecasts provided by the SOWM at a grid point 40 nautical miles to the west and 1.3 hours earlier is the heavier dashed line. The agreement is generally within 15 to 30 degrees. The lighter dashed lines indicate the approximate spread of any notable energy in the SOWM forecast. This comparison, as well as others taken over the last several years often show reasonable agreement. Difficulties in the data analysis techniques and in resolving some combinations of sea and swell (e.g., when their frequencies overlap) do not permit conclusiveness on the validity of the directional data of the HCC at this time. However, agreement is sufficiently good that application of the data is proceeding.

HCC APPLICATIONS

The HCC is widely used throughout the U.S. and abroad for engineering applications. Clearly, it is applicable to the prediction of ship motion. This can be accomplished by applying the spectra directly, as illustrated in Figure 6. Here a hindcast spectrum has been used to backfit the conditions existing when a frigate suffered severe structural damage. As shown on the speed polar plot, the ship was operating at about 17 knots with high seas approaching off the port bow. A speed change would not have lessened the motions. But a course change of about 20 degrees would have greatly improved the likelihood of avoiding damage due to high waves and excessive ship motions.

For ship design evaluations, the HCC is usually applied by selecting appropriate combinations of wave height and period, e.g., from Table 1, to initialize two-parameter wave spectra such as the Bretschneider formulation. Upon calculation of the ship motions, weights can be assigned using percent frequencies of occurrence developed from Table 1. The results can be analyzed in various ways including the example shown in Figure 7. The set of geographic contours shows ship performance, in this case in terms of sonar and helicopter operations, as a function of longitude and latitude.

FUTURE WORK

The present plan is to continue the hindcast work for several more years. If all technical and financial obstacles are overcome, the HCC will be extended to include far northern latitudes, the Mediterranean, the Indian Ocean, and the Southern Hemisphere. This should permit the design of marine vehicles which can, if necessary, operate safely all over the globe.

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Table 1. Annual Sea State Occurrences (Hindcast)

Sea State Definition					Open-Ocean North Atlantic (Revised March 1984)			Open-Ocean North Pacific (Revised March 1984)		
Sea State Number	Significant Wave Height (m)		Sustained Wind Speed (Knots)*		Percentage Probability of Sea State	Modal Wave Period (Sec.)		Percentage Probability of Sea State	Modal Wave Period (Sec.)	
	Range	Mean	Range	Mean		Range**	Most Probable***		Range**	Most Probable***
0-1	0-0.1	0.05	0-6	3	0	–	–	0	–	–
2	0.1-0.5	0.3	7-10	8.5	7.2	3.3-12.8	7.5	9.0	5.1-14.9	6.3
3	0.5-1.25	0.88	11-16	13.5	22.4	5.0-14.8	7.5	15.9	5.3-16.1	7.5
4	1.25-2.5	1.88	17-21	19	28.7	6.1-15.2	8.8	30.4	6.1-17.2	8.8
5	2.5-4	3.25	22-27	24.5	15.5	8.3-15.5	9.7	22.6	7.7-17.8	9.7
6	4-6	5	28-47	37.5	18.7	9.8-16.2	12.4	13.9	10.0-18.7	12.4
7	6-9	7.5	48-55	51.5	6.2	11.8-18.5	15.0	6.7	11.7-19.8	15.0
8	9-14	11.5	56-63	59.5	1.2	14.2-18.6	16.4	1.3	14.5-21.5	16.4
>8	>14	>14	>63	>63	<0.05	18.0-23.7	20.0	<0.05	16.4-22.5	20.0

*Ambient wind sustained at 19.5 m above surface to generate fully-developed seas. To convert to another altitude, H_2, apply $V_2 = V_1(H_2/19.5)^{1/7}$

**Minimum is 5 percentile and maximum is 95 percentile for periods given wave height range.

***Based on periods associated with central frequencies included in SOWM Hindcast Climatology.

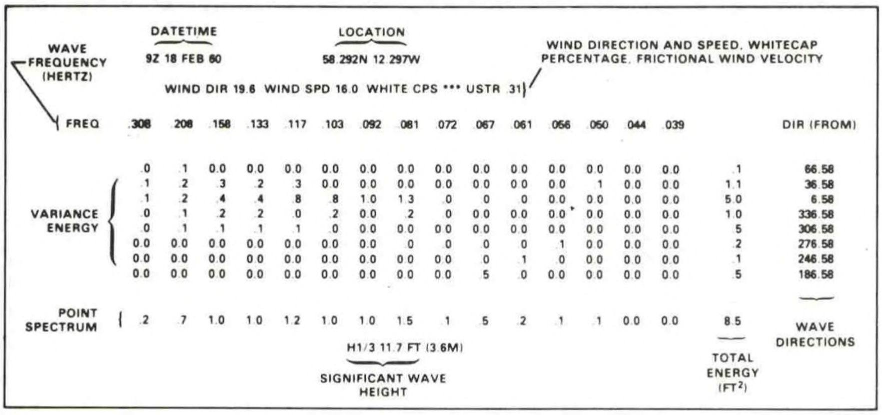

Fig. 1. Typical Hindcase Directional Variance Spectrum for Grid Point 127 in the Northeast Atlantic

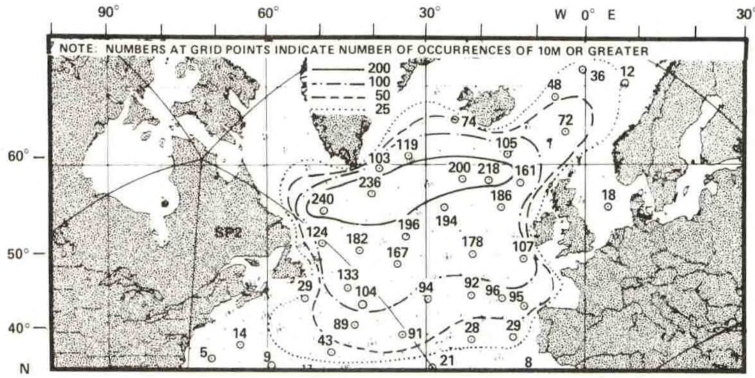

Fig. 2. Contours of 10 M or Greater Significant Wave Height Occurrences During 1959 to 1969

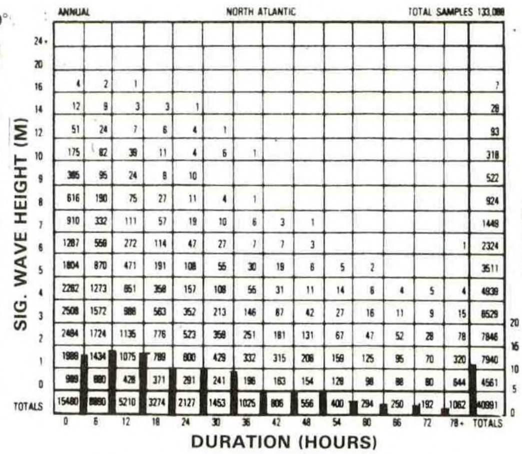

Fig. 3. Persistance of Significant Wave Height (Number of Events)

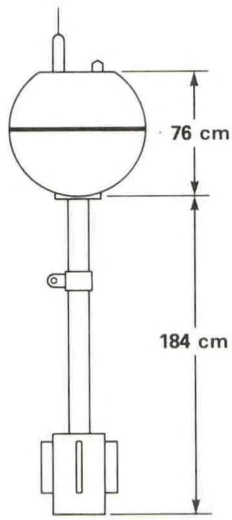

Fig. 4. ENDECO Wave-Track™

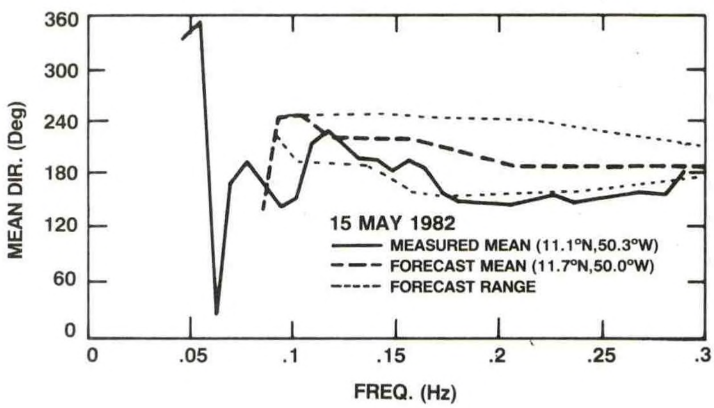

Fig. 5. Comparison of Measured and Forecasted Wave Directions

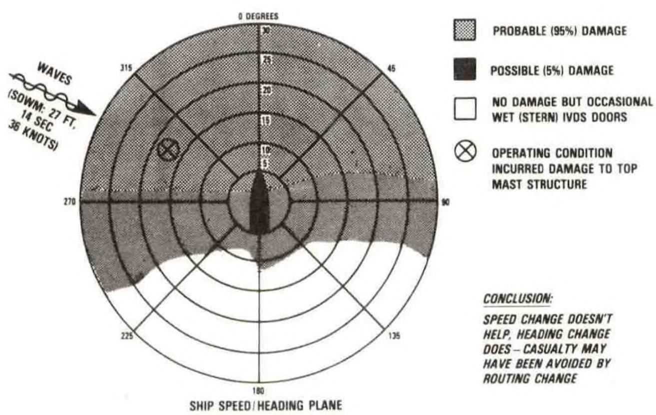

Fig. 6. Frigate Operating in North Pacific, 8 March 1974, 0300 GMT

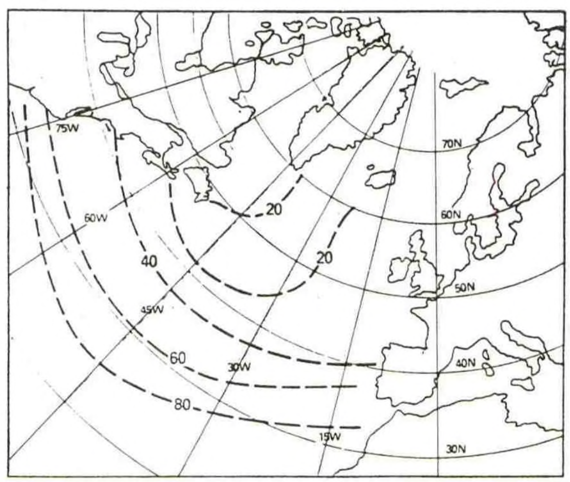

Fig. 7. Percent Availability of Frigate Helo./Sonar System During Winter Operations

OCEAN DUMPING MONITOR SYSTEM

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ABSTRACT

The dumping of treated sewage sludge, hazardous chemicals, and toxic materials in our oceans continues to be a problem. There is pressure from state governments and the U.S. Environmental Protection Agency (EPA) to move designated dumping areas for sewage sludge farther offshore. This raises the costs of dumping operations and increases the temptation for contracted vessels to dump short of those areas, placing a greater burden on those that monitor these operations for compliance with regulations. An Ocean Dumping Monitor System (ODMS) that will lessen this burden and improve surveillance is now under development.

DESIGN CONSIDERATIONS

Since 1972 the Coast Guard has been charged with monitoring ocean dumping and enforcement of ocean dumping regulations. Until now this monitoring has been performed by a combination of Coast Guard aircraft and ships, radar, and observers placed aboard vessels that are engaged in dumping operations. Recently it has been proposed that the dump site located 12 nautical miles from New York City be moved to a new site 106 nautical miles from the city. The current methods for monitoring these sewage sludge dumping operations are no longer practical at such an extended range due to the increased demand on the Coast Guard's personnel and material resources. An electronic system that will provide the identification, location, and dumping status of all dumping vessels and barges in the New York--New Jersey area is now under development. Two approaches to system operation were considered:

1. Record all dump mission information on magnetic media aboard the vessel for processing and review after the mission.

2. Send dump mission information at frequent intervals over a communications link to a base station located at an existing Coast Guard operations center for immediate processing and display.

The second approach was selected since it offers the important advantage of detecting violations almost as soon as they occur and increases the probability of apprehending a suspected violator at the time the violation occurs. In addition, the base station operator is alerted to any failures of the ODMS as they occur. This eliminates difficulties that can occur in attempting to verify the occurence of dumping violations using taped information that is discovered to be invalid only long after completion of the mission in question.

Any ODMS to be used by the Coast Guard must minimize the workload of the watchstanders at the base station and the personnel at the operations center that submits reports to the EPA. The watchstanders often are personnel with little or no technical training. This demands that particular attention be given to the design of the man-machine interface. While the current system will monitor the dumping of sewage sludge in the New York--New Jersey area shown in figure 1., the system must be of modular construction to allow for future use in other areas, at longer ranges, and with other cargoes.

ODMS CONFIGURATION

The prototype ODMS consists of a base station and four shipboard stations as shown in figure 2.

The base station consists of a Hewlett-Packard HP-1000 minicomputer system equipped with 500 kilobytes of random access memory and 28 megabytes of hard disk data storage for overall system control and database management tasks, an HP-150 desk top computer that serves as the watchstander's console, another HP-150 that serves as the ODMS system manager's console, and a high frequency (HF) radio

*This paper is the sole responsibility of the author. It does not necessarily reflect official U. S. Coast Guard policy.

communication system that uses a commercial grade HF transceiverin conjunction with a multi-tone, time-diversity modem made by BR Communications, Inc. A design feature of the HP-150 computer that was a large factor in its selection for use in the ODMS system is its touch sensitive video display. This allows the user to interact directly with the screen without the need for a keyboard. This feature is important in meeting the design requirement for a user interface that non-technical watchstanders can use confidently.

Each shipboard station contains a draft sensor system, a position monitor system, a controller, and a communication system. The draft sensor system consists of three stainless steel jacketed pressure transducers. These transducers are mounted below the water line and on the centerline of the vessel's hull. They are housed in perforated steel enclosures for protection. A transducer located at the bow and another at the stern are used to determine the draft of the vessel while a third transducer mounted amidships can be used in the event that one of the other two transducers fails. This sensor system was chosen for use on sludge vessels and barges since it can be used on any vessel without regard to the form of dump valves that are employed. This simplifies the maintenance support for the system. The positioning system is a commercial grade, low cost LORAN-C receiver with its associated antenna and coupler. The communications system is compatible with that of the base station. A controller based on a single board microcomputer using an eight bit microprocessor coordinates the functions of the shipboard station. This controller reads position information from the LORAN-C receiver and analyzes the readings from the three pressure transducers to determine when a vessel is dumping and whether it is dumping within the prescribed dump site for the cargo it is licensed to dump. Local time is available for the time stamping of any data from a real-time clock located on the computer board. Programming is done in BASIC with machine language routines for functions requiring faster execution than is available in the BASIC language. The complete program is stored in a read only memory (ROM) so that the system starts automatically whenever the vessel's power system is producing power. A vessel identification (ID) code is incorporated in each shipboard controller.

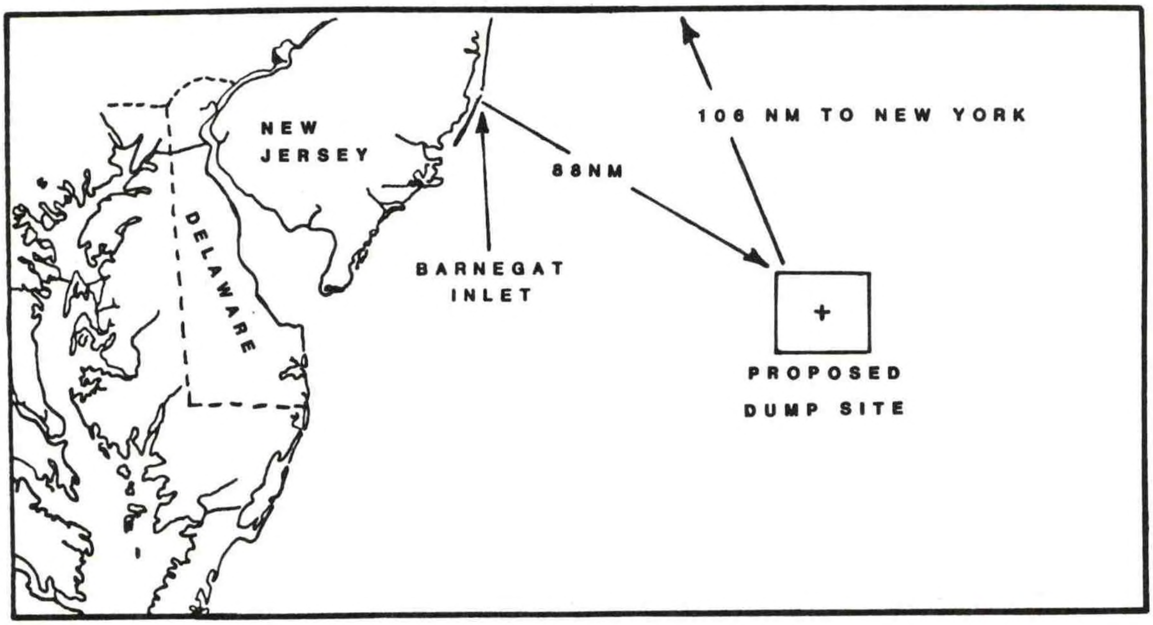
SYSTEM OPERATION

The base station interrogates each shipboard station in sequence by identification number and obtains the location, dump status, and back-up battery status from each remote. This information is displayed on the watchstander's console as shown in figure 3. Should the status of a vessel change an alarm is sounded and the affected vessel's display is highlighted on the display. The watchstander acknowledges an alarm by touching the boxed area of the HP-150 video display containing the name of the appropriate vessel. Figure 4 shows information that in a similar manner is available to the operator. It can be obtained by using the "LAST/NEXT--MENU" area of display and the boxed area containing the vessel's name (see figure 3) to call up this more detailed information from the data base available on the HP-1000 minicomputer system. This data is initially entered by the ODMS system operator using the keyboard on his HP-150 console. This console also provides for editing of the data base and generation of summary reports on all the dumping operations monitored by the system. A printer provides copies of the watchstander's display on demand, and also automatically prints report forms for submission to the EPA and other regulating agencies.

FUTURE USES AND IMPROVEMENTS

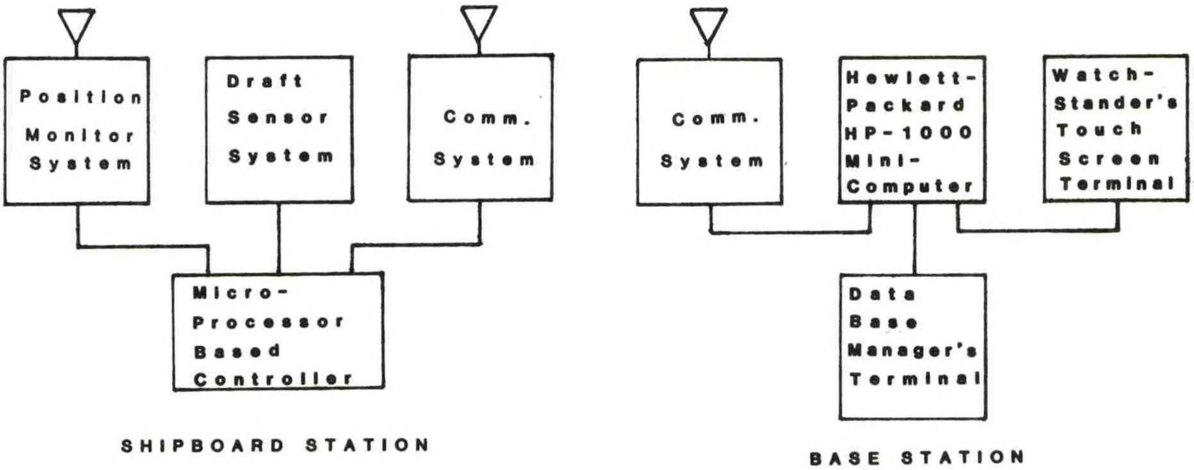
An operational field test of the prototype is scheduled to begin in the spring of 1985 and continue for several months. Comments from the watchstanders and other system operators will be used to refine the system in preparation for procurement of a quantity of shipboard units when regulations are enacted requiring their use by sewage dumping contractors.

