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UJNR

U.S./Japan Cooperative Program in Natural Resources

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15TH MEETING U.S.–JAPAN MARINE FACILITIES PANEL

MAY 1988

CONFERENCE RECORD

15th Meeting of the United States-Japan Cooperative Program in Natural Resources (UJNR)

Panel on Marine Facilities

May 1988

PREFACE

This document contains 50 technical papers and special reports presented at the 15th annual meeting of the Marine Facilities Panel of the United States - Japan Cooperative Program in Natural Resources (UJNR), held May 9-10, 1988, in Tokyo, Japan.

From May 11-23, the panel toured numerous marine facilities in Japan. A final meeting of the joint panels was held May 23 at the Ship Research Institute in Tokyo. A complete schedule and more detailed summaries of the meeting and tour are provided in this conference report.

The UJNR was established in 1964 to facilitate cooperative efforts and technology exchange in the field of natural resources between key scientific and technical representatives from Japan and the USA.

Seven of seventeen UJNR panels deal with marine science and technology and are a part of the Marine Resources and Engineering Coordination Committee (MRECC) of the UJNR. The National Oceanic and Atmospheric Administration of the U.S. Department of Commerce has the responsibility for leading and administering the marine panels. The Marine Facilities Panel has met 15 times, alternating annually between the USA and Japan. Each panel meeting has been documented in the form of a proceedings to provide a permanent record and to enable a wider dissemination of the technical information presented and exchanged at the meeting.

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

Participating governmental agencies in the USA have included the: Department of Agriculture, Department of Commerce, Department of Energy, Department of the Interior, Department of Transportation, Department of State, Department of Defense, and the Environmental Protection Agency.

Special recognition is given to Ms. Mary L. Leach for making the U.S. Panel arrangements, to Mr. Richard B. Krahl for handling the U.S. Panel finances, and to Mr. John A. Pritzlaff for providing many of the photographs in this conference report.

W. E. Hudson
Editor

MARINE FACILITIES PANEL CHARTER

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

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

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

OPENING REMARKS

Kazuo Sugai

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 and advisers of the U.S. Panel at the opening of the 15th Japan and U.S. Joint Meeting of the UJNR Marine Facilities Panel.

I would like to express our appreciation to the National Oceanic and Atmospheric Administration of the USA, the Science and Technology Agency of Japan, and the Japan Foundation for Shipbuilding Advancement for their cooperation and support extended for this meeting.

Our Marine Facilities Panel is now meeting for the 15th time since the first meeting was held in 1970 here in Tokyo. The need for marine facilities both in the U.S. and Japan has expanded in scope and intensity, and the Panel has met this challenge admirably throughout the years. I believe the Panel is one of the most active panels within the UJNR.

The Japan Panel has appreciated the cooperation, technical ability, and cordiality of the U.S. Panel, especially shown during the last meeting held in the USA two years ago.

At this 15th meeting, I am pleased to find that so many technical papers have been submitted and that some of them are designated as reference papers. I trust that these presentations will contribute to the UJNR activities and to significant discussions on the development of marine facilities.

We are seeking opportunities for more cooperative efforts between the two countries. This meeting and study tour will be informative and valuable in providing an equitable technology exchange with mutual benefit in the development of the oceans for the 21st century. We sincerely hope that the U.S. and Japan panels will find this 15th Joint Meeting and Study Tour mutually beneficial and successful.

OPENING REMARKS

Joseph R. Vadus

Chairman, U.S. Panel

On behalf of the U.S. Panel, it is a distinct honor and pleasure for me to extend warm greetings to Dr. Kazuo Sugai, Chairman of the Japan Panel, and to each of the members and advisers of the Japan Panel. We are delighted to be once again in Japan, visiting with our friends for this 15th meeting of the UJNR Marine Facilities Panel.

This is the 20th Anniversary of the Marine Facilities Panel. Our Panel was formed in 1968 to contribute to the development and utilization of our valuable natural resources through close cooperation between our governments with representation from government agencies, industry and universities of the United States and Japan. Since the first joint meeting, held in Tokyo in 1970, the Marine Facilities Panel has grown in size and stature, and has provided a valuable means for engaging in cooperative projects and for equitable exchange of information on advancing marine technologies.