There is already interest in using this system for the monitoring of ocean incineration ships and hazardous waste dumping vessels that will burn or dump their cargoes up to 500 nautical miles from shore. The use of satellite communications and alternate sensors for detection of cargo disposal are being studied in the event that such use becomes reality.



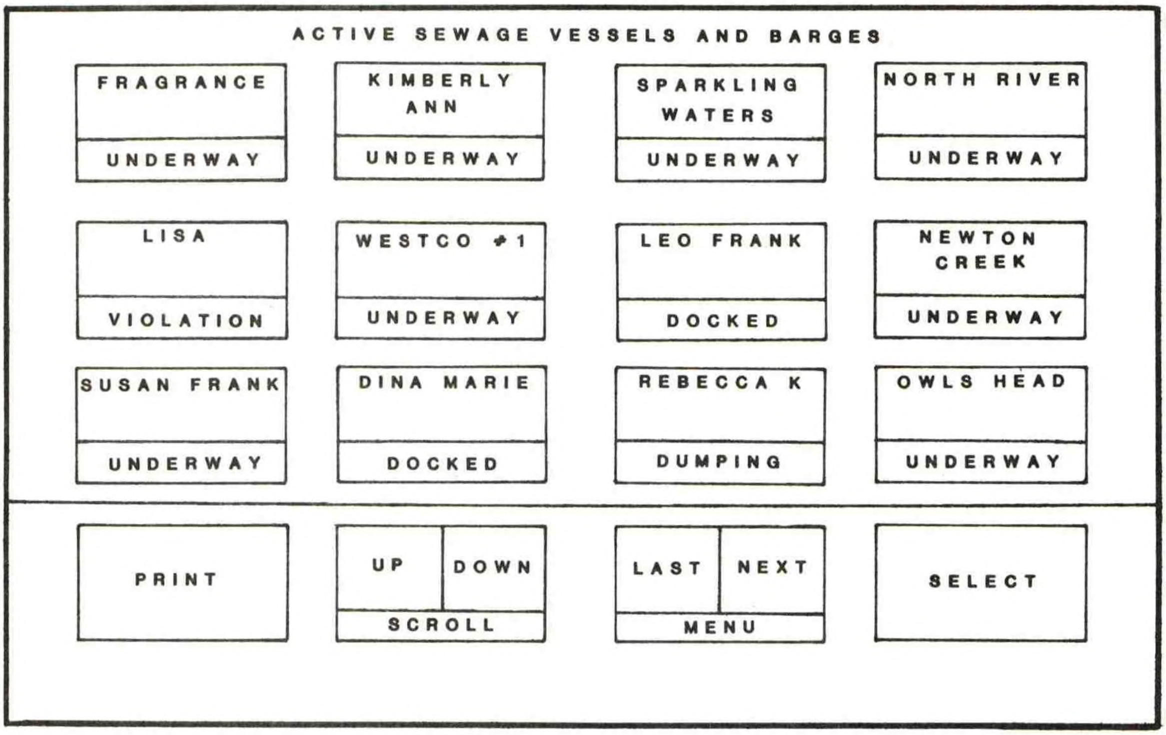
Proposed 106 Mile Dump Site

Figure 1



ODMS System Block Diagram

Figure 2



Typical ODMS Watchstander Display

Figure 3

VESSEL: Kimberly Ann

8MAR84 0643

DESCRIPTION: Type: Sewage Sludge Barge
Displacement: 8500 tons
Length: 272 FT
Beam: 68 FT
Draft: 18 FT
Crew: 2 while underway

OWNER: Modern Transportation
1234 XYZT Street
Newark, NJ 12345
(201) 432-8765

OPERATOR: Same as owner.

PERMITS: NYC 18746Q

CONTRACTED BY: City of New York

CURRENT POSITION: 38-22-10N, 73-35-18W

LAST POSITION: 38-22-11N, 73-35-17W

STATUS: Underway and Dumping

ACTION:

In the event of a dumping violation:

1. Verify that you have hardcopy of this data screen.
2. Notify OD of violation.
3. Call LCDR TOWER: 555-1345 (W) or 555-5632 (H)

Typical Vessel Information Display

Figure 4

SHIPBOARD SMOKE CONTROL USING TRACER GAS

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ABSTRACT

Shipboard smoke control remains the single most troublesome aspect of marine fire dynamics. A recently completed research project ("A Method for Evaluating Smoke Control on Ships Using SF6 Tracer Gas") is part of the U.S. Coast Guard effort in this field. A simple, portable and relatively inexpensive marine fire research methodology has been developed in the accomplishment of the overall objectives of the project. The tracer gas concept and techniques developed are presently being used in a series of full scale shipboard smoke control tests. There is further potential for the application of this tracer gas technology in direct laboratory experimentation and reduced-scale testing. As future application becomes more wide spread, this powerful new marine fire research tool may result in enhanced correlation between scaling and modeling, full-scale testing, and the study of actual marine fire experience.

INTRODUCTION

Fire losses to all merchant ships in U.S. ports and waters, and U.S. Flag merchant ships at sea and in foreign ports and waters, for the time period 1980 - 2000, have been projected to average over $100 million per year. The type of sporadic reactive shipboard fire safety improvements prior to the last two decades, was at best an evolutionary process and did little to stem this devastating drain on the U.S. marine transportation system. If significant reductions are to be made in marine fire losses, a total ship fire safety systems approach is required. Aggressive marine fire research programs are essential to support the continued development of this type of total systems method.

The U.S. Coast Guard provides continuing and comprehensive RDT&E (Research,Development, Testing and Evaluation) in marine fire safety. The technical approach to specific RDT&E projects used by the Marine Fire Research Branch (MFRB) of the CG Research and Development Center includes a wide range of methodologies: laboratory experimentation and analysis; field testing and evaluation; on scene ship fire casualty studies and analysis; and full-scale shipboard fire testing. A major thrust of these RDT&E efforts is directed toward the single most troublesome aspect of marine fire safety, SHIPBOARD SMOKE CONTROL.

One major technological constraint in the study of shipboard smoke control remains. All marine fire research can be viewed in one of three general categories: small-scale testing and predictive modeling, full-scale shipboard fire testing, and the study of actual shipboard fire experience. Correlation between these three catorgories is very limited.

During 17 - 25 March 1983, a series of smoke control tests were conducted aboard the USCG VIGOROUS (WMEC 627). Sulfur hexaflouride (SF_6) was used as a traceable simulated smoke. The overall objectives of the project have been accomplished, specifically,(1) the development of a technique to determine air movement using SF_6 as a tracer gas, and (2) the demonstration that the tracer gas techniques can provide quantitative air flow data aboard operational ships.

The published test report is technically comprehensive and graphic representations are provided for test ship configurations, smoke control theory, pressure mapping, test procedures and test results. The intent of this paper is to convey the significance of this powerful new research tool through a brief description of the selected tracer gas characteristics, a synopsis of the test plan and a forecast of future applications.

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*This paper is the sole responsibility of the author. It does not necessarily reflect official U. S. Coast Guard policy.

TEST PLAN SYNOPSIS

Preliminary Testing

Preliminary Trial A was conducted to determine the air transfer patterns for an "inport" status. Both supply and exhaust fans were operated at low speed and the watertight doors and hatches were placed in the positions of "In Port Configuration".

Preliminary Trial B was run with the conditions identical to the first preliminary trial and the resulting data were compared with the first trial. It confirmed the reproducibility of the tests and provided confidence for subsequent data and time interval sampling. The tests indicated that sampling at 5-minute intervals was appropriate in locations of rapid change or fluctuation, and 15-minute interval sampling was sufficient at all other locations.

Preliminary Trial C simulated an emergency condition. Both supply and exhaust blowers were turned off and the access fittings were positioned as for "General Quarters Configuration", and baseline samples were taken.

Berthing Compartment Series

After the preliminary trials were completed, two series of tests were developed. Both series were designed to compare the effect of different configurations and fan settings on limiting the movement of SF_6.

For the first series of tests, the movement or confinement of SF_6 was studied as affected through the manipulation of just one variable, the watertight door (WTD) at frame 52.

Paint Locker Series

In the second series of tests attention was turned to the effect that supply dampers have on the movement of air. The paint locker was chosen as the release area. Two variables were manipulated in this series, the WTD between the laundry and the passageway forward and the supply damper to the paint locker. All tests were conducted to simulate actual fire conditions.

Methods of Testing and Instrumentation

The SF_6 was released from a 0.015 cu ft. cylinder at a flow rate of 3-5 ml/min for a 30-minute period. The 30-minute period commenced five minutes after the start of each test. A release rate of 4.5 ml/min was determined to yield good test results. This release rate provided a well mixed and evenly distributed concentration of SF_6. It was low enough so that it did not saturate the detector yet high enough to still be detectable for low concentrations in remote locations. The flow rate of SF_6 was regulated by a flow meter that could be set to release gas in the range of 3-27 ml/min. Fifty milliliter air samples were taken with disposable syringes at 60 inches above the deck by a team of three samplers. In locations where a rapid change in concentration was anticipated, samples were taken at 5 minute intervals. In all other locations samples were taken at 15 minute intervals.

Between 80 and 125 samples were taken for each test. Samples were capped, marked, and brought back to a central room to be analyzed. The concentration of SF_6 in the air samples was measured by a portable gas electron chromatograph, fitted with a 0.25 ml sampling loop and a capture detector with a 200 ml tritium source. The instrument was calibrated before and after each test by standard SF_6/air mixtures. Output of the instrument was recorded by a reporting integrator.

TRACER GAS CHARACTERISTICS

Sulfur hexafluoride (SF_6), the selected tracer gas, is colorless, odorless and easily detectable at levels down to one part per billion (ppb) by an electron capture detector. It has a molecular weight of 146.05 and a density at 70° F and 1 atm of 0.382 lh/cu ft making it about five times as dense as air. It is suitable for a gas-air tracer and is described as physiologically inert. Rats have been exposed to the maximum concentration of SF_6 without lowering the oxygen supply to an unsafe level (80% SF_6 and 20% O_2) for periods of 16-24 hours. The rats showed no sign of intoxication, irritation or other toxic effects, either during exposure or afterward. No health hazard to personnel is indicated.

Sulfur hexafluoride is an extremely stable gas. It does not react with water, alkali hydroxides, ammonia or hydrochloric acid. It is noncorrosive to any metal at ambient temperatures. Additionally, it is nonignitable and nonflammable. One of the largest uses of SF_6 is in gas-filled circuit breakers. It is also used in gas insulated transmission lines and electrical power-distribution substations. These applications for SF_6 are not found in a normal shipboard environment and risk of contamination of test samples is minimal.

Results

Figure 1 depicts the results of Test NO.1(3/20/83); the first test with the SF_6 released from the berthing area. For clarity, only four sample release locations of the SF_6 are shown; deck berthing, the passageway aft of deck berthing, first class quarters, and the main deck head. The relative concentration of SF_6 detected is plotted against time. The concentration curve for deck berthing shows a steadily increasing rate and generally follows the SF_6 concentration curve for operations berthing but with a time lag. The other three locations, show negligible amounts of SF_6 until 55 minutes after release when WTD 1-52-1 was opened. The graph is representative of the nine graphs contained in the full test report. The raw numerical data for all segments of the project are maintained with the project file, allowing additional graphs to be constructed to study a particular sample location.

FUTURE APPLICATIONS

The basic concept and techniques developed by this project are presently in use in a series of full-scale fire tests. Additional applications will include; laboratory experimentation, and reduced scale testing. The technique is further enhanced by the ability to perform full-scale studies in various operational modes of a test ship. This new marine fire research tool can ultimately result in improved correlation of reduced-scale and full-scale testing. More significant improvement in correlation between reduced-scale and the study of actual marine fire casualties is anticipated.

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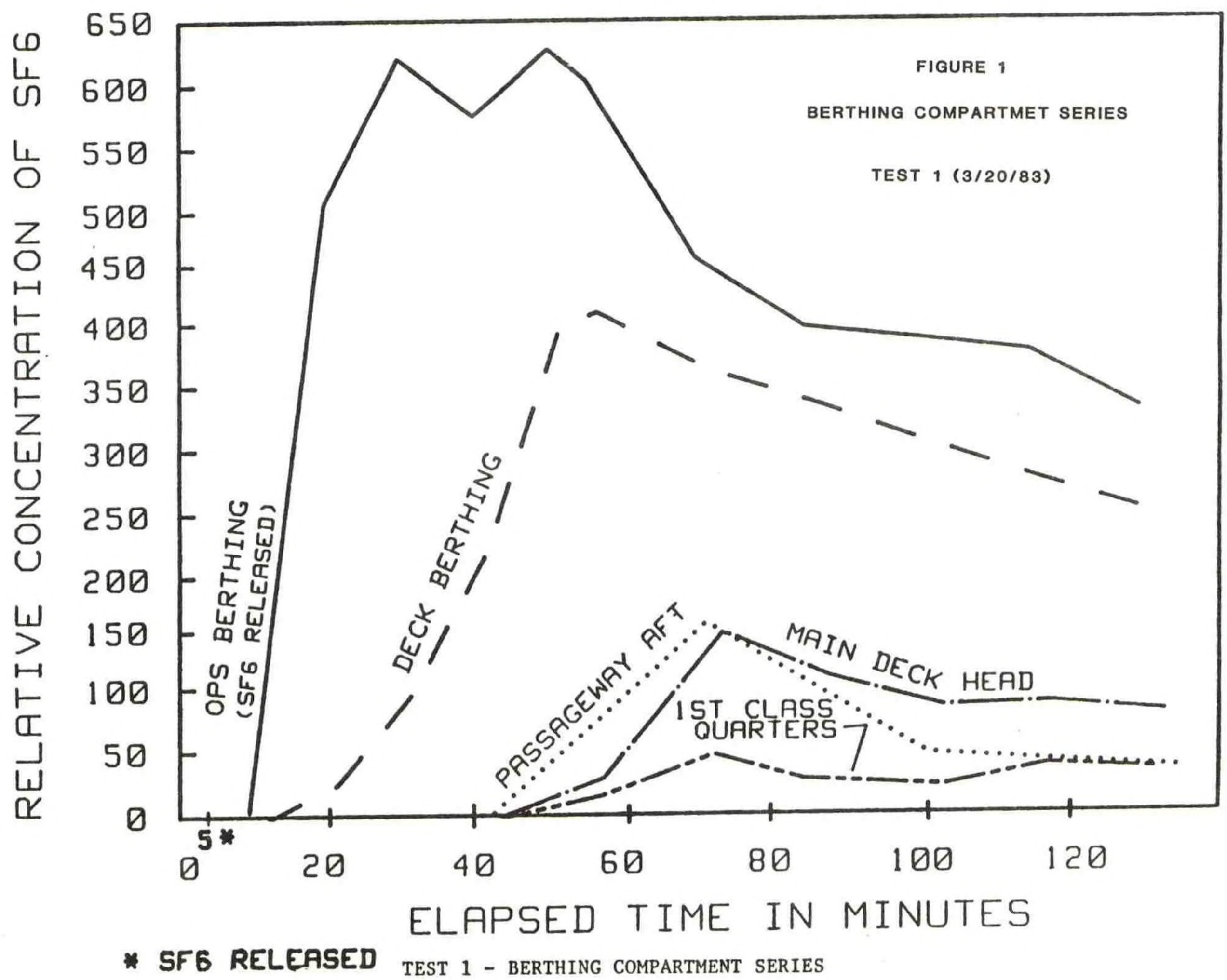

TEST 1 - BERTHING COMPARTMENT SERIES

THE SEARCH FOR A COST-EFFECTIVE REPLACEMENT FOR A MARINE RESEARCH VESSEL

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Abstract

The design of research vessels involves trade-offs among costs, research requirements and ship characteristics. The design of a replacement research vessel for the University of Southern California provides a good example of how these three factors were integrated to produce a unique cost-effective solution to regional research requirements.

Background

The University of Southern California has operated a research vessel since 1910. Beginning with early field studies in Santa Monica Bay using the 35-foot Anton Dohrn, the University has developed a comprehensive marine studies program and the requisite facilities to support it. As other academic institutions in the area developed marine programs, these facilities became increasingly identified as regional in nature, and today USC's field laboratories, marine support facility and research ship are utilized regularly by marine scientists from throughout central California.

For the past 34 years, the University has owned and operated the R/V VELERO IV, a 110-foot converted tuna clipper. Over the years, the VELERO has proven to be a highly capable and efficient research vessel. For some types of field work and in local coastal waters, she is still a capable platform. At the same time, it is clear that the science requirements are changing and expanding and that VELERO has neither the capacity or sea-kindliness characteristics to adequately support many of these emerging needs. Consequently, and in consultation with traditional users of VELERO and with other marine scientists of the central California research community, the University, with the National Science Foundation's support, initiated a survey of available ship platforms that have the requisite basic operating characteristics to meet the current and projected needs of the community over the next 15-20 years.

Research Requirements

Research requirements include 220-250 days per year of operations in the eastern pacific and include a full range of biological, geological, physical and chemical measurements at all depths. Typical research projects include studies of marine boundary layer meteorology, upper ocean boundary layer dynamics, and oceanic turbulence. The vessel will also serve as a platform for the study of ocean optics and acoustics and large-scale phenomena such as coastal upwelling and current patterns. In support of the nation's need to determine the properties of the seafloor within the exclusive economic zone, the vessel will also be utilized for extensive sediment coring and high-resolution geophysics. Deployment of towed and manned/remotely controlled vehicles is also a requirement.

Vessel Characteristics

The specifications and operating characteristics of a replacement vessel were derived from the specific needs of regional research ship users and discussions with other potential users from the central California research community.

Basic specifications include:

Age	0-16 years
Length	135-200 feet
Beam	25-50 feet
Displacement	500-1500 tons
Range	3500+ nautical miles
Cruising Speed	12-18 knots
Endurance	20-40 days
Crew	6-14
Scientists	12-20
Operating Days/Year	250

In addition, good slow-speed maneuverability, roll stabilization and adequate open deck and laboratory space are considered essential.

Less essential but highly desirable characteristics include the ability to handle a helicopter and manned/remote controlled vehicles.

Availability of a Replacement Research Vessel

In assessing the availability of a replacement vessel, certain basic assumptions were made. One of these was an assumption that procurement of a new-construction research vessel through government sources was not an option because of time (a replacement vessel was required before the unwieldy government procurement process could be energized). Secondly, several existing academic research vessels were included in the assessment. Consideration of these vessels was based upon recommendations contained in various government advisory body reports. A third assumption was that if procurement of a nongovernment vessel was selected as the most viable option, the procurement costs would have to be borne by the University. An arbitrary limit of $3 million was established for purposes of this review. While this exceeded the amount that could be made available, depending upon the source of procurement, the cost might be largely or partially offset by a donation. Sale of VELERO IV would also reduce the acquisition cost. A fourth assumption was that reasonable initial repair, alteration and equipment costs would be shared between the government and the University, with an upper limit of $4.5 million on these costs. While these costs could not be fixed until a replacement vessel was selected, approximate costs for various classes of commercial vessels considered in this review have been calculated. A final assumption was that the operating and maintenance costs of the replacement vessel should not exceed those of a medium-sized (170-foot) government research vessel (i.e., $1.77 million/year in FY84 dollars).