The populations of both the United States and Japan are increasing, especially in the coastal areas, and the demand for food, shelter, energy, recreation and coastal living space is similarly increasing. Since its inception, the Marine Facilities Panel has recognized and responded to this challenge by focusing on the development and utilization of the oceans and their resources.

We are indebted to Dr. Sugai and the Japan Panel for their cooperation in planning and organizing an excellent technical program. I would also like to give special recognition to Mr. Kousei Watanabe, past Chairman of the Japan Panel, for his early contributions to this meeting, and to Mr. Obara of the Ship Research Institute Staff, and Mr. Yukihiro Narita and the Japan Marine Machinery Development Association for their valuable assistance in organizing the study tour.

Together, we have developed a very strong program and have made much progress. We appreciate the valuable technical contributions, friendship, and hospitality of the Japan Panel over these 20 years.

As we approach the 21st century there is much to do and the oceans have a vital role. Our technical program now begins to project into the 21st century, and we look forward to continued cooperation.

SPECIAL RECOGNITION

On May 10, 1988, representatives of the Marine Facilities Panel met with Mr. Ryoichi Sasakawa in his reception room in Sasakawa Hall. Members of the Japan Panel included Dr. Kazuo Sugai, Dr. Eifu Kataoka, and Professor Seizo Motora. Members of the U.S. Panel included Mr. Joseph R. Vadus, Mr. Charles N. Ehler, Mr. Richard E. Metrey, Mr. Richard B. Krahl, 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 that has formed the basis of many for his accomplishments. Mr. Sasakawa is interested in marine activities and supports the objectives and progress of the Marine Facilities Panel.

During the reception, Mr. Vadus presented a plaque on behalf of the U.S. Marine Facilities Panel to Mr. Sasakawa in recognition and appreciation of his continued interest in and support of the activities of the U.S.-Japan Marine Facilities Panel.

J. Vadus presenting special award to R. Sasakawa

Meeting with R. Sasakawa (l to r): R. Krahl, C. Ehler, R. Metrey, J. Vadus, K Sugai

To the left of R. Sasakwa is K. Sugai, J. Pritzlaff, E. Kataoka and S. Motora

Plaque awards presented by U.S. Chairman J. Vadus to Japan Chairman K. Sugai (above) and Past Chairman K. Watanabe (below) for their distinguished service and valuable contributions to the Marine Facilities Panel.

Japan Chairman, K. Sugai and U.S. Chairman, J. Vadus

Plenary session at Sasakawa Hall

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Mr. Richard M. Shamp
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Dr. William C. Webster
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Executive Secretary

Ms. Mary L. Leach
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*** Provided papers, but did not participate**

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Plenary session at Sasakawa Hall

ITINERARY

DATE	EVENT	CITY
May 7 (Sa)	U.S. Panel arrives Tokyo; New Sanno Hotel and Sanjoen Hotel	Tokyo
May 8 (Su)	U.S. meeting at New Sanno Hotel	Tokyo
May 9 (Mo)	15th Joint Meeting Japan Reception, Sasakawa Hall	Tokyo
May 10 (Tu)	15th Joint Meeting U.S. Reception, New Sanno Hotel	Tokyo
May 11 (We)	Port and Harbor Research Institute	Yokosuka
	Japan Marine Science and Technology Center (undersea technology, alternate energy research)	Yokosuka
May 12 (Th)	Tsukuba Science City: Electrotechnical Lab, Mechanical Lab (robotics, OTEC research), Japan Foundation for Shipbuilding Advancement (magnetohydrodynamic ship propulsion)	Tokyo
May 13 (Fr)	Tokyo Bay harbor facilities and artificial islands	Tokyo
May 14 (Sa)	Fly to Kyoto: Itami Airport; Shin-Miyako Hotel	Kyoto
May 15 (Su)	Free Day	Kyoto
May 16 (Mo)	Lake Biwa Research Institute (government implementation of anti-pollution policy)	Kyoto
	Disaster Prevention Research Institute Kyoto University	Kyoto
May 17 (Tu)	Depart Kyoto by train to Kobe; New Port Hotel	Kobe
	Osaka International Port and Facilities	Osaka
	New Kansai International Airport (under construction in Osaka Bay)	Osaka