The first step in ascertaining the availability of a replacement research vessel included reviewing the specifications of government-owned vessels that might be available for transfer, and soliciting commercial ship owners, operators and brokers for information concerning availability of vessels meeting the basic specifications. Next, those vessels that exceeded the arbitrary limits placed on age and acquisition/ operating costs were eliminated from consideration, as were any that appeared to be in poor condition.

Candidate replacement vessels that met the basic specifications and that survived the initial screening are listed in Table 1 (selected AGOR and OCEANUS class government research vessels are also listed for comparison purposes).

TABLE 1

COMPARISON OF SHIP CLASS CHARACTERISTICS - OCEANUS/AGOR/ISELIN/CAPE/ PURSE SEINER/MUD BOAT/OFFSHORE SUPPLY/SEISMIC

Name/Class	Owner/ Operator	1984 Operating Cost	Complement Crew	Complement Rsrch	Endurance (Days)	Acq. Cost $M	Built (yrs)	Length Beam Draft	Cruise Speed (kts)	Max Speed (kts)	Range (Naut mi)	Bow Thruster	Frames Cranes Winches	Est Alt $
WECOMA (O)	NSF/OSU	1.9M	13	16	30 (F)	3.1	1976	177x33/18.6	11.5	14.5	5000	yes	1/1/3	-
ENDEAVOR (O)	NSF/URI	1.6M	12	16	30 (S)	-	1976	177x33/17.6	12	15.4	5540	yes	2/1/3	-
OCEANUS (O)	NSF/WHOI	1.8M	12	12	25 (F)	3.5	1975	177x33x17.5	12.5	15	7000	yes	3/1/2	-
MELVILLE (A)	USN/SIO	3.2M	23	29	41 (F)	6	1969	245/46/16.4	10	11.5	9000	yes	2/2/4	-
THOMPSON (A)	USN/UW	2.3M	22	22	40 (F)	3	1965	209/39/15	9.5	11.5	8500	yes	1/1/3	-
WASHINGTON (A)	USN/SIO	3.2M	23	21	42 (F)	-	1965	209/39/14.5	11.5	13.2	8700	yes	1/2/3	-
KNORR (A)	USN (WHOI)	3.2M	25	23	45 (F)	-	1970	245/46/15	10	11.5	10000	yes	0/2/3	-
GYRE (A)	USN (TAMU)	1.9M	11	22	60 (F)	3.1	1973	174/36/13.1	9.5	11.8	8000	yes	3/1/3	-
ISELIN	UOM	1.7M	12	16	30 (S)	-	1972	170/36/10.5	13	14.5	9700	yes	2/2/3	NA
CAPE FLORIDA	NSF/UOM	1.2M	9	12	21 (S)	3.1	1981	135/32/9	11	12.5	7680	no	1/2/3	NA
CAPE HATTERAS	NSF/Duke	1.4M	10	12	24 (S)	3.1	1981	135/32/9	11	12.5	7000	no	1/1/3	NA
OSPREY (PS)	Van Camp	1.72M	14	19	75 (F)	1.0	1973	220/38/15	13.5	17.2	24000	yes	0/2/6	$3.0M
FINISTERRE (PS)	StarKist	1.72M	14	18	35 (F)	2.5	1973	203/40/19	13	15	10500	yes	0/1/6	$3.0M
KERRI M (PS)	StarKist	1.51M	12	16	16 (F)	2.5	1969	180/36/17	13	15	4608	yes	0/1/3	$2.8M
STATE SWAN (MB)	State Boat	.95M	12	12	33 (F)	1.7	1980	150/35/12	12	12	7800	yes	0/0/1	$2.5
EAGLE (SUPPLY)	State Boat	1.1	12	TBD	26	1.2	1976	150/34/11	11	11	6800	no	-	
STATE HAWK	State Boat	1.1	12	TBD	28	1.5	1978	150/35/12	11	12	7800	yes	-	
STATE ARROW	State Boat	1.3	12	TBD	20	.8	1978	165/36/12	13	13	6200	no	-	
STATE QUEEN	State Boat	1.3	12	6	24	.95	1978	166/38/13	12	13	6500	yes	-	
STATE TREASURE	State Boat	1.4	14	4	38	1.5	1972	176/38/14	12	13	11000	no	-	
STATE DIAMOND	State Boat	1.4	14	4	38	1.5	1972	176/38/14	12	13	11000	no		
1535RV(Seismic)	Midland	1.3	14	12		.95		180/38/14				no	-	
KANA KEOKI (Supp)	Hawaii (UOH)	1.0M	16	15	42 (S)	-	17	156/36/11.7	10.5	13.5	10000	yes	3/1/2	NA
CORAL SEA	Seal Fleet	1.4	14	17	28		14	165/38/13	10	12	6667	no	-	
FENICIO (PS)	Van Camp	1.72	14	18	75 (F)	1.0	1972	214/36/14.8	13.5	16.2	22000	yes	0/2/1	$3.5
INTREPIDO (PS)	Van Camp	1.72	14	18	75 (F)	1.0	1972	214/36/14.8	13.5	16.2	22000	yes	0/2/1	$3.5
ROSA OLIVIA (PS)	Van Camp	1.72	14	18	75 (F)	1.0	1972	214/36/14.8	13.5	16.2	22000	yes	0/2/1	$3.5
MARY S (PS)	Bank	1.72	14	18	75 (F)	.1	1971	214/36/14.8	13.5	16.2	22000	yes	0/2/1	$4.5
ENTERPRISE (PS)	Leasing Co.	1.65	14	18	75 (F)	1.2	1971	213/39/16.4	13	16	24000	yes	0/2/1	$2.5

Conclusions

Projected user requirements dictated the need for a larger, more capable vessel to replace the VELERO IV in 1986. These requirements stemmed from an extrapolation of the science needs of current VELERO users as well as the needs of government laboratories and the fact that new and increased requirements for field work are emerging off the central California coast and eastern Pacific ocean.

The need for replacement of VELERO IV within the next 2 years dictated that the replacement vessel be a transfer from existing fleet assets rather than by new construction. While many of the candidate vessels listed in Table 1 would have been acceptable as a replacement for VELERO IV, review of those vessels having the requisite characteristics and within reasonable limits of age, acquisition and operating costs indicated that, as a class, the modern purse seiner was the most suitable. The purse seiner design combines the range and sea-keeping characteristics of the largest research vessels of the U.S. academic fleet with the economy of operation of the smallest of these vessels. Further, because of a decline in the needs of the tuna industry, purse seiners were available at a fraction of their replacement value. The selection of a purse seiner had the additional advantage of adding a capability to deploy large nets and trawls to the academic fleet. A comparison of the characteristics of major existing U.S. research vessels with those of a modern purse seiner conversion is presented in Table 2.

TABLE 2

Ship	Range nm	Endurance days	Speed KTs Crusing/Max	Complement		Science Work Space			Open Deck AFT ft^2	Fuel Con. gal/day cruising	Acquisition Cost/year
				Sci. party	Crew	Dry lab ft^2	Wet lab ft^2	Storage ft^2			
AGOR 14 class	9500	37-60	10.2/13	25-30	20-25	1950-3000	1950-400	923	3592	2800-3144	$3.2M/1970
A II	10000	60	12/13	25	25	4300	400	704	2632	?	-
AGOR 3 class	10000	36-45	11/12.5	18-23	19-25	890-1475	231-900	520	2005	1800	$3M/1965
OCEANUS class	8300	30	14.5/15.4	12-16	12	600-800	300-550	420	1652-2128	2000-2100	$3.1-3.5M/1976
ISELIN class	7000-12000	30	11.5/14	13	12	758-1500	252-300	144	2365	1800-2060	-
OSPREY	24000	75	13/17.2	18	14	2650	1100	15,000	2100	1800	$3.5-4.5M/1984
Necor conference 19-22 APR 84 recommendation	11000	60	15/16.5	25-30	-	3600	400	10,000	3000	3000	$32M/1984 (if SWATH)
Gilbert study Oct 81 (Alvin support)	8000	30	12/15	14-	-	850	400	5,000	2200	-	-

Comparision of Ships Characteristics

SEARCH AND RESCUE SATELLITE AIDED TRACKING (SARSAT)

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ABSTRACT

Quickly detecting and locating persons in distress at sea or on land are the two most challenging problems facing rescue personnel today. Studies have shown that if survivors of an air crash on land are rescued within eight hours, their survival rate is over 50%. If the rescue is delayed beyond two days, their chance of survival is less than 10%. In distress situations at sea, time is even more critical if the person is unable to stay out of the water. Direct radio communications between rescue personnel and the distress unit is the best method of distress notification. Direct radio communications are not always possible due to being out of range, no one listening, lack of sufficient time to broadcast, no radio equipment or for many other reasons. Small emergency radio beacons were developed in the early 1970's to automatically alert rescue forces of distresses in aircraft (Emergency Locator Transmitters (ELTs) and in marine vessels (Emergency Position Indicating Radio Beacons (EPIRBs). For years, detection of ELTs and EPIRBs was only done by overflying aircraft. Although many persons were saved through emergency beacons, many others were not detected because aircraft overflights give incomplete and sporadic coverage and localization is difficult because the initial reported position can be 300 miles or more from the distress site. In the late 1970's, the Search and Rescue Satellite Aided Tracking (SARSAT) System was developed by the U.S., Canada, and France. Satellites orbiting around the poles about 600 miles above the earth receive the emergency beacon signals and locate them using the "Doppler Effect" and highly sophisticated computer techniques. The USSR joined the SARSAT team with an interoperable counterpart (COSPAS), and a cooperative program (COSPAS-SARSAT) was established. Other nations joining the project as investigators include Norway, United Kingdom, Finland, and Bulgaria.

*This paper is the sole reponsibility of the author. It does not necessarily reflect official U.S. Coast Guard policy.

CONCEPT

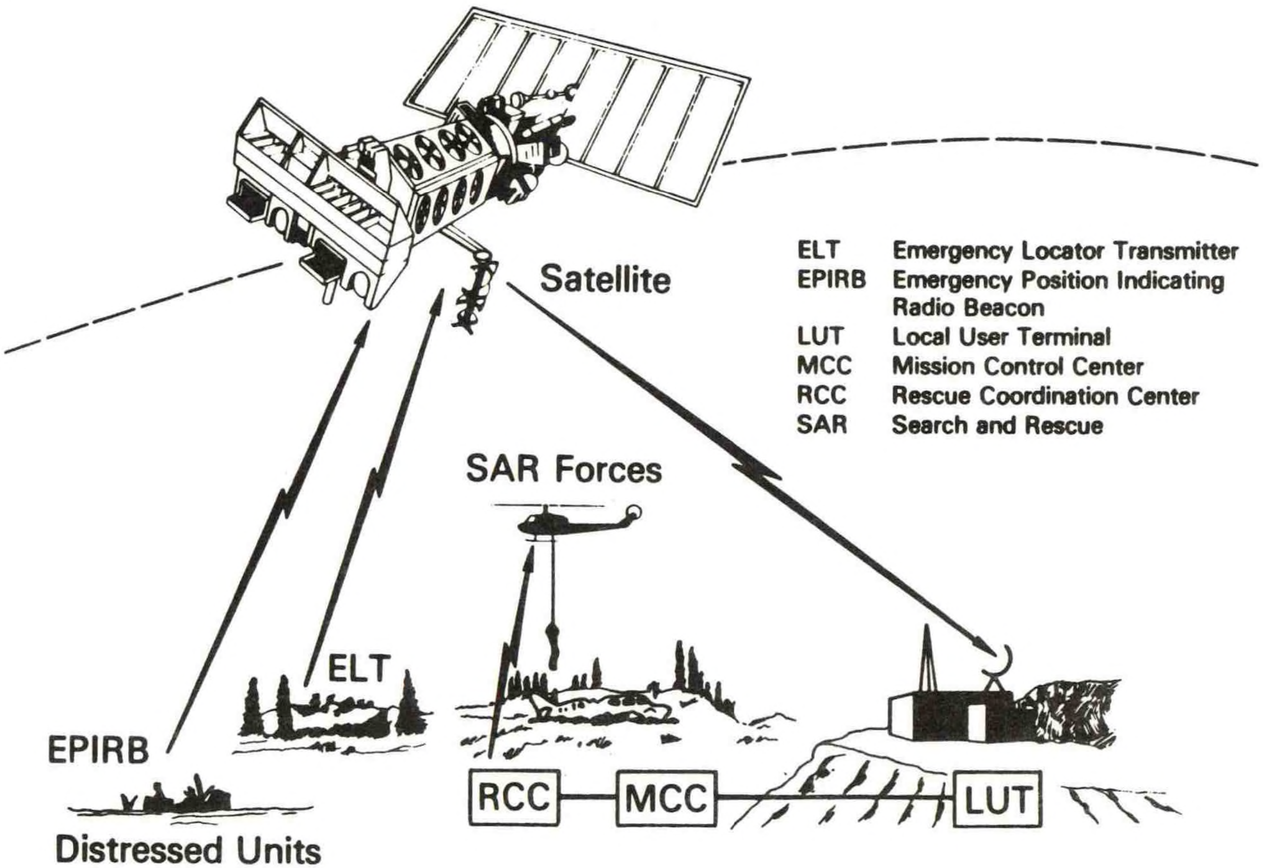
The basic operational concept of the system is illustrated in Figure 1. Satellites circling the globe in near-polar orbits about every 102 minutes detect signals emanating from 121.5 and 243 MHz ELT/EPIRBs and from experimental 406 MHz ELT/EPRIBs and relay the data to ground stations. (The 406 MHz beacons are not commercially available; they are presently being used for testing only.) Ground stations, referred to as Local User Terminals (LUTs), process the signals received from the satellites, determine the locations of the beacons, and transmit the position information to a Mission Control Center (MCC). The MCC sorts the incoming data by geographic position and distributes the information to the appropriate Rescue Coordination Center (RCC).

The system operates in two modes, regional and global. In the regional mode existing ELT and EPIRB transmitters operating at 121.5 and 243 MHz are detected and immediately rebeamed to the ground station. For this to occur, the satellite must simultaneously be in view of both the ELT/EPIRB and the ground station.

Signals from the experimental 406 MHz transmitters can be received, processed, and stored on board the satellite itself. The stored data can then be transmitted to the ground on command when a ground station is in view of the satellite. This system thus provides full orbit or global coverage. The 406 beacon also operates in the regional mode.

The 406 MHz system can pinpoint the site of the distress within two to five kilometers (one to three miles). The regional coverage system using the 121.5 and 243 MHz ELTs and EPIRBs provides a location accuracy of 10 to 20 kilometers (5-10 miles). Both systems use "Doppler" data, determining location according to whether a signal's radio waves come together or fan out as the satellite either approaches or moves away from the signal.

FIGURE 1 THE PATH OF A DISTRESS MESSAGE



SARSAT System Concept

SUMMARY OF SYSTEM DEMONSTRATION AND EVALUATION

During an 18 month demonstration and evaluation the COSPAS-SARSAT project, has met with overwhelming success. And, while the detailed evaluation of the performance of the COSPAS-SARSAT search and rescue satellite system continues, some of the following anticipated benefits of the system are being realized:

- COSPAS-SARSAT is contributing to the rapid detection and location of people in distress and thus relieving human suffering and enhancing the protection of property.

- Individually, the SARSAT and COSPAS systems have demonstrated that facilities developed, meet and in many cases exceed, specification requirements. Collectively, all interoperability requirements have been achieved.

- Experimentation at 121.5/243 MHz has been overwhelmingly successful. As of July 1984, the system has provided alert and location data in 112 distress incidents worldwide, involving 333 people, of which 289 survivors were rescued.

- Experimentation at 406 MHz has demonstrated the benefits of using beacons designed for satellite detection. Benefits include global coverage, beacon identification and improved location accuracies and probability of detection.

FUTURE PLANS

In view of the successful demonstration of the system, the COSPAS-SARSAT nations have agreed to continue to operate and to provide search and rescue satellite services until 1990. The COSPAS-SARSAT system will consist of four satellites; two provided by the USSR and two provided by the SARSAT countries. The decision to extend the COSPAS-SARSAT service was made to permit the continuity of service while the planning for the establishment of a future global operational satellite-aided search and rescue system is concluded.

The SARSAT countries will continue to provide service at 121.5/243 MHz and 406 MHz on the NOAA series of weather satellites. The USSR will provide service at 121.5 MHz and 406 MHz on the COSPAS series of satellites. During this period of time, efforts will be made to reduce the level of false alarms and number of interference sources that currently degrade system performance.

In general, the system provided through to 1990 will build upon the experience attained during the COSPAS-SARSAT demonstration and evaluation phase. At 121.5/243 MHz, improvements will be made to the LUTs to enhance system performance. The regional coverage provided by COSPAS-SARSAT will increase through the deployment of additional LUTs. The mode of communication between MCCs and RCCs and the type of data being transferred will continue to be studied and where necessary, modifications will be made to MCCs to make them more responsive to SAR user needs.

At 406 MHz, beacon development will continue to ensure that reasonable cost beacons, which meet all necessary performance specifications, will be available when the 406 MHz system is expected to become operational in mid 1985. Finally, the optimum use of COSPAS-SARSAT data with geosynchronous satellite data is being investigated. One experiment is to determine if search and rescue performance can be enhanced by adding geosynchronous satellite alerting data to complement position locating data provided by COSPAS-SARSAT satellites.

All the COSPAS-SARSAT nations are considering proposals for the future institutional basis of the system. These proposals will include system configuration, organization, management and funding arrangements. After agreement of the COSPAS-SARSAT nations, a plan to achieve international acceptance will evolve and these nations will commence international initiatives to achieve this objective. During this time, efforts will continue to keep the CCIR, ICAO, IMO and INMARSAT organizations informed of the system progress. Prior to 1990, the COSPAS-SARSAT nations will continue to encourage other countries, not yet involved, to participate as investigators of the system.

THE ROLE OF MARITIME SIMULATION IN PORT AND WATERWAY DEVELOPMENT

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Abstract

One of the primary objectives of the U.S. Maritime Administration (MARAD) is to promote the development of U.S. ports and commercial transportation systems. As part of the effort towards realizing this objective, MARAD has built and developed one of the world's most sophisticated shiphandling computer simulators. The simulator is housed at the Computer Aided Operations Research Facility (CAORF) in Kings Point, New York, and consists of a full ship's bridge and related hardware and software required to develop realistic simulations. The simulated ship is piloted by experienced licensed mariners in simulated ports and harbors. Simulation makes possible the integration of all of the important variables in marine transportation system – man, ship, and environment – in the study and evaluation of proposed system design modifications. These modifications include port and waterway developments, vessel and instrument design, modification of operational procedures and risk management. The purpose of this paper is to illustrate the use of maritime simulation in one of the areas described above – port and waterway development. Two studies are described, one for Hampton Roads, Virginia, and the other for the Panama Canal, for which CAORF was used in the evaluation of channel designs proposed to enable these ports to better accommodate deep-draft vessels.

1. Introduction

One of the primary objectives of the U.S. Maritime Administation (MARAD) is to promote the development of U.S. ports and commercial marine transportation systems. A major research tool utilized by MARAD to further this objective is the Computer Aided Operations Research Facility (CAORF) (Figure 1) located at Kings Point, New York. CAORF houses a real-time, full-mission shiphandling simulator that is one of the most sophisticated simulators of its kind in the world. Rather than being devoted to training, which many people associate with simulation, CAORF is used almost exclusively for basic and applied research in marine transportation systems and port and waterway development.

This paper is intended to accomplish two objectives: first, to briefly describe the simulator and explain its importance in the area of marine transportation research; second, to illustrate the value of marine simulation as a tool in the engineering of ports and waterways. Two studies performed at CAORF, one for Hampton Roads, Virginia, and the other for the Panama Canal, are described. These studies were performed to evaluate proposed channel designs that were developed to better enable those waterways to accommodate deep draft vessels.

2. Background

Historically, simulation has been associated with training, such as the aircraft cockpit simulators, i.e., the Link aircraft pilot trainer. The simulator at CAORF, on the other hand, was conceived as a research facility to be applied to real-world operational problems. In the early 1970's, it became

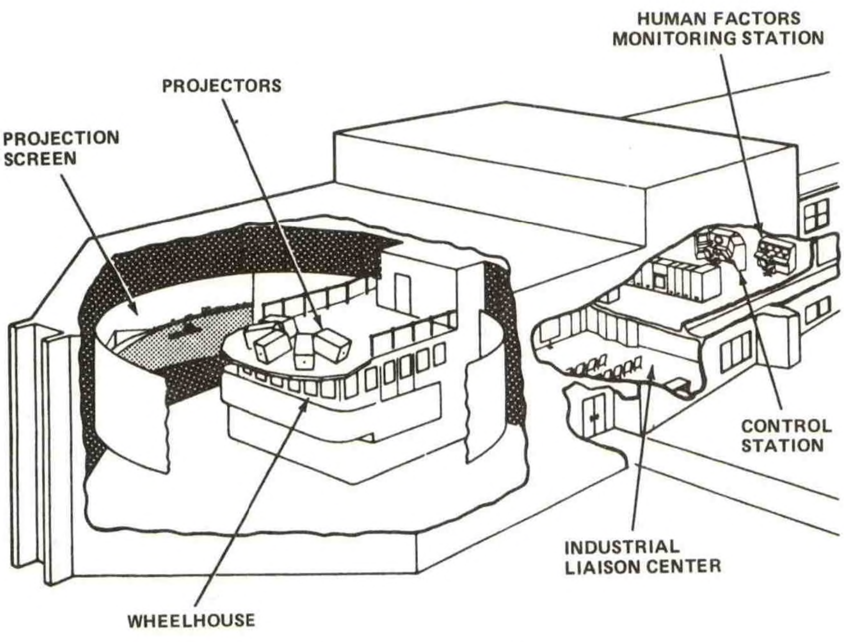

Figure 1. Cutaway of CAORF Building

apparent to MARAD that a research tool was needed to investigate problems associated with marine transportation, with the flexibilty to investigate all aspects dealing with the human control of ships.

The mission, as defined at CAORF's inception in 1970 was to create a facility to perform research and and to test and evaluate ship operations in harbor confines and open seas.

The facility addresses man/ship issues facing the maritime industry, concentrating on areas where past efforts lacked the required sensitivity. To this end the CAORF research program aims toward investigation, understanding and development of the man/ship/environment and its interaction. CAORF offers the unique ability and sensitivity to respond to this need, and provide objective data to establish government and industry requirements in varied areas of marine research. CAORF research efforts have been focused towards obtaining a greater insight and understanding into key maritime issues, with the goal of achieving effective solutions to such issues as the following:

- Reduction of vessel casualties
- Stimulation of industry and production
- Investigation of operational safety and efficiency of vessels engaged in commerce in U.S. territorial waters.
- Establishment and evaluation of regulatory requirements
- Improvement of navigational efficiency, safety, and versatility of waterway design and vessl/ship traffic flow plans
- Facilitation of harbor designs and associated sea lane safety (Risk Management)
- Facilitation of accident analysis and development of maritime operational standards and criteria such as:
  - Shiphandling procedures
  - Training and certification requirements
- Evaluation of man/ship/environment interaction
- Determination of performance characteristics and requirements such as:
  - Human operator work load
  - Vessel/Ship maneuverability
  - Port and harbor design, channels and maneuvering areas
- Determination and evaluation of design requirements for:
  - Ship design and controllability
  - Cost-effective shipboard design to meet navigational criteria

In the past, the engineering approach to examination of problem areas such as the human control of vessels in restricted waterways was largely fragmented, i.e., the U.S. Coast Guard for aids to navigation, psychologists for the decision-making processes of the mariner on the bridge, etc. Such a fragmented approach, however, is inappropriate and inedequate when scientifically examining the profoundly complex interaction of man, ship, and environment. A complete examination of the marine transportation system requires the incorporation into the study of all relevant factors and their interactions, including, for example:

- Channel geometry impact on vessel/ship controllability
- Vessel hydrodynamics and aerodynamics on course keeping
- Prevailing current and wind forces
- Formal aids to navigation, such as ranges and buoys
- Informal land based navigation aids
- Visibility, ambient lighting, and meteorological environmantal effects
- Human operator control and decision processes
- Availability and uses of vessel maneuvering assistance, such as types of tugs and tug forces

Considering the need to include the complex interrationships of such factors when examining the marine transportation system, it might seem logical to study that system in vivo, i.e., in its natural environment. Such an approach, however has several serious drawbacks. First, the costs and risks associated with conducting marine transportation research in the field are prohibitive. Second, it would be difficult, if not impossible, to exercise appropriate scientific controls (i.e., to control extraneous factors) or to collect enough data to form reliable conclusions and recommendations. Third, and perhaps most importantly, it would not be possible to evaluate the benefits of proposed changes to marine transportation system prior to their implementation. For example, the determination of the effects on vessel controllability and safety of a channel deepening project would have to await project completion. At that point, millions, perhaps hundreds of millions of dollars would have been expended. To help ensure that problems would be minimized at that point, a customary procedure has been to conservatively overengineer the channel design. That is, design more channel than optimal to provide adequate safety in the face of unforeseen factors. Such an approach is not cost-effective when considering modern dredging costs. It would clearly be desirable to examine proposed modifications to the marine transportation system prior to implementation, be they changes in channel design, vessel design, aids to navigation, operational procedures, or any other mitigating factor.

With these considerations in mind, MARAD concluded that a shore-based research facility was desirable and the CAORF facility was constructed. A full-mission real-time simulator "piloted" by experienced mariners under realistic conditions seemed to have the proper balance between realism, flexibility, and cost-effectiveness; however, other models including fast-time simulation are also utilized at CAORF. The simulator at CAORF was constructed to meet these research needs. Since 1976, CAORF has played a significant role in the growth and development of a number of ports, waterways and harbors in the United States and abroad. The analytical tools used by the CAORF staff have included:

- Formal risk management procedures
  - Risk assessment
  - Risk mitigation
- Fast-time computer simulation
  - Hydrodynamically valid ship models
  - Realistic environmental conditions
  - Shallow water/bank/passing effects
  - Ship control algorithms
  - Ability to represent specific port, channel, and operating conditions
- Real-time simulation (CAORF SIMULATOR)
  - Realistic simulation of the total environment
  - Man-in-the-loop performance
  - Assessment of the effect of the human element

3. Description

Before providing examples of CAORF's role in marine transportation research, a brief description of the simulator is in order. A simulation at CAORF involves the interplay of six major subsystems; Figure 2 shows their system location:

- The Ship's Bridge, its Instrumentation, and Hardware
- Image Generator and Display Hardware
- Radar Signal Generation Hardware
- Control Data Processor (Computer Systems) and Software
- The Control Station
- The Human Factors Monitoring Station

The first three major subsystems comprise the full-scale replication of the bridge of a ship and a view from that bridge. The first subsystem is the CAORF bridge which replicates the bridge system of a modern merchant ship. It contains all the instrumentation required to maneuver "ownship" including gyrocompass, throttle, RPM and rudder angle indicators, helm, communication devices, and radars. The equipment is actual marine hardware, not simulated equipment.

The second major subsystem consists of the Image Generator and Display hardware. The visual scene is in full color. All important details of an area are modelled. These details are derived from photographs, charts, and maps of the area, and discussions with local pilots to be certain that all essential visual cues are represented. There are five projectors which display a computer generated image on a screen which encircles the wheelhouse with 240° of azimuth. When on the bridge looking dead ahead, the visual scene takes up the entire field of vision. The screen itself is 60 feet in diameter, 15 feet high, and situated approximately 30 feet from the wheelhouse. illumination can represent daylight, moonless night, haze, fog, passing ship lights, harbor lights or any realistic combination of these. For example, to simulate an early morning voyage, the CAORF computer can start with a moonless night, gradually increase illumination to hazy daylight, and then gradually lift the haze so that the visibility is unlimited (to the horizon).

The third major subsystem is the Radar Signal Generator, which synthesizes video signals to simulate the bridge radars and Automatic Radar Plotting Aids (ARPA) where up to forty moving ships can be displayed in the radar screen. Up to six moving ships and numerous stationary ships can be included in the visual scene. These moveing "traffic" ships can be individually controlled to ownship. For example, if the master of ownship wishes

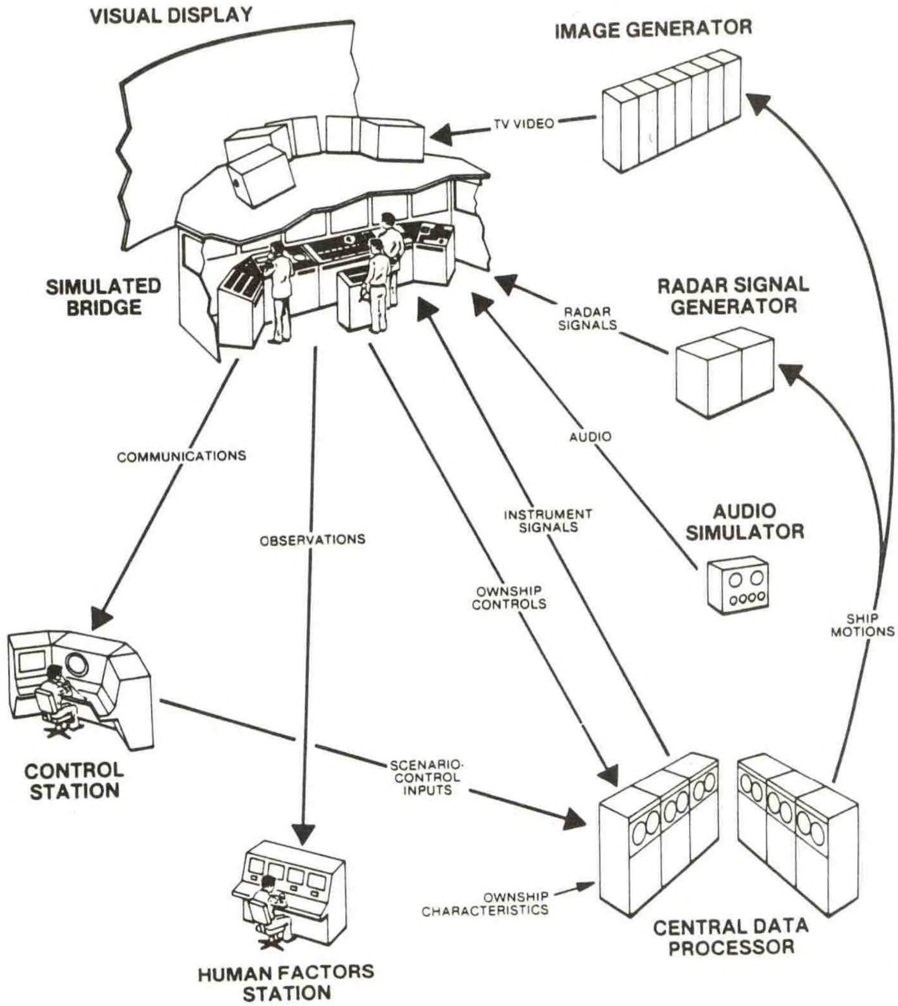

Figure 2. CAORF Subsystems

to pass "port to port" with one of the target vessels, he can pick up his VHF radio and communicate with the master of the other ship (in reality, a member of the experimental team at the control station).

There are computers to process and coordinate the following information: the visual scene, the radar image, the characteristics of the vessel being modelled, the depth/bank/current effects, wind effects, the bridge equipment stimulus, and the recording of data for analysis.

As the master or pilot takes action to control the ship (such as ordering a course or speed change) a central computer interprets these actions and alters the visual scene accordingly. The central computer also adjusts the instrument readings to correspond to the changing visual scene. Radar displays are also coordinated with the outside visual scenes. Thus, the radar depicts, buoys, shorelines, and other ships in their proper locations with respect to ownship. In the case of simulated fog, the radar depicts objects which may not be visible in the visual scene.

CAORF staff interact with the bridge and can start and stop the simulation with the Control Station, the fifth subsystem. For instance, if a pilot contacts a traffic vessel over VHF or calls a mate onboard via sound-powered phone, a response is made from the Control Station. If the study calls for instrument failures or manipulation of traffic vessels, these can be initiated and controlled from the Control Station. From the Control Station environmental conditions such as current, wind and visibility, as well as any required assist tugs, can be manipulated. All experimental conditions are reset from the Control Station once the passage is over.

The Human Factors Monitoring Station permits the observation and recording of bridge activities. Closed circuit television cameras and microphones are located on the bridge to display and record all activities, comments, and commands. Communication with the bridge can also be made from this station.

It is through the interworkings of these six major subsystems that CAORF simulation is applied to maritime research. To summarize, the fundamental approach in the CAORF research program is to scientifically investigate marine transportation issues by:

- Building (simulating) alternative marine system components under investigation into an appropriate configuration for research.
- Placing a mariner on the bridge and allowing him to use his knowledge, skill, and experience to work through test scenarios.
- Recording data and collecting the mariner's opinions and comments
- Analyzing data to serve as the basis from which to draw conclusions and make recommendations.

4. Port and Waterway Development

The approach which has been described will be illustrated with two examples drawn from studies conducted at CAORF. The projects are being conducted for one of the largest coaol ports in the United States, the Port of Hampton Roads, Virginia, and the Panama Canal. The first project involves designs to permit ports to better accommodate large, bulk carriers (coal colliers), by deepening existing channels to 55 feet. The objective of the CAORF studies is to determine the channel width requirements, based upon specific man, ship, and environmental interactions.

This project is funded by The Norfolk District of the U.S. Army Corps of Engineers (USACE) whose responsibility it is to dredge and maintain federal navigation channels. The USACE has noted the importance of examining the entire marine transportation system in the design of U.S. waterways. The recently issued Engineer Regulation 1110-2-1404 states that "Navigation channel design requires careful consideration of human factors in vessel piloting. Human judgement and reactions must be considered in addition to physical design factors. Therefore, optimum channel dimensions for a specific project will require an evaluation of ship maneuverability and pilot or captain response" (1982, pg. 2).

5. Hampton Roads Project

The central purpose of this project is to determine channel design requirements for Hampton Roads, Virginia, the largest coal exporting area in the United States. However as indicated earlier, the economics of scale dictate that large, 100,000 plus DWT, deep-draft vessels will account for the bulk of future coal exports. The area presently cannot accommodate such vessels fully loaded, so the port and the USACOE are embarking on a large scale port improvement program to allow deep-draft carriers to fully load at Hampton Roads. These plans include : (1) constructing several new coal loading facilities (two to three in Newport News alone); (2) dredging the major access channels from 45 to 55 feet; and (3) employing an asymmetrical design by constructing outbound lanes on one side of the channel to accommodate fully-loaded bulk carriers. Figure 3 provides a chart of the general area.

The general objectives of the CAORF component of this program are: (1) to determine navigability by larger ships of existing channel features, (2) to determine maneuvering area requirements of large coal carrying vessels, (3) to determine minimum required widths of the outbound lanes, (4) to evaluate the effects of the asymmetrical channel design on pilot contollability of vessels, and (5) to identify operational restrictions (i.e., wind, current, visibility) that may be necessary.

The vessels of interest are large coal carrying vessels. The study examined two designs:

- A 150,000 DWT model representing the largest class of vessels currently calling on Hampton Roads. The vessels are approximately 915 feet long, 145 feet in beam, with a loaded draft of 52 feet.
- A 225,000 DWT model representing a shallow-draft, wide beam collier not yet constructed but which is likely to come into service in the next decade. This vessel is approximately 1100 feet long, 178 feet wide, with a loaded draft of 53 feet.

The participants in the project include 22 active members of the Virginia Pilots Association, with local knowledge and experience with 150,000 DWT colliers.

The CAORF investigation is a multiphase series of studies examining the entire area. Two phases of the Hampton Roads project are briefly described to illustrate the problem of determining the channel dredging requirements. These two phases relate to The Norfolk Harbor Reach and The Newport News Channel, two prominent parts of the Hampton Roads area.

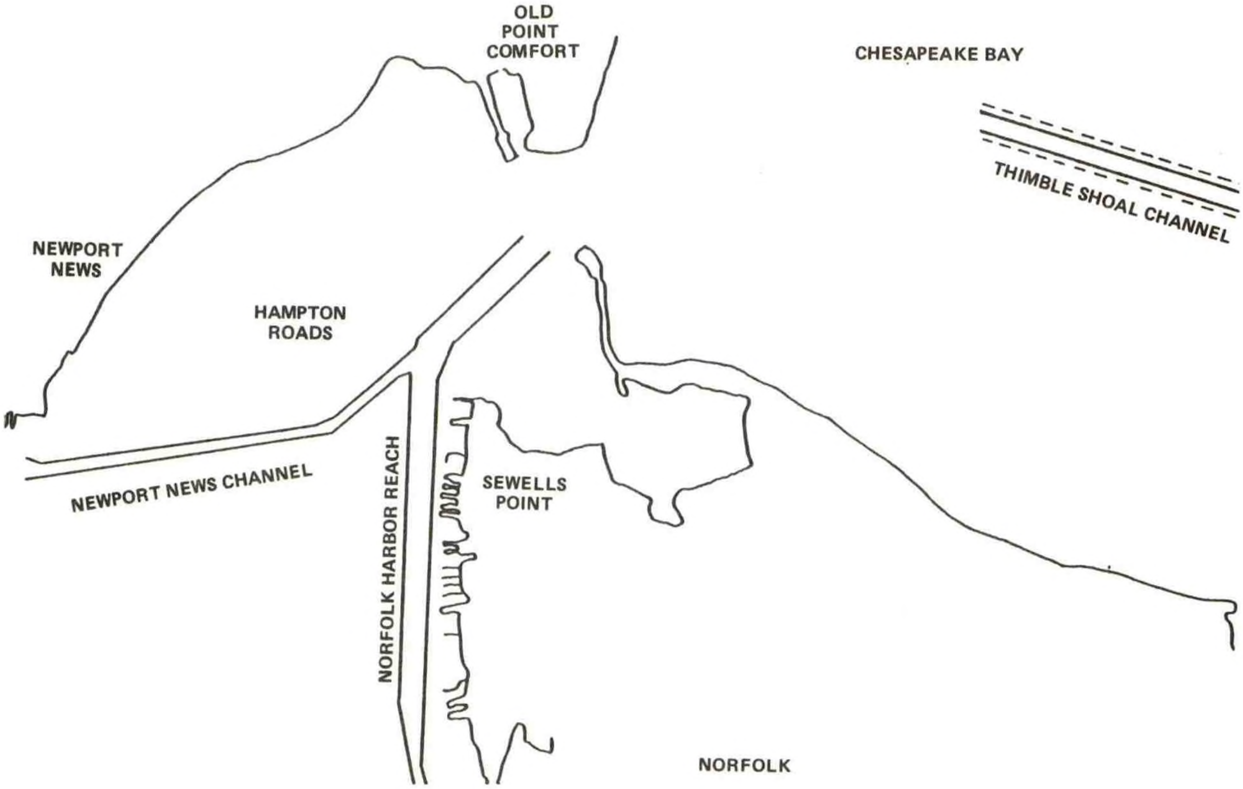

Figure 3. Hampton Roads and Chesapeake Bay with Major Access Channels

6. Norfolk Harbor Reach

This channel connects Norfolk and Portsmouth with the entire harbor. It is 1500 feet wide and heavily trafficked with vessels calling on container facilities at Lamberts Point, and on container facilities at Norfolk International Terminals and the U.S. Navy facilities located along the channel. The study of the Norfolk Harbor Reach Channel was accomplished in two parts, the first part addressing more general channel design issues and the second part addressing refinements. Both parts of the study looked at partial widths dredged to 55 feet on the outbound onshore side.