DATE	EVENT	CITY
May 18 (We)	Kawasaki Heavy Industries, Ltd., including Shinkai 6500 Support Ship "Yokosuka"	Kobe
	Kobe International Port and Facilities, including Port and Rokko artificial islands	Kobe
	Mitsubishi Heavy Industries, Ltd., including Shinkai 6500 project	Kobe
May 19 (Th)	Fly to Chitose Airport (Sapporo) from Itami Airport (kyoto); Century Royal Hotel	Sapporo
	New Ishikari Port	
May 20 (Fr)	Presentation of the coastal development in Hokkaido by the Hokkaido Prefectural Government	Sapporo
	Institute of Low Temperature Science of Hokkaido University	Sapporo
May 21 (Sa)	By bus from Sapporo to Noboribetsu; Grand Hotel Bio-Marine Company (bio-technology program)	Noboribetsu
May 22 (Su)	Fly to Tokyo from Chitose Airport (Sapporo); New Sanno Hotel, Sanjoen Hotel	Tokyo
May 23 (Mo)	Ship Research Institute: Ice laboratory and offshore test facilities, and	Tokyo
	Final Meeting	Tokyo
May 24 (Tu)	U.S. Panel departs	Tokyo

Plenary session at Sasakawa Hall

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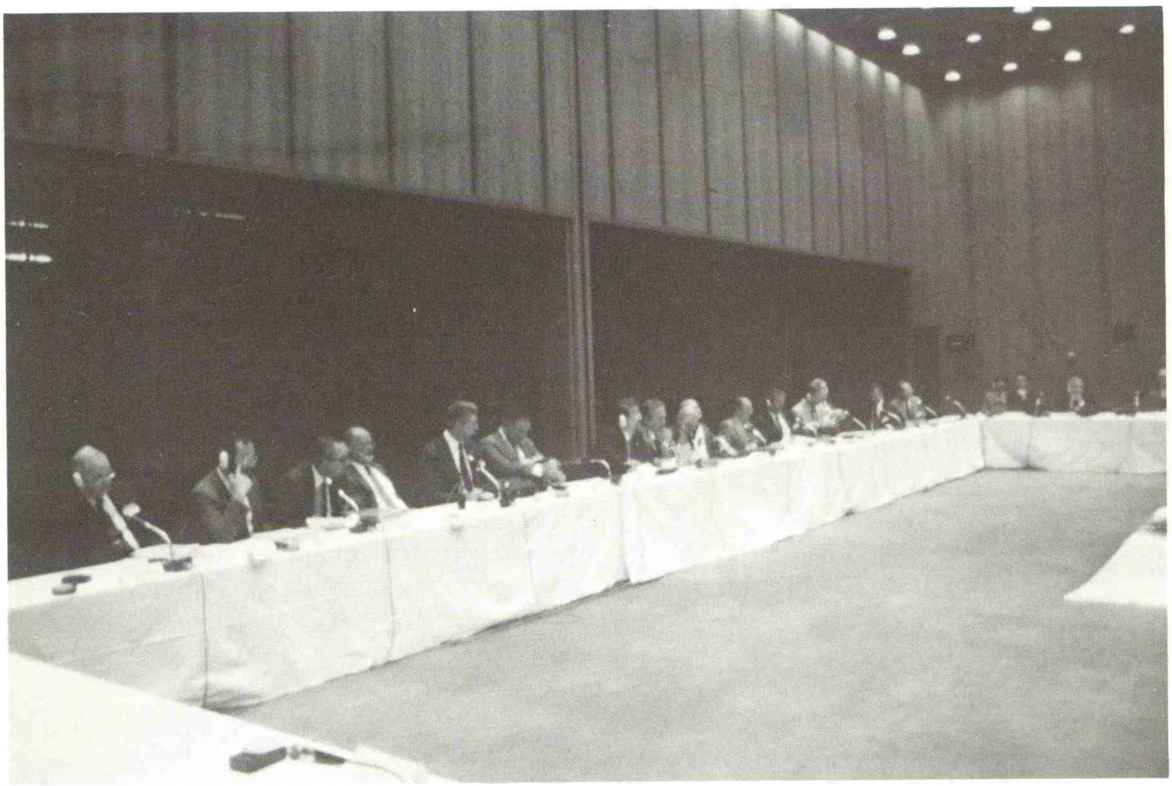