The primary objective of this phase of the study was to determine the channel width requirements of the outbound lane for deep draft vessels. The initial investigation compared a 500-foot width to a 750-foot width. Another width was also examined – 650 feet (see Figure 4). In addition, effects of the following variables on channel passage were investigated:

- Environment (wind: 10 vs. 40 knots, and visibility: 1.5 vs. 12 nm)
- Vessel design (150,000 DWT vs. 225,000 DWT)
- Navigational aids (a range marker was placed at the northern end of the channel to aid vessels in aligning in the channel)
- Effect of asymmetric channel design on vessel controllability

Two performance measures were examined: vessel proximity to the channel boundary and vessel controllability as indicated by swept path. Swept path represents the area in the channel occupied by the vessel. The minimum swept path is equal to the vessel beam and the maximum is approximately equal to the vessel length, if the vessel is perpendicular to the channel.

The results indicated that the 500-foot channel was inadequate since frequent channel exits occurred. The 750-foot channel was certainly adequate since no channel exits occurred in that condition. These results held regardless of wind, visibility, or ship type. The 650-foot wide channel was subsequently tested foradequacy. At this width, only one channel exit occurred and this was in a 12-mile visibility condition although no exits occurred when visibility was in the 0.5-mile visibility condition. This one exit appeared to be an anomalous passage because on no other passage did a vessel come within 100 feet of the boundary. The range marker did not seem to aid pilots in remaining within the channel.

As for vessel controllability (swept path), the asymmetrical channel design was not found to hinder controllability. Typical values of swept path were only slightly above the vessel's beam width (minimum swept path).

It was concluded, therefore, that the 650-foot wide channel was adequate as a minimum lane width.

7. Newport News Channel

The Newport News Channel connects facilities in Newport News with the Chesapeake Bay (see Figure 3). Its entrance is located near Piers 14 and 15 at Newport News. A worst-case condition occurs when undocking from a bow-in position when a strong ebb current from the James River sets the vessel to the south. The usual practice is to back the vessel and turn it upriver. Toward the end of the channel, the James River turns northward just before the channel bend. It was expected that both these areas might pose navigational difficulties.

The main objectives of this phase of the study were (1) to test the ability of large vessels to negotiate the existing channel design, (2) to specify potential problem areas and determine additional channel requirements, and (3) to examine the effects of (a) environment – current (1.5 vs. 2.5 knot ebb) and visibility (0.5 vs. 12 nm), (b) ship type (150,000 DWT vs. 225,000 DWT), and (c) aids to navigation (the presence of a special purpose buoy at the northern entrance boundary of the channel). For this study, a simulation was conducted of an undocking of a collier from the tip of Newport News (Pier 14), entering Newport News Channel and sailing to entrance reach. As the James River flows past the tip of Newport News, it creates strong currents during ebb and flood conditions. The simulation involved undocking under strong ebb currents (1.5 knots and 2.5 knots) and variable wind and visibility. Docking masters from Chessie System and Virginia pilots, participated in the simulation.

Performance measures were, again, proximimity to channel bounds and vessel controllability (swept path). A total of 23 pilots participated in this phase of the project. For each run, a docking master from the Chessie sys-

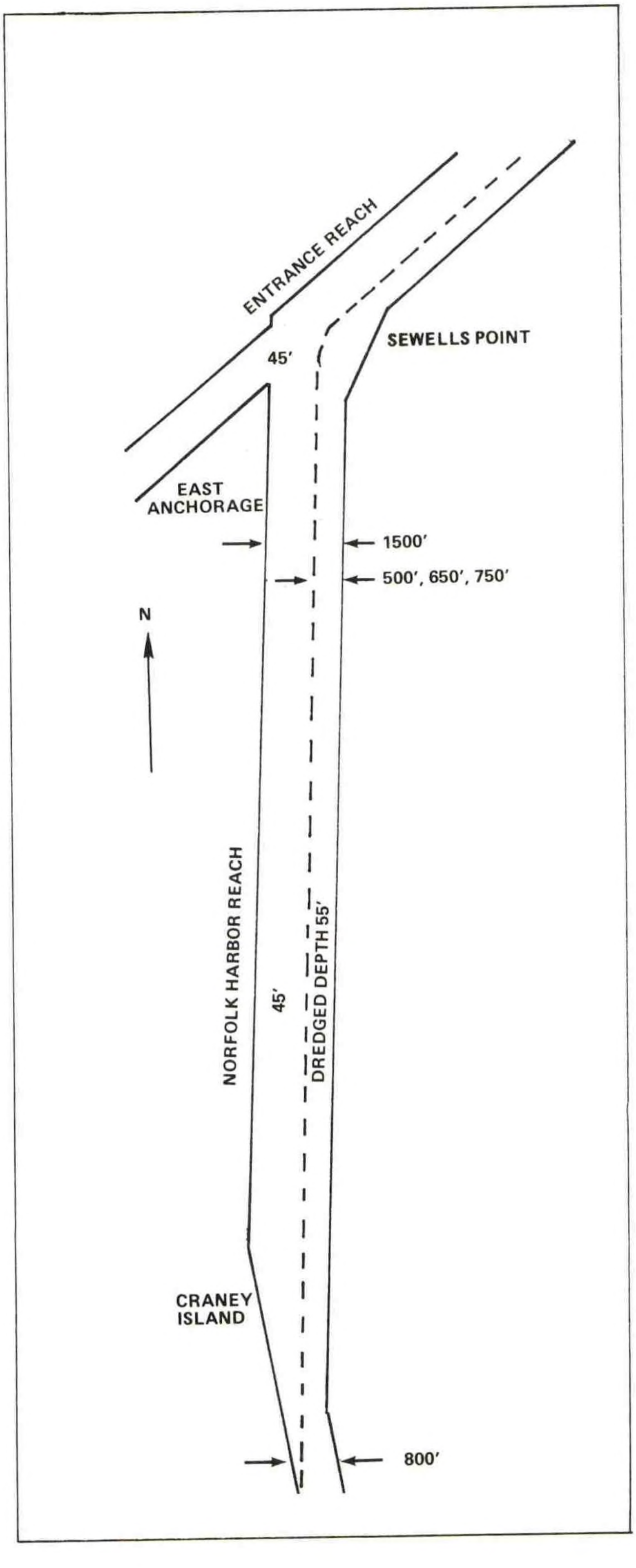

Figure 4. Dredged Lane Configuration in Norfolk Harbor Reach

tem was present to perform undocking maneuvers from the western side of Pier 14. The docking master had the aid of tugs to be utilized at his discretion. Once clear of the berth, the docking master turned the vessel towards the channel entrance. He had to counter the current pushing the vessel toward the south where an explosive anchorage is located. Once tugs were released, the docking master turned the vessel over to the pilot who proceeded on to Entrance Reach.

The results indicated that the entrance at the west end of the Newport News Channel was marginally acceptable. The number of failures (channel exits) was very high in the 2.5 knot condition regardless of ship type. There were also failures in the 1.5 knot condition as well. The special purpose buoy did not have an impact upon navigability, nor did the visibility variable. Based upon the performance of all pilots, a composite envelope and estimate of added dimension requirements for the 1.5 and 2.5 knot current conditions with the 225,000 DWT collier were generated. Figure 5 shows the actual dimensional requirements of each perimeter in the Newport News Channel. In Figure 6, the shaded area (composite envelope) shows the area outside the existing channel on the southern boundary used by the pilots under 1.5 knot current. However, in simulation such as this, we are not only interested in the performance observed in the specific sample of passages in the study. Rather, we wish to estimate performance of all possible passages based on the performance of the sample. The dashed line represents the statistically estimated perimeter which would accommodate 90% of all runs and the dotted line represents the statistically estimated perimeter which would accommodate 95% of all runs. Figure 7 shows the very same information for the 2.5 knot current. Note the large increase in the area required outside the channel under this condition as compared with the 1.5 current condition shown in Figure 6.

The eastern portion of the channel also was found to be marginal and visibility seemed to be an important determinant. For the southern boundary, the incidence of channel exits was fairly constant across all conditions. At the northern boundary, performance seemed worse in the 0.5 nm visibility condition compared with the 12 nm visibility conditions. Again, as in other areas discussed, the specific vessel type did not seem to be an important factor. In addition, more exits occurred in the southern boundary of the channel entrance.

Boundary crossings did not occur in the rest of the channel, thus suggesting that dredging is needed only to flare the east and west ends of Newport News Channel.

There are several other phases to this project in progress, as well as several phases proposed for the future. These two, however, illustrate the usefulness of the man-in-the loop simulation approach to examining the dredging requirements of the Hampton Roads area.

The Norfolk District USACE has conducted a preliminary assessment of the effect of simulation on the Hampton Roads Deepening Study. Their preliminary report evaluated the original plan and adjusted the original cost estimates for inflation, better dredging techniques and measurements, and incorporated the channel design modifications developed from the CAORF simulation. The USACE has estimated that a savings of $74.5 million may be realized as a result of the simulation studies. Compared to the original cost estimates by the USACE, this reduction on costs results in approximately 20% savings in the total investment required to implement the Hampton Roads Deepening Study. Additional annual savings in maintenance dredging will be realized.

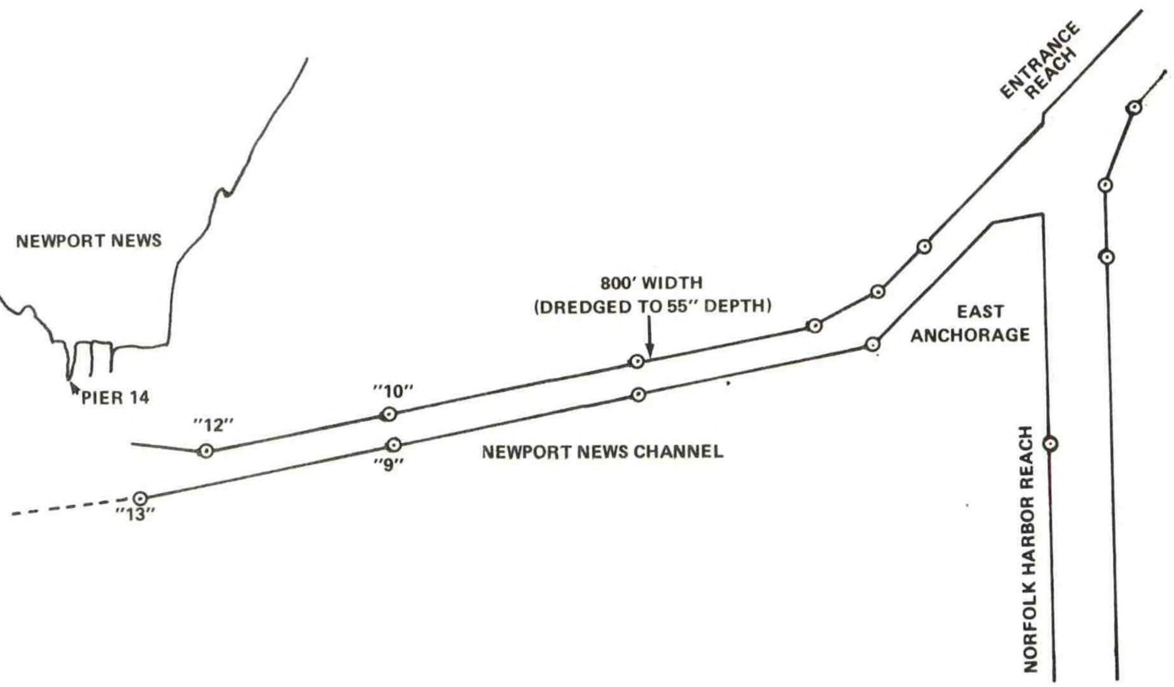

Figure 5. Newport News Channel

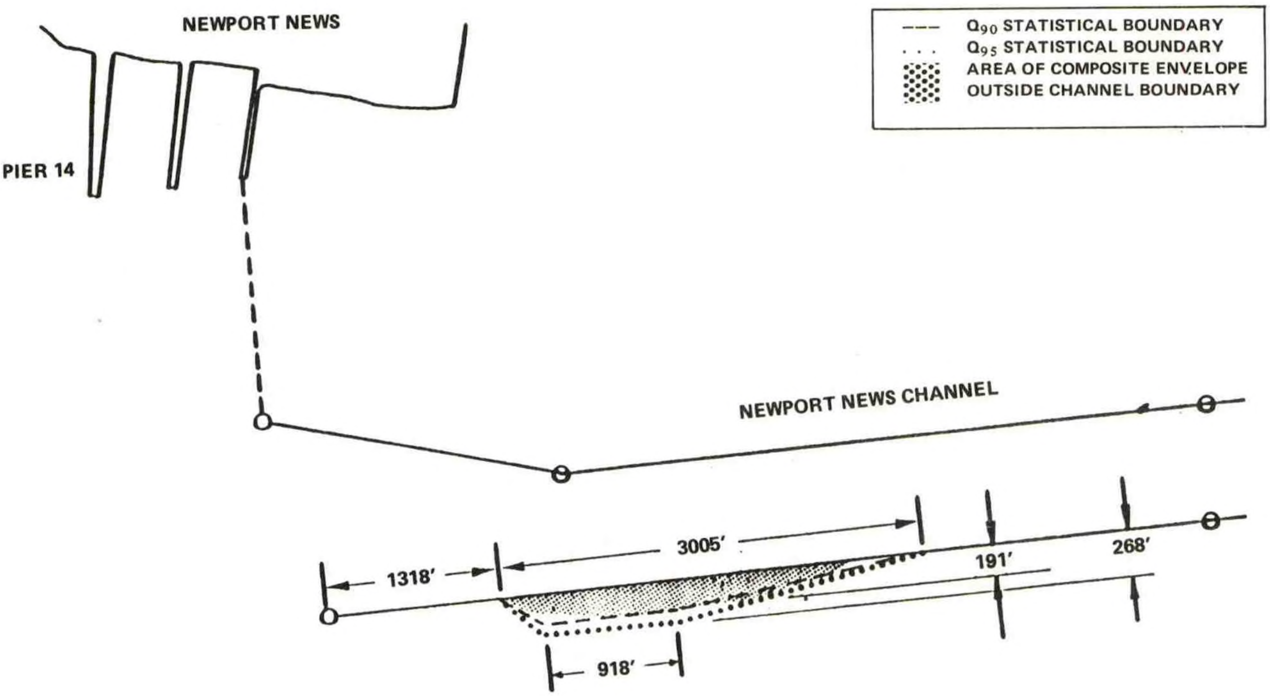

Figure 6. Statistical Perimeters Depict Dimension Requirements of the 225,000 DWT Vessel in 12 NM Visibility, 1.5 Knot Ebb Current at the Western End of Newport News Channel (from McGee, et al, 1983)

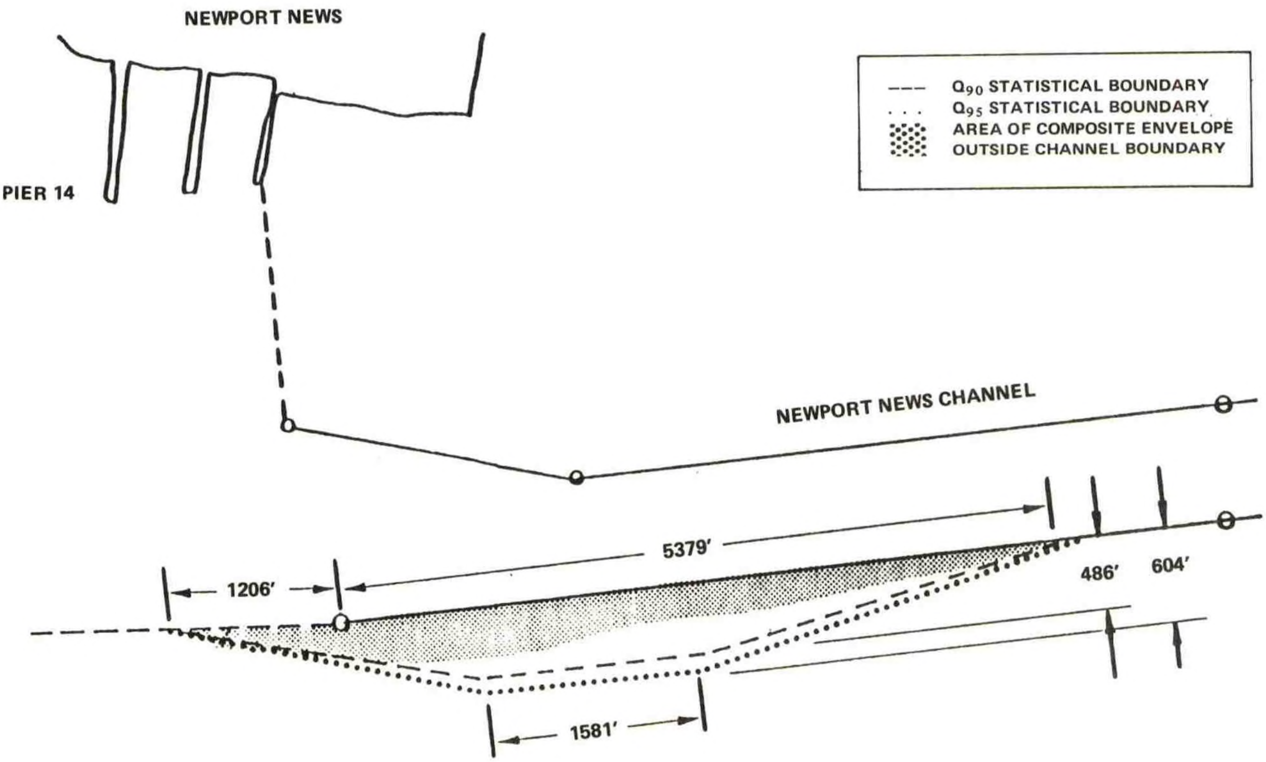

Figure 7. Statistical Perimeters Depict Dimension Requirements of the 225,000 DWT Vessel in 12 NM Visibility, 2.5 Knot Ebb Current at the Western End of Newport News Channel (from McGee, et al, 1983)

8. Panama Canal Widening Study

In an effort to increase the throughput of large vessel traffic in the Panama Canal, the Panama Canal Commission, (PCC) has undertaken a study of Canal modifications necessary to permit two-way traffic of Panamax-size vessels throughout its length. At present the Gaillard Cut is the narrowest section of the Canal (See Figure 8). It is 500 feet wide with several curves, making the meeting of Panamax vessels operationally hazardous. In order to increase the Canal's future thoughput, the Gaillard Cut would have to be modified to accommodate large vessels in meeting situations.

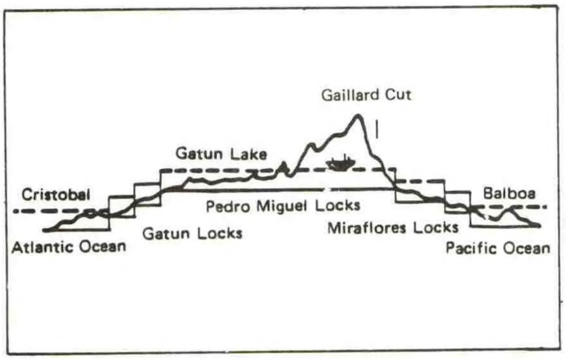

Figure 8. Panama Canal Profile

PCC is considering the redesign of the Gaillard Cut to achieve safe meetings between Panamax-size vessels while incurring the latest excavation and maintenance costs. The objective of the Widening Study is to determine the specific dimensions which will afford a reasonable balance between excavation costs and safety. Technical, operational, economic, financial, and environmental considerations are being evaluated to provide the information necessary for the PCC Board of Directors to render a decision regarding the project.

To gain assistance in the required technical analyses, PCC entered into an interagency arrangement, early in 1983, with MARAD to allow for the utilization of CAORF in the evaluation of various channel configurations. PCC's decision to utilize CAORF followed a world-wide evaluation of simulation facilities and research capabilities. CAORF offered both the fast-time and real-time simulation capabilities necessary for the determination of an optimum navigation channel.

To systematically evaluate the relative safety of various channel configurations, PCC decided to utilize a combination of fast-time to real-time simulations as the primary method of assessment. The method uses fast-time simulation to compare the relative safety of numerous channel layouts in combination with numerous operational conditions. The result of the fast-time analysis would be a set of candidate solutions which PCC would evaluate in the light of geotechnical analysis. While the simulation analysis primarily addresses the safety of various channel layouts, the geotechnical analysis addresses the excavation requirements of various channel layouts. Thus, the list of candidates for the optimum channel design would be derived from a combination of simulation analysis and the geotechnical analysis. Finally, the "best" solution – that is, the channel configuration and accompanying operational conditions which afforded the most safety (above the minimum acceptable level) with the least excavation and maintenance cost – would be subjected to real-time simulation analysis. During real-time simulation, PCC pilots would be required to maneuver a Panamax-size vessel through the Gaillard Cut during which several meeting encounters with other Panamax-size vessels would occur. Only if this last simulation analysis yields results which indicate that such meetings could occur safely within the new design dimensions of the channel would the new channel design be deemed acceptable.

The Panama Canal Widening Study is one of the largest single endeavors in CAORF's history. It requires the expansion of CAORF's in-house fast-time simulation analysis capabilities, the development of new, reliable and valid measures of safety in passing situations, and the exercise of virtually all of the real-time simulation capabilities of CAORF. In addition, the development of a valid mathematical model of a Pananmax ship, so important to the validity of the entire study, has been undertaken by the Swedish State Ship Experimental Institute (SSPA) and Stevens Institute of Technology under subcontract to MARAD.

The following sections of this paper address the methodology of this project, and report of progress to date.

9. Methodology and Progress Report

Stages of Project

Figure 9 illustrates the flow of work through the course of the project. There are five conceptual stages in the project: (1) the development of ship models, geographic data bases, mathematical model of a navigator, and performance measures; (2) the validation of each of these models and measures; (3) the establishment of a baseline of safety against which alternative channel designs could be measured; (4) the systematic evaluation of many channel and operating conditions using fast-time simulation techniques; (5) the verification of the choice of best channel design using real-time simulation techniques.

Development. During this stage, all the tools necessary to accomplish the study are being developed. These include the ship models, geographic data bases, a new performance measure for reliable assessing the safety of a passing situation ("steering quality index"), and a mathematical model of human navigator ("autopilot") to be used in fast-time analysis routines.

Validation. During the validation stage, the tools developed for this project are evaluated in the light of their comparability to the real world. For example, the performance of a simulated ship model will be compared to its performance in the real world. Like wise, the mathematical model of the human navigator ("the autopilot") will have to yield results in the fast-time simulation equivalent to that of a human pilot in real-time simulation.

Establishment of a Baseline of Safety. During this stage, a baseline of safety for passing vessels is established. The baseline measures will then be used as the minimum acceptable criterion for evaluating the safety of various channel layouts when two Panamax-size vessels pass. This effort will produce an operational definition of safety, than quantify and validate it.

At the outset of this project it was decided that the current operational level of safety associated with the meeting of two smaller vessels in the Gaillard Cut is acceptable. The goal of this study is to achieve the same level of safety with two Panamax-size vessels meeting in an improved Gaillard Cut; i.e., safety is defined as the degree to which a pilot is in control of the vessel.

Since the subsequent stages of simulation will use both fast- and real-time simulations, it is necessary to establish a baseline level of pilot controllability for use with a human pilot as well as with an automated model of the human pilot ("autopilot").

The actual measurements of the baseline safety occurs when each of several PCC pilots successfully handles a small validation vessel through the Gaillard Cut and safely passes another vessel of the same size in several curves on the real-time CAORF simulator. A similar exercise is then performed using the autopilot with a fast-time simulation routine. These results will then be compared and the autopilot will be tuned so that it responds in a manner equivalent to the response of the human pilots. The resultant baseline measures will be used as the selection criterion for the fast-time simulation stage, and as measures of acceptable performance in the verification of the "best" solution.

Evaluation of Layouts and Operating Conditions Using Fast-Time Simulation. There are seven curves in the Gaillard Cut which may require a customized channel layout. The number of combinations of channel variables (e.g., radius of curvature, width, depth) and operating conditions (e.g., speed, tug assistance, meeting location) associated with each curve are so great that fast-time simulation will be used to systematically evaluate alternative solutions. That is, fast-time simulation will serve as a method for eliminating unacceptable solutions and narrowing down the number of candidates for best channel design. The final product of the fast-time simulation analyses will be the identification of specific optimal layouts for specific sets of operating conditions.

If every posible combination of factors were to be evaluated for each curve of the Gaillard Cut, over 10,000 simulation runs would be required. Instead

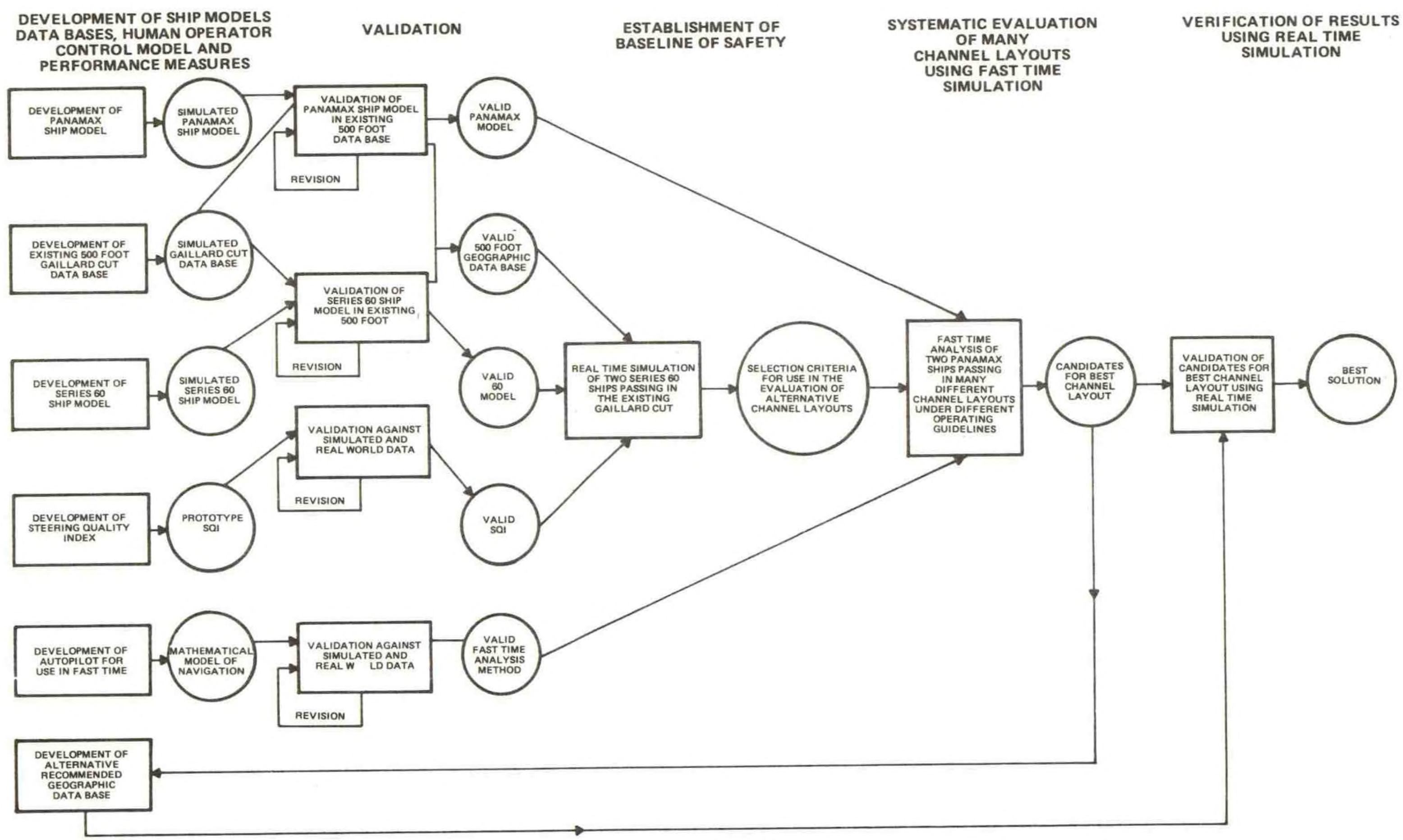

Figure 9. Work Flow Gaillard Cut Widening Study

of running every possible layout, CAORF has developed a decision tree for systematically eliminating certain combinations of conditions, the results of which could be logically inferred from previous results.

The fast-time simulation analysis will be programmed to select each combination of conditions in the proper order, carry out the run with the autopilot, compare the results to the baseline level of steering quality, record the outcome, and select the next appropriate set of conditions. The entire series of runs can be made with little or no human intervention.

Verification of the Best Solution Using Real-Time Simulation. Following the fast-time analysis, the PCC will examine the list of candidate solutions with respect to the cost of excavation and maintenance as determined through their geotechnical analysis. One or more potential solutions will then be chosen for simulation in real-time. Panama Canal pilots will handle a Panamax-size vessel through the newly designed Gaillard Cut while passing other Panamax-size vessels. The pilots' performance in these scenarios will be evidence used to verify the recommendations for the optimal channel design for a particular set of operating conditions.

Technical Developments Required for the Study

In order to complete the above five major conceptual stages of the project, it has been necessary to develop or improve mathematical models and simulation techniques at CAORF. Two new ship models, a Panamax-size vessel and a Series 60 tanker (the "validation vessel"), had to be generated and validated; a geotechnical data base of the existing Gaillard Cut had to be constructed and validated; a new performance measure of piloted controllability had to be developed and validated ("the Steering Quality Profile"); and the off-line simulation program had to be modified to simulate the performance of a pilot in meeting situations (the "autopilot"). Each of these techniques is described below.

Panamax Ship Model. The Panamax-size vessel which has been modelled is a **San Clemente** Class bulk carrier having the following characteristics: 855-foot length, 106-foot beam, 40-foot draft. 0.83 block coefficient, 650 square-foot rudder area, with 16,000 SHP at 95 shaft RPM. SSPA has performed hydraulic model tests of the Panamax vessel to provide test data to characterize the inherent ship maneuverability in deep and shallow waters, and the ship-channel interaction effects of meeting ships in straight channels of 650-foot to 750-foot widths. The resultant mathematical model of the Panamax-size vessel will be used by CAORF as the design vessel which PCC pilots must conn past another Panamax vessel in the newly designed channel.

Validation Vessel. The "validation" vessel is a Series 60 Class vessel and is the largest vessel that is currently permitted to pass another vessel of the same size in the Gaillard Cut. The development of a model of the "validation" vessel was accomplished by Dr. Haruzo Eda of Stevens Institute of Technology, and was based upon real world data, model data and theoretical considerations.

Real-world data, upon which the development of the "validation" vessel is partially based was collected in July 1983 as a collaborative effort between CAORF and PCC. Ship position in the Canal was recorded by photographing the radar plan position indicator presentation at 0.5-minute intervals. Aerial photographs of the ship were taken by helicopter at 0.5-minute intervals. Ship position was recorded by using land-based reference transponders. The pilot commands and the helmsman's reponses were recorded on the audio portion of one of the video cameras located near the helmsman's stand.

Continuous monitoring of the wind speed and direction, propeller rpm, ship speed, achieved helm, and gyro compass heading was also accomplished. During the occurrence of a meeting situation, the relative velocity of the passing ship was measured using a doppler velocimeter. The distance to the passing ship was measured using a tri-pod mounted range finder.

The real-world data collected at the Panama Canal in July 1983 was the primary data against which the performance of the CAORF Model was compared. Two methods of validation were used.

The first method exercised the simulation model so that it followed the same trajectory within the Gaillard Cut as that achieved by a similar vessel in the real world. Comparisons were then made between the rudder activity used to achieve this trajectory in the real world and the rudder activity used to achieve the same trajectory on the CAORF simulator. The ship model is considered valid if similar rudder activity in the model and in the real world is used to achieve the same trajectory.

The second method of validation was recommended by PCC. This method required that the rudder and engine orders given in the real world be duplicated on the simulator, and the resultant trajectories be compared. The ship model is considered valid if the same rudder and engine orders achieve the same resultant trajectory both on the simulator and in the real world. This method of validation requires precise recording of rudder and engine orders and an accurate accounting of the initial conditions of the vessel measured in the real world. These real-world conditions will then be duplicated on the simulator.

CAORF performed both validation methods and compared these methods. While both methods supported the validity of the model, the first method was found to be more cost-effective.

Following the fine-tuning of the ship model based upon the results of these two tests, the ship model was presented to PCC pilots for an evaluation of its handling characteristics.

Existing Gaillard Cut Data Base. The construction of the visual scene, situation display, plotting and depth/current/bank data bases to represent the existing Gaillard Cut was accomplished by using a combination of engineering drawings, charts, photographs and PCC pilot input. The geographic data base represents the Gaillard Cut of the Canal from Pedro Miquel Locks to Chagres Crossing, a section of which is shown in Figure 10. The depth of water varies from approximately 43 to 52 feet. The data base for use with the validation vessels was constructed to have an average depth of approximately 49 feet in order for its depth to correspond to that of the Gaillard Cut during July 1983 when the real world data was collected.

Of particular interest was a sensitivity analysis conducted to determine whether the data base had to include a complex bottom structure. Since the bottom of the Gaillard Cut is not a smooth surface, and includes rocky hills and valleys, a study was conducted to ascertain which of these bottom features may have some effect on shiphandling. In order to determine which bottom contours would be included in the test, each bottom feature on the charts was examined, based upon its size and form to determine whether it could possibly affect the maneuvering of a 40-foot draft vessel. A study of smooth bottom shiphandling was then conducted in two data bases, one with smooth bottom and another with an uneven bottom.

Steering Quality Profile. The Steering Quality Profile is the primary measure of performance to be used in the assessment of various channel layers. It is designed to quantify a pilot's control of a vessel. In order for a proposed channel layout to be considered "safe", it would be necessary for pilots passing a Panamax, in the proposed channel layout, to achieve an acceptable level of performance.

Ten pilots handled a 30,000 DWT tanker through each of the scenarios which varied with respect to difficulty of vessel control. The prototype dimensions of the steering quality profile would be considered valid if values on each of these dimensions varied according to the difficulty of the scenarios.

From approximately 15 prototype dimensions which were studied, the following measures were selected: amount of control force available, a relative measure of ship and bank clearance, smoothness of course-changing (for curves), yaw rate variance (for straight sections), and two measures of subjective ratings.

Autopilot. The development of a trackline autopilot was necessary so that fast-time analysis of various channel layouts could be accomplished with a model of a navigator. CAORF's compressed-time simulation program autopilot operates on a heading error and lateral off-track distance to generate rudder commands which will control the transit of the vessel. This particular fast-time program can simulate two "intelligent" autopilots, one on each side of the vessels which meet. A trackline is specified by the user to indicate the path the ship will attempt to follow. In the case of the Panama Canal Widening Study, the trackline will be the centerline or sailing line of the Gaillard Cut (See Figure 11). The autopilot anticipates turns in the track by looking ahead of the vessel by a specified distance. It also

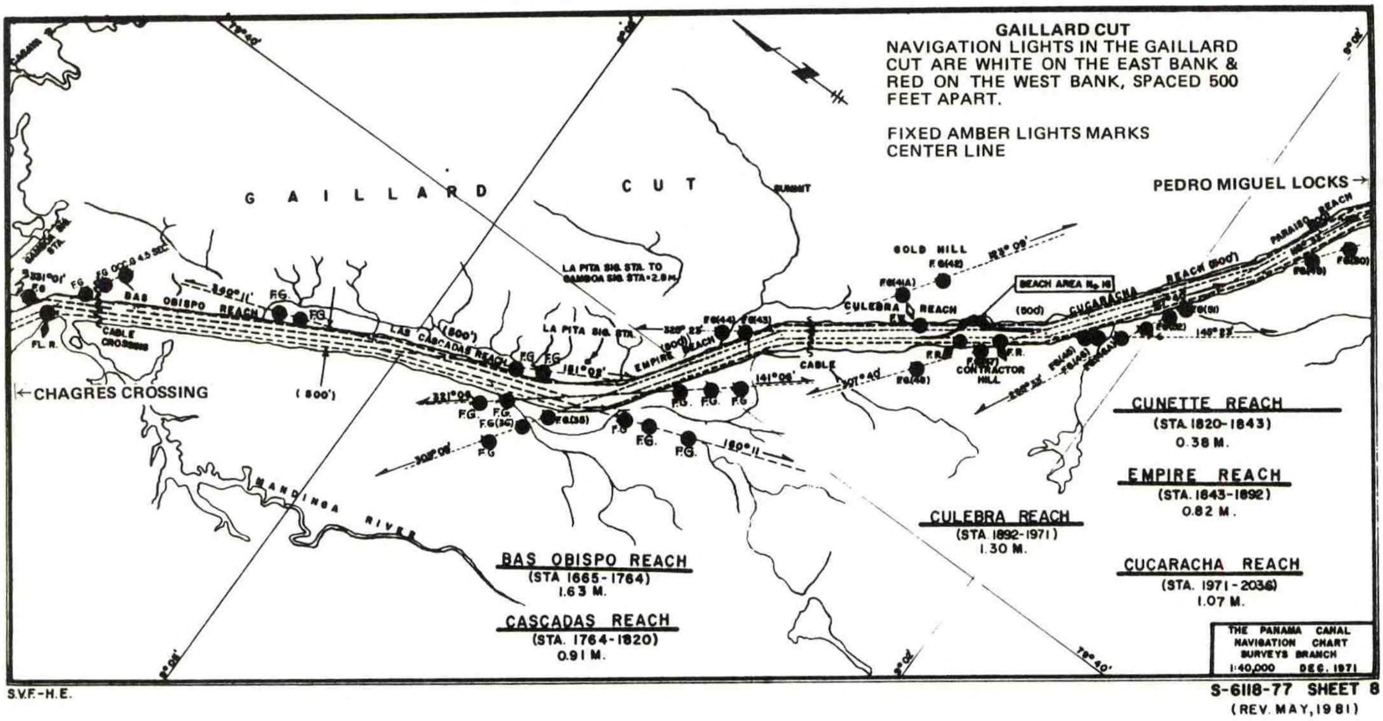

Figure 10. Gaillard Cut

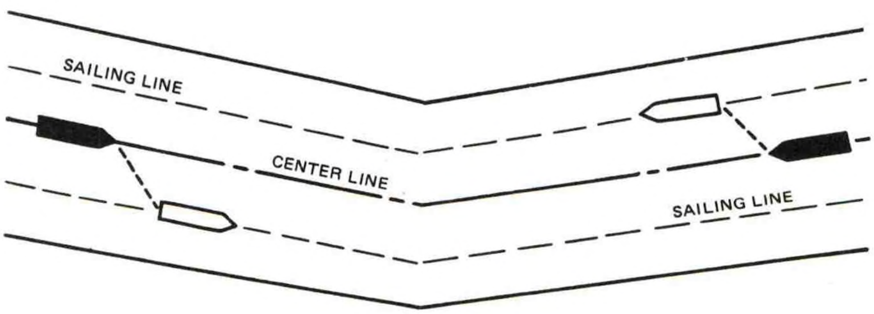

Figure 11. Sailing Line/Center Line, Vessels Passing in Gaillard Cut

anticipates the approach of another vessel, and in response to the presence of another vessel, will initiate a maneuver to move from the centerline to the sailing line. During meeting and passing, the position of the vessels are controlled within the limits of controllability of the rudder to avoid an oncoming vessel. If either vessel is unable to maintain position on the sailing line, then the other vessel will attempt to move closer to the channel wall until some minimum specified distance has been reached.