Plenary session - U.S. Panel

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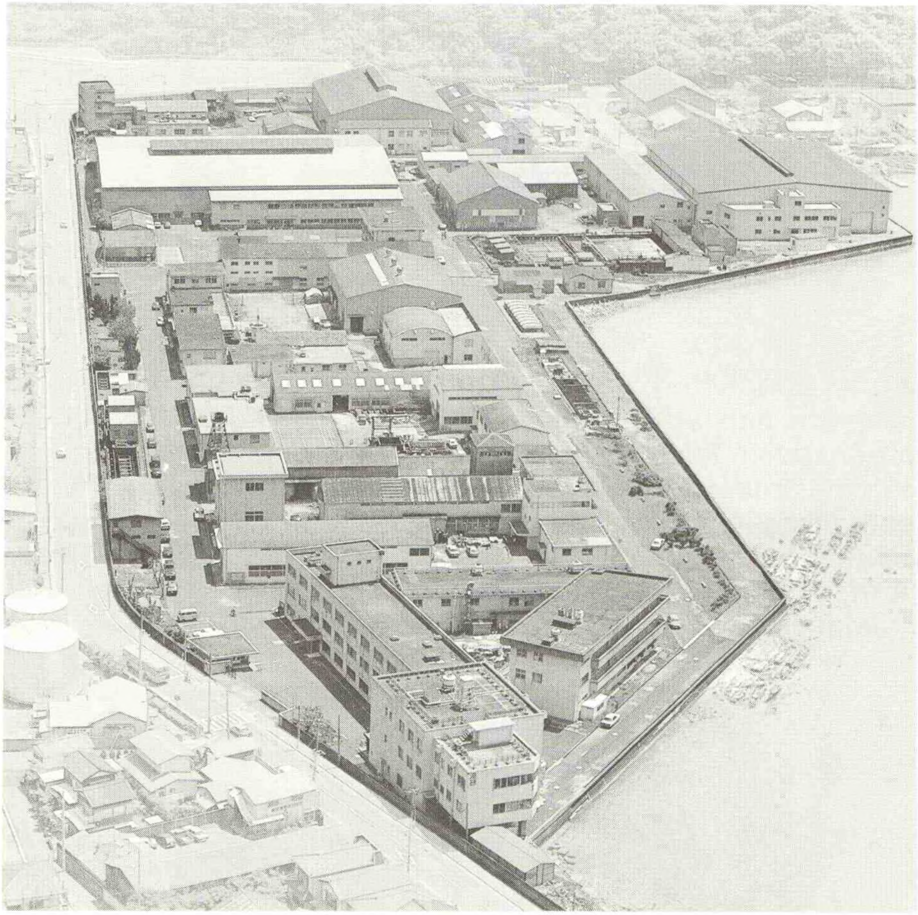
STUDY TOUR

Port and Harbor Research Institute, Ministry of Transport

The Port and Harbor Research Institute, a national laboratory under the Ministry of Transport, has the responsibility to solve various engineering problems related to port and harbor projects so that various government agencies in charge of port development can execute the projects smoothly and rationally. Its research activities also cover the studies on civil engineering facilities of airports.



Aerial view of the Port and Harbor Research Institute

Research on ports and harbors under the Ministry of Transport began in 1946, and the present institute was established in 1962. The institute is unique as a laboratory specializing in engineering studies related to port development, while at the same time, covering a wide variety of research fields such as physical oceanography; coastal and ocean engineering