The CAORF staff has added several special options to the autopilot which improve its sophistication; for example, the option to have the vessel execute a slow down/speed up maneuver to enhance rudder effectiveness during a meeting encounter, and the option to require tug assistance during the transit. Tug assistance will be given when the value of the rudder angle generated by the autopilot exceeds some specified value.

The autopilot has been validated by comparing its performance in standard scenarios with that of seven Panama Canal pilots who performed on the CAORF real-time simulator. In addition, observations of pilot performance have been made while handling real-world vessels in the actual Gaillard Cut. These data were used to evaluate the performance of the autopilot.

10. Summary

The marine transportation system is a broad complex network which, in addition to the operations of ships at sea, encompasses such diverse activities as the operations of shore-side terminal facilities and the design of channels and harbors. The various simulation techniques at CAORF can be extremely useful in designing that portion of the system which requires consideration of the interaction of the man, the vessel, and the environment in which they operate.

The Hampton Roads and Panama Canal projects, illustrated in this paper, represent only a part of the CAORF research effort aimed at increasing productivity and safety in marine transportation. Aiding the design of channels by determining their optimal dimensions is, however, an important step toward enabling the development of U.S. and foreign ports in the most efficient and cost-effective manner.

These and similar projects for other sponsors have demonstrated the value of the computer simulation techniques in the design, development and evaluation of port and waterway projects. Simulation permits the interpretation of all relevent variables in the marine transportation system, thus providing important engineering tools with which to study and evaluate alternative system designs. Looking at CAORF's research and development programs conducted since its operational beginning in the mid 1970's, we conclude that CAORF has met and exceeded the challenge which inspired MARAD's original efforts to develop a flexible useful, and realistic marine transportation research instrument.

11. Conclusions

In recent years, the maritime industry has witnessed a dramatic increase in the size and cargo capacity of ships. While advances in shiphandling technology have led to substantial gains in the productivity of shipping, this trend has had some negative ramifications as well. The size and capacity of channels and port facilities have not generally increased in proportion with the size of vessels that must be handled. This has led to situations in which the relationship between the ship size and channel size leaves little or no margin for error, a situation which has, unfortunately, been borne out by the rise in the maritime accident rate. While it is vital that economic efficiency of shipping be maximized, this cannot be done at the expense of safety. Thus, it is important to utilize every available tool in designing harbors and waterways to mitigate risks as much as possible.

CAORF has been utilized by many segments of the marine community to conduct waterway design analysis. Through this work, CAORF has developed an evaluation approach to design assessment which is based in the collection of objective data within the framework of a rigorous method. The integration of this data with subjective evaluations by experts (e.g., pilots, ship masters, operation personnel) associated with the specific areas under investigation provide a thorough evaluation of a proposed design. Thus simulation has been proven to be a most valuable tool in port and waterway engineering.

Simulation supplies data which is essential to make credible, real-world decisions. It is generally the case that the maritime simulation facility (CAORF) acts as a project facilator by providing data which is quantitive and unambiguous. Planners and decision makers, seeing the results of simulation, know better what the relative trade-offs involved really are, and such knowledge produces action –– action to build, action to dredge, action to implement.

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WAVE POWERED PUMP

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ABSTRACT

Attempts to use wave power to generate electricity have been hampered by the variability of the energy source, by the destructive power of storm waves and by excessive maintenance on moorings and cables.

The authors have developed a wave powered pump for seawater which eliminates these problems. The pump is bottom mounted in shallow water and uses the horizontal, rather than vertical water motions for power. The shallow location filters out destructively large waves. Model tests with random waves at 1/8 scale have verified a predictive model for performance. A full scale pump with a body diameter of 4.5 meters delivers 145 liters/minute against a 14 atmosphere head.

Applications include fresh water production by reverse osmosis, dredging and harbor clearance projects.

BACKGROUND

Most wave power projects have utilized the vertical motions of the ocean surface to drive a mechanical device. The development of the Masuda air turbine concept in Japan from small buoys to a major power generation facility in the Kaimei [see, for example, Miyazaki and Masuda (1978), Koriki (1983)], represents the most successful of these efforts. The principal use of wave power has traditionally been seen as the generation of electricity, for reasons that are obvious in the economic climate of today. Many of these wave-driven systems must be moored to hold position. They tend to be sited in locations with energetic waves to increase their average power output.

This combination of requirements and conditions produces a series of difficult design and operational problems that have impeded the acceptance of wave power.

1)The electrical power customer needs a constant and dependable source. Wave energy is highly variable. Expensive plants must be held in reserve for periods of small wave conditions.

2)The deep water, exposed conditions selected for high average waves will produce very large waves during major storms, introducing extreme design loads, heavy and expensive structures, and poor small wave response.

3)Moored systems, because of fatigue and stress corrosion, have very short lifespans.

4)Power cables, connecting the moored systems to shore, are very expensive and vulnerable to fatigue in the sections subject to flexing [Marine Board (1982).]

A SOLUTION TO THE PROBLEMS

Recognizing these characteristic problems, the authors have devoted some effort in developing a set of design criteria for wave power projects that would eliminate some or all of these inherent difficulties. In brief, these criteria are:

a)The system should produce a product or service that can be economically stored or which can be used with widely varying production rates.

b)The system should operate in very shallow water so that the large destructive storm waves will be diminished by breaking before striking the machinery.

c)As corollaries to b), first, the system should utilize the horizontal wave motions, because these are amplified significantly in shallow water compared to the vertical motions. Second, the device should operate successfully in breaking, or already-broken waves.

d)The system should be fixed to the bottom, rather than moored and be easily removed for maintenance purposes. The product should be removed through fixed rather than flexible means to eliminate fatigue problems and increase reliability.

WAVE POWERED PUMP DESIGN

One simple and straightforward method for extracting power from the oscillatory motion of waves is to use these motions to pump a fluid. Several proposed systems, particularly in Great Britain, have suggested using hydraulic fluid as a working medium. [Ross (1981)] An even simpler arrangement is to have the machine pump seawater. To meet the design criteria defined above, the pressurized seawater must then meet some economic requirement. At least two such applications are immediately apparent. Reverse Osmosis (RO) is a desalinization process that requires seawater at high pressures (about 70 atmospheres.) About half of the cost of producing freshwater by this method is in the energy costs of pumping the saltwater.

This work was supported in part by grants from the Foundation for Ocean Research and the University of California Appropriate Technology Program.

This is obviously an application in which wave power could be expected to compete. Fresh water can be stored readily, so that a variable production rate is not a significant problem. A second, and potentially much greater market exists in providing pressurized seawater for dredging or harbor clearance projects. Again, a very large fraction of the costs of these operations is in the energy costs for pumping seawater. If the wave powered pump is used to support a semi-continuous harbor clearance process (such as a by-passing plant) it will produce more water on days when the waves are large. Typically, the demand on the sediment movement system will increase with wave energy, so that the pump system appears well matched to the demand.

To meet these needs, a pump was developed that meets the design criteria set by the authors [for details of design, see Seymour and Castel (1985).] The general configuration is shown in Figure 1. It consists of a cylindrical displacement body, constrained to move horizontally on tracks. It is directly coupled to a double-acting, positive-displacement piston pump. The body is driven by the horizontal orbital motions of the waves. Typically, the pump would be mounted in water about 8 m deep, with a diameter of about 4.5 m on the displacement body. At this depth, long period Pacific swell have greatly elongated horizontal excursions and provide a powerful driving force.

In shallow water, considerable refraction has already taken place. Therefore, waves tend to be nearly normal to the shore, side forces are minimized, and most of the wave energy can be effectively used. Waves are limited in height to about 8 m by the water depth so that the maximum wave loading is known accurately. A unique feature of the design is that the entire system can be installed beneath the water. This allows its use in locations where the appearance of large, above-surface structures would degrade the visual environment.

The system can be supported on a gravity foundation or with piles as shown in Figure 1. The pump and valves are shown schematically in Figure 2. A 1/8 scale model of the pump has been tested with random seas in a wave tank. A series of experiments was performed that confirmed the predictive skill of an analytical model of pump performance. Scaling to prototype size results in the following typical outputs with 1.4 m significant wave heights:

146 liters per minute at 14 atmospheres head

33 liters per minute at 70 atmospheres head.

This is the output from a single pump. Multiple units can be mounted very close together for increased output. Figure 3 shows the predicted output for the prototype as a function of wave height against two representatives heads.

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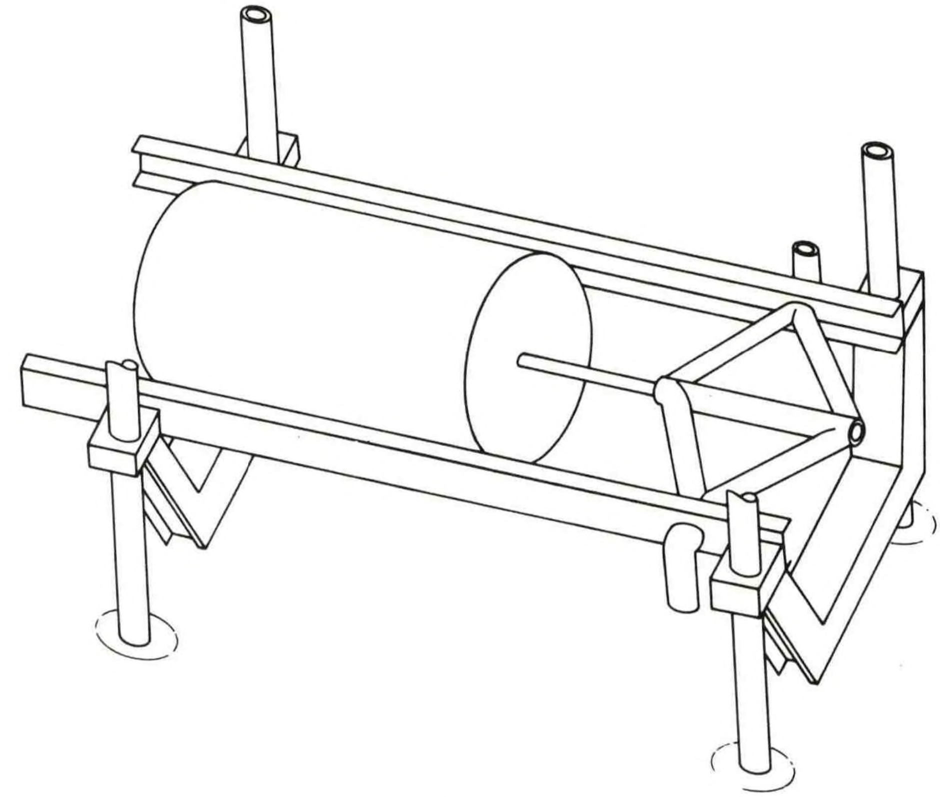
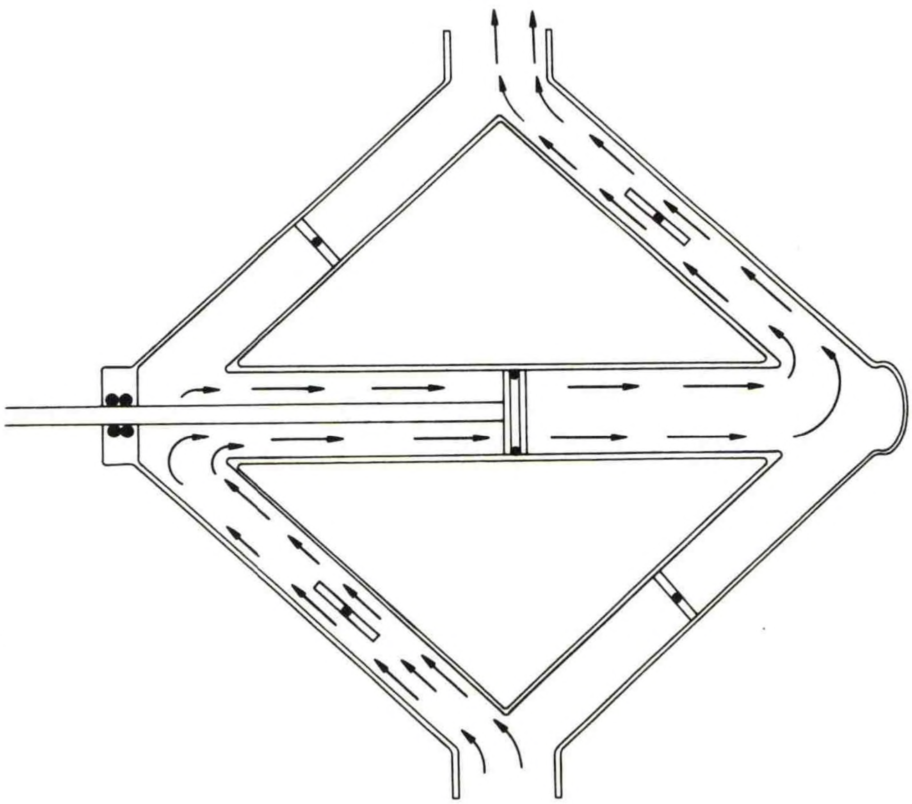


PROPOSED CONFIGURATION OF FULL-SCALE WAVE POWERED PUMP
Figure 1



ARRANGEMENT OF PUMP CYLINDER AND VALVES
Figure 2

Pump Output v. Incident Wave Height

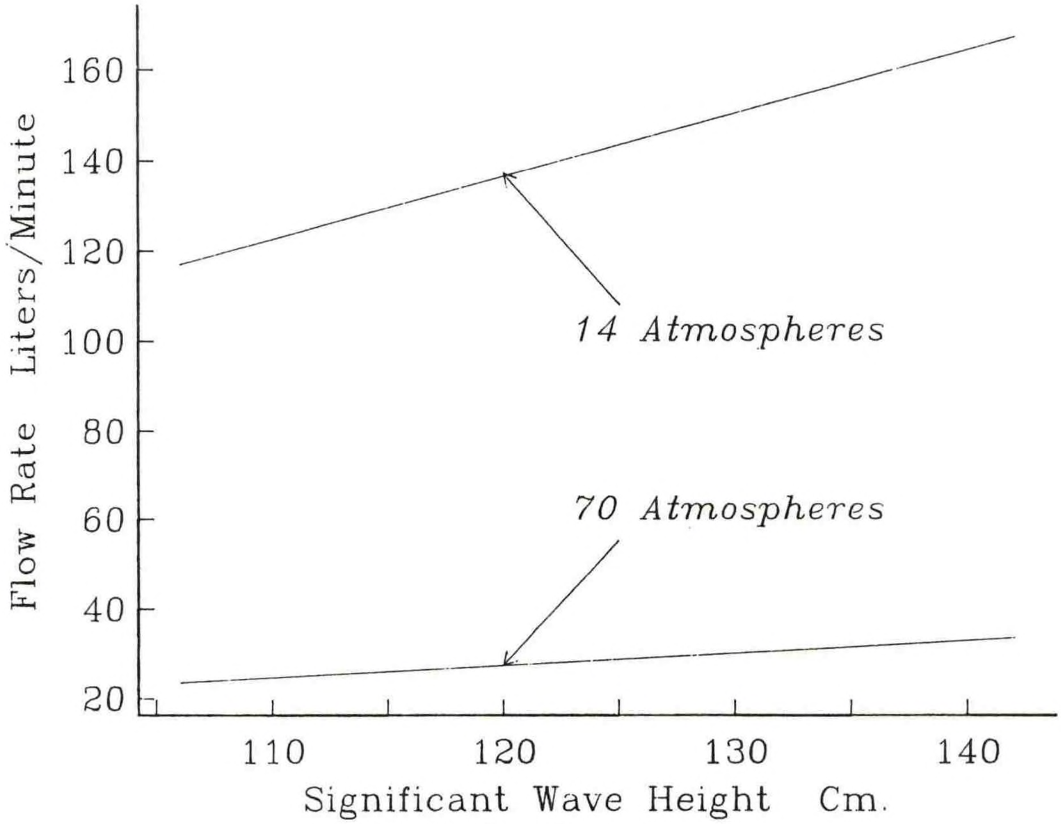


FIGURE 3

INITIATION OF TURBIDITY CURRENTS
ON SHELF AND SLOPE

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ABSTRACT

Turbidity currents present hazards to construction on steep slopes with unstable sediments. Among currently planned projects that could face these hazards are OTEC cold water intake lines in Hawaii and Puerto Rico, and inter-island electrical power cables in Hawaii.

Turbidity currents observed in nature are often two-dimensional (trapped in canyons) and may often be initiated by oscillatory shelf currents rather than landslides.

The theories of Bagnold appear to explain the steady-state behavior of observed turbidity currents better than other competing theories. Laboratory experiments suggest that the initiation energy for two-dimensional flows can be predicted.

THE PROBLEM

Several ocean engineering initiatives, now under consideration, will involve massive construction projects on relatively steep slopes covered with unstable sediments. The possibility of turbidity currents -- density flows driven by sediment entrainment -- exists under such conditions. Ocean Thermal Energy Conversion (OTEC) plants are being planned for Hawaii and Tahiti [see, for example, Castellano et al. (1983), Gauthier (1984).] A third is possible in Puerto Rico. All of these sites contain nearly vertical cliffs on the shelf that appear to be ancient reef structures. These steep cliffs severely complicate the design and installation of the cold water intake pipes, which must reach to great depths. In both Hawaii and Puerto Rico, natural canyons exist that provide a more gently sloping access for the intake structure.

Coastal submarine canyons are known to be locations for turbidity currents [Reimnitz (1971), Inman et al. (1976).] At the Hawaiian site, during Hurricane Iwa in 1982, there was almost certainly a turbidity current of large magnitude detected by downslope movement of oceanographic instruments [see Dengler et al. (1984).] Thus, by selecting a location where gradual slopes cut through a steep cliff, the OTEC plant designers may be selecting the exact place where turbidity currents are most likely to occur.

This work was supported in part by a grant from the Foundation for Ocean Research.

The State of Hawaii is studying the possibility of interconnecting all of the islands within a single electrical power grid. This requires that high voltage cables be laid down steep slopes to depths greatly exceeding existing capabilities. The potential for turbidity currents most certainly exists somewhere along the proposed alignments. Cables were damaged or parted in the Hurricane Iwa turbidity current as well as the well-studied cable breaks off Newfoundland.

TURBIDITY CURRENT INITIATION

There are, at present, no models in the literature that predict the requirements for initiating turbidity currents. Geologists, who have studied the evidence of ancient massive marine flows, have generally assumed that they were caused by landslides, slumping or cliff failure under water. This is one of the two theoretically possible ways to start such a density current -- introduce a very high concentration of suspended sediment and allow the flow to accelerate until it reaches the autosuspension point. Autosuspension implies that the flow speed is great enough to entrain at least as much sediment as is being lost by gravity, assuring the continuation of the flow. The second method is to start with a high enough speed of flow with initially clear water to cause an increasing concentration of sediment. If the proper concentration is reached before the speed is diminished too far, autosuspension results. Observations in nature of turbidity currents suggest that this second initiation mechanism is often the dominant one. In particular, it appears that low frequency oscillations on the shelf may provide the critical suspending velocities.

Most of the documented turbidity currents are two-dimensional in character, at least near the initiation point. That is, they start in narrow submarine valleys or canyons. This eliminates momentum losses at the sides which could halt the flow. It would seem that if the initial flow were wide enough it could survive even in a three-dimensional flow, however no theoretical models exist for this condition.

Determining the conditions necessary to initiate and sustain a turbidity current appears necessary for at least two reasons:

1) make it possible to predict the probability of a naturally-occurring turbidity current at any site, and

2) determining the feasibility of a manmade turbidity current to clear out unstable sediment accumulations prior to construction.

TURBIDITY CURRENT THEORY

A review of existing theories for steady state turbidity flows (there are no theories for initiation or other non-steady attributes) is contained in Seymour (1985). This work also reviews all of the field observations and tests the various theories against the results in nature. The theory of Bagnold (1962) was shown to be the only one to predict all observed turbidity currents. A laboratory-scale evaluation of Bagnold's criteria using oscillatory cross-shore currents as the initiation mechanism is also reported in Seymour (1985).

It appears from this study that the engineering tools may be relatively obtainable to make reasonable predictions about the energy required to initiate full-scale turbidity flows in the ocean. A confirmatory experiment is being planned.

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Technology Assessment to Determine
Incipient Failures in Marine Structures

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ABSTRACT

Industry's move into the deeper and more hostile regions of the Outer Continental Shelf (OCS) in search of new sources of oil and gas has stimulated the development of new technologies for the inspection of marine structures. Historically, the structural integrity of offshore platforms has been assessed through the use of divers and/or submersibles, both manned and remotely controlled. However, these methods have serious limitations when applied to the newer structures and their environments. This paper discusses the need for an inspection philosophy, the various inspection techniques employed, and the development of new technologies to assess the integrity of marine structures.

The ever-present need for new oil and gas resources has driven Government and industry to venture into progressively deeper waters and increasingly more hostile environments of the OCS. Just this past summer (1984), exploration activities were conducted on the U.S. Atlantic OCS in water depths up to approximately 7,000 feet and recent lease sales in the Gulf of Mexico (Nos. 81 and 84) included areas in water depths up to 3,500 feet. These deepwater sites will call for the use of new technologies to make field development economically attractive. Deepwater production operations can also be expected in the North Sea where hydrocarbons in commercial quantities have been found in waters over 1,100 feet deep. In addition to deep water, structures will be deployed in or near the ice-shear zone in both the U.S. and Canadian Arctic. It is the deep waters and hostile environments encountered in these frontier areas which have stimulated the development of many new inspection techniques to verify the structural integrity of marine structures.

Another concern which has not received much public attention is the structural integrity of many existing platforms. Between 1947 and the present, approximately 3,400 structures have been erected in the Gulf of Mexico for the production of oil and gas. Many of these are still in service today, and the only requirements for periodic inspections are those which the platform operators/owners elect to impose upon themselves. Sufficient knowledge of the integrity of a structure must be available to assure reliable performance. The ability to demonstrate such reliability has necessitated rigorous inspection requirements which, in turn, have led to new developments in the inspection technologies. It is important to note that for an inspection method to be truly useful, either for the new frontier structures or for the older structures in shallow water, the method must be reliable and cost effective.

Historically, the structural integrity of offshore platforms has been assessed by visual techniques through the use of divers and manned or remotely controlled unmanned submersibles. However, progressively larger structures, deeper waters, and more hostile environments have seriously limited the use of current nondestructive examination (NDE) techniques. Even in fairly shallow waters, techniques for inspecting facilities are only marginally effective, time-consuming, and costly. In view of this situation, current developments have been and will continue to be made in two major areas.

The first is the improvement of the capabilities of remotely operated vehicles (ROV) as replacements for divers. At the root of this technology are microprocessors that can be programmed in a manner to perform the various necessary work tasks. The second approach, structural monitoring, is more basic. This approach is conducted by global monitoring techniques, that is considering the total structure, instead of the local techniques presently used. Examples of global structural monitoring are vibration-monitoring techniques, acoustic emission techniques, and acoustic imaging techniques, to name a few.

The need to perform periodic inservice inspections is clear when considering some of the past failures that have resulted from undetected structural defects. The loss of the Alexander Kielland, a hotel platform, illustrates this point. Although industry's past performance with fixed platforms has been excellent, future exploration and production activities in new environments, using new structural concepts, will be approached cautiously.

Underwater inspection and defect assessment have been and will continue to be a major concern to all involved in ensuring the long-term integrity of offshore facilities. Considerable experience, drawn mainly from the aircraft and nuclear industries, has been gained in the assessment and consequences of growth of small cracks into major failures. Yet, even with these advances, numerous questions remain to be answered regarding offshore underwater inspections. These major questions include the following:[1/]

- What should inspectors actually look for?
- Will it be recognized when it is seen?
- What items should be inspected/where should an inspector look?
- What mimimum defect might be found?
- How frequently should an inspection be performed?
- How does the design, particularly the estimated fatigue life of particular structural elements affect the need, objective, nature, and frequency of an inspection?
- What type and size of defect should inspectors look for to ensure continued safe operation of an installation?
- What is the significance of a given defect in a given position on a structure?
- To what extent does the underwater environment affect the feasibility, accuracy, and frequency of inspections?

These major questions are difficult to answer and, in fact, require different answers for differing structures (e.g., a fixed steel-jacket platform versus a compliant tension-leg platform) or for differing environments (e.g., the Arctic versus the Gulf of Mexico or the North Sea). Answers to the above questions are necessary to develop the comprehensive philosophies needed for the inspection of the various types of offshore structures. These answers require a knowledge of the capabilities for the available inspection and monitoring techniques.

Before reviewing the newer developments, it is useful to look at NDE techniques which have been and are currently being used for underwater inspections. Numerous NDE techniques have been developed for quality control operations in industry; however, relatively few have been adapted for the underwater environment. Most techniques were developed for use with a particular material; whereas, some found a wider range of application. Traditionally, the offshore industry has used the NDE techniques as follows:

- Visual (detection of surface cracks and missing or damaged members).
- Ultrasonics (surface and subsurface flaw and crack detection, material thickness measurements).
- Magnetic Particle (surface and shallow subsurface crack detection).
- Radiography (internal flaw and crack detection, material thickness measurements).
- Electrical Potential (corrosion potential measurements).

Each of these methods have advantages and limitations and is dependent on the use of a diver and his ability to gain access to a structure. Also, for these methods to be effective, a thoroughly clean and smooth metal surface is required. In fact, the cleaning process can be a major problem, often more time consuming than the actual testing. The density of marine growth decreases significantly beyond a water depth of approximately 200 feet, but increasing water pressure will reduce the efficiency of a diver or prevent his use altogether. To avoid going beneath the water surface, many of the inspection techniques and work functions have been transferred to unmanned ROV's. Manned submersibles have been widely used by the offshore industry, and the technology is well established.

For underwater inspections, divers have good facilities for viewing and maneuvering and are quite responsive to changing situations. Their weakness usually results from a lack of proper NDE training, depth capability, and underwater time exposure. The unmanned ROV, on the other hand, exhibits no such limitations. It has a high endurance and depth capability. In addition, the inspection data can be presented in real time and viewed by a number of inspectors. Conversely, the ROV only presents a two-dimensional view, and its manipulative capability is not equal to that of a diver. A tethered, free-swimming ROV is subject to cable fouling, and it can be unreliable in terms of equipment performance.[2/]

There are four types of ROV's--tethered, free-swimming; towed; bottom-crawling; and autonomous. From an NDE point of view, the first type, tethered, free-swimming ROV's, are used almost exclusively. The latter type, autonomous ROV's, are several years away from operational usage, but they do indicate potential for future NDE utilization.

The tethered, free-swimming ROV is capable of maneuvering in three dimensions. Power is supplied from the surface by means of a relatively heavy umbilical cable. Standard equipment consists of closed-circuit television (TV), lights for TV viewing, and a depth sensor. An array of navigational and work instrumentation may be carried in combination with a manipulator, depending upon a vehicle's power and purpose.

Autonomous ROV's, on the other hand, operate independently of umbilical cables and carry battery power onboard. Within the past few years, new technologies have appeared which offer much promise for greatly reducing the need for online controls. Ultimately, this technology, robotics, will allow machines to be programmed in advance to perform specified tasks and to communicate directly with highly trained technicians located on the surface facilities. The scope of applications for an unmanned autonomous submersible ROV is wide and varied, offering many potential advantages over a tethered, free-swimming ROV. As previously stated, the autonomous ROV is presently in the development stage, and additional research is required in such areas as energy storage, guidance and control systems, information and communication systems, and the intelligence-coordinating systems. With further development, the autonomous ROV will greatly enhance the ability to inspect structures in deep waters and hostile environments.

It has been demonstrated that their are techniques available for direct NDE or visual inspection of a marine structure. However, there are techniques available which can monitor the integrity of a structure without requiring an inspector to enter the water or dispatch an underwater vehicle on his behalf.

Several monitoring techniques have been identified in reference 3 as feasible candidates for structural integrity monitoring. These are as follows:

- Attitude Measurements.
- Strain Gauges.
- Leak Testing of Tubular Members.
- Ultrasonic Imaging.
- Vibration Monitoring.
- Acoustic Emission.
- Optical Fibers.
- Trace Elements in Welding Consumables.

The first three techniques are relatively simple systems in concept. Attitude monitoring is based on measuring the changes in the inclination from the vertical alignment of a platform. Strain-gauge systems may be useful in obtaining stress or strain data for fatigue monitoring; however, these systems have many problems which result from the placement and maintenance of gauges. Leak testing of tubular members reveals cracking by measuring either leakage of air or influx of water into members. Once leakage has been determined to have occurred, a diver or an ROV would be deployed using standard NDE techniques to find and assess the defects.

Imaging systems using a scanning sonar beam are under development and are intented for the global inspection of structures. Such systems could easily be deployed and give real-time information on certain structural deficiencies, i.e., missing or bent members. However, additional research is necessary to produce an operationally acceptable imaging device.

Vibration monitoring is a technique in which the measured vibrational response of a member or structure is related to its stiffness properties and hence its structural integrity. This technique is based on measured changes in either the natural frequencies or mode shapes of a member or structure which, in turn, reflects a decrease in the structural stiffness and degradation within the platform. Vibration monitoring can be conducted at both the local or global level. The global mode provides information on a critical failure within an entire structure; whereas, the local mode would provide information on crack initiation or growth only near a sensor.

The first attempts at global monitoring consisted of placing accelerometers on platforms above the water to measure their structural responses under ambient conditions and then compare these responses to previously taken baseline measurement. A change in the response indicates damage or a failure within a structure. It was found that other factors not associated with structural damage or failure could cause changes in the responses, for examples marine growth, topside load changes, and conductor or riser movement. Another problem is that large structures have so many redundant members that even the removal of a major member would not sufficiently change responses of the above-water accelerometers. Thus, most offshore engineers consider that it is not an acceptable inspection tool.[4]

A variation of this global system called flexibility monitoring has been tested and has shown promise as a valid inspection method. It is basically a vibration technique specifically designed for a fixed steel-jacket platform. For this technique, accelerometers are placed on the deck and the legs of a structure at different bay levels, ideally all the way to the mud line. These instrument packages are attached to the legs of a platform during construction. Vibrational data obtained are used to determine mode shapes, depicting movement at each bay level, which are compared with previous baseline measurements. Analytical models are then used to determine the responses at various levels of the structure. In this manner, decisions can be reached about the structural integrity of the platform at each of the instrumented levels.

A local vibration-monitoring technique is being used to some extent in the North Sea. For this technique, accelerometers are attached to individual members, the members are then excited by a vibrator, and the measured responses are compared to previously obtained baseline data. A change in the response indicates structural damage or flooding of a member due to a crack.

A variation to the local vibration-monitoring technique is the random decrement method. It is based on the analysis of a set of graphs known as "randomdec" signatures which present information on higher structural frequencies and damping characteristics. These signatures are generated from random response data obtained when a platform is subjected to random excitations such as ocean waves. Incipient structural failures can be detected by noting the changes in these signatures.

Two other techniques, acoustic emission and optical fibers, have been proposed recently as a means for inspecting offshore structures.

Acoustic emission techniques measure the acoustic waves generated in materials from crack evolution or from contacts due to crack closures. This technique has been used successfully in onshore installations but has met with very limited success in offshore applications. The optical fiber system is based on the fracturing of optical fibers at a predetermined strain level. Fibers are attached to selected structural members with an adhesive, and when light transmission through these filaments degrades, failure or damage is indicated. Both of these systems are under development and currently are not suited for marine operations.

The trace-element technique is developmental and is an innovative approach for detecting cracks or corrosion in a weld. This technique consists of incorporating a trace or radioactive material into a welding consumable for use in the fabrication of a structure or pipeline. Activated material would be used only on certain interior beads of multipass weldments. Ions of the traceable material when cracks or corrosion penetrate the interior of the specially fabricated weldment. Detection of the ions by monitoring the fluid being transported in a pipeline, or by periodic scanning of the water adjacent to a structure, would indicate the presence of cracks or corrosion. The significance or magnitude of a required repair or the need for additional inspection could be assessed by the level of ion concentration. As previously stated, a technique of this type would not be used for all weldments but reserved for critical locations. Additional research and development are necessary if this technique is to become operational.

CONCLUSION

This paper has highlighted the major new technologies under development for inspecting offshore structures. It has not presented, however, a complete account of all inspection techniques employed within the industry. Because of the many variables and alternatives inherent in an inspection program, a number of requirements should be considered. Ideally, an inspection program should be keyed to a specific structure because no single inspection technique can be successfully applied to all facilities. Several important factors should be recognized in selecting a specific inspection program and interval for a particular structure--age, condition, economic importance and consequence of a failure, and location. All NDE techniques and interpretations are operator dependent, and recent developments have been directed towards reducing or removing this human interpretation factor from the inspection process. Another problem with presently used NDE techniques is the requirement for a clean, smooth surface. More expeditious techniques to reduce the time required for cleaning structures should be developed, though significant improvements have been made in the past several years for high-pressure water jets.

The ROV offers the most immediate potential for reducing the time and logistics of an underwater inspection program. The various problems encountered by divers when operating in deep waters or hostile environments can be mitigated by the use of ROV's. This is a very dynamic development area of underwater technology as more and more inspection requirements are being placed on ROV's. The concept of an unmanned, untethered, or autonomous ROV is very appealing and is presently under development, though operational usage except for simple tasks is several years away.

Most of the structural monitoring techniques appear promising but will require further development and field testing. Other techniques investigated have significant limitations that may prove impossible to overcome. For example, vibration monitoring in the global mode has not lived up to its earlier expectations although monitoring by the local method, flexibility method, trace element method, and acoustic-emission technique appear to have various degrees of merit. All of the techniques require further development and testing to determine the extent to which they can be relied upon and the limits to which they can assess the integrity of a structure. Monitoring techniques will not totally replace the need for divers and/or submersibles; however, they will ensure that both divers and future ROV's are used and deployed in a safe and proficient manner.

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NATIONAL UNDERSEA LABORATORY FOR THE UNIVERSITY OF SOUTHERN CALIFORNIA

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Abstract

As part of the U.S. National Oceanic and Atmospheric Administration (NOAA) Undersea Research Program to foster, coordinate and support the nation's undersea science activities, the University of Southern California (USC) and NOAA have designed a semi-mobile undersea research laboratory system. The system consists of a large double-lock pressure chamber, a support barge, way stations and a personnel transfer chamber/deck decompression chamber (PTC/DDC) for emergency rescue.

The laboratory will be initially emplaced in 70 feet of water adjacent to USC's Catalina Marine Science Center on Santa Catalina Island, 26-miles off the southern California coast.

State-of-the-art design of the system will enable scientists to perform long-term in-situ research in temperate waters of the world's continental shelf.

Background

Historically the scientific diving community has been severely restricted by the inherent limitations of traditional diving methods. Since the 1940's the Self Contained Underwater Breathing Apparatus (SCUBA) has greatly increased access to the shallow waters of the continental shelf, but bottom time below 40 feet is limited.

Scientific underwater habitats developed in the 1960's greatly increased bottom time, and the positive result of numerous research projects undertaken using these facilities provided the impetus for developing a new, more capable underwater laboratory system.

Conceptual design of this new system was initiated in 1980 under a cooperative agreement between NOAA and USC. Basic precepts which guided the design included:

A. Maximum mobility of the system;

B. Operation in temperate water to 120 feet depth;

C. Laboratory accommodations for up to 6 aquanauts; and,

D. Capability to conduct 12-16 saturation missions of 7-10 days per year.

System Design

The underwater laboratory system will consist of the laboratory itself, a ballasted baseplate as anchor, a surface support barge, personnel transfer capsule/deck decompression chamber (DDC/PTC) for emergency rescue and a series of "way stations" for conducting excursions away from the laboratory and for use as safety havens in an emergency.

The laboratory "building" will be an insulated double lock 9 foot diameter pressure chamber. Integral with, but external to the chamber will be nitrox and compressed air cylinders, a "wet porch" for diver entry/exit, surface umbilical attachments, and other equipment which can be housed external to the laboratory. Overall dimensions of the laboratory will be 40 feet by 12 feet by 16.5 feet in height.

The laboratory's small outer lock will contain sanitary facilities, an environmental control unit, and a "wet" laboratory. The main "dry" chamber will be the principal work/sleeping area and contain a fully equipped laboratory, computer, control panel, environmental control unit, observation ports and hotel facilities for 6 scientists. The laboratory will be maintained at a comfortable temperature and humidity level with an atmosphere made up of nitrox (oxygen partial pressure between .21 and .50). This gas mixture is used at saturation depths below 50 FSW to reduce the possibility of pulmonary oxygen toxicity from long exposures.

The "wet porch," attached but external to the outer lock, will be open to the sea for diver egress and will contain a fully equipped diving locker, hot tub for diver rewarming and the diver umbilical attachments. Excursion diving will be on compressed air.

A series of several "way stations" will extend the horizontal excursion range of the divers. These mini-laboratories will be supplied with gas, power, hot water and communications by an umbilical linked to the main laboratory.

The surface support barge will contain all the essential support equipment to enable the underwater laboratory system to operate independent of additional external support. The barge will supply the laboratory with power, nitrox, hot water and fresh water. It will also contain a deck decompression chamber and handling equipment for the personnel transfer capsule. A monitoring station onboard the barge will enable a surface observer to monitor all life support systems in the laboratory.

The deck decompression chamber and personnel transfer capsule are essentially emergency equipment for evacuating divers from the laboratory in the event of fire or other major catastrophe. They may also be used for the decompression of divers who participate in a saturation mission for periods shorter than an ongoing mission. In either case, the procedure will involve transfer of the divers at ambient bottom pressure in the PTC to the deck decompression chamber on board the surface support barge.

The normal sequence of operations will be to tow the laboratory and support barge to a site, launch the baseplate from the barge or towing vessel, flood it down and secure it to the bottom on an even keel, then winch the laboratory to the bottom and secure it to the baseplate. The PTC will then be lowered to the bottom and positioned adjacent to the laboratory, after which the laboratory will be occupied and way stations established in desired positions.

The system can be emplaced in temperate coastal waters at depths up to 120 FSW. Tethered excursion diving may be conducted to depths of 200 FSW. The system should be capable of operations in sea states up to three and in currents of up to one-half knot.

Status

Engineering design of the system was completed by Perry Oceanographics, Inc., in 1982. After a series of delays caused by funding problems and design modifications, a construction contract for the laboratory was awarded in August 1984 to Victoria Machine Works of Victoria, Texas. The completed laboratory will be delivered to the University's Marine Support Facility on Terminal Island, Los Angeles, California, in early 1986 for integration with the support barge, PTC/DDC and baseplate and subsequent testing. It is anticipated that the underwater laboratory system will become operational for scientific use in mid-1986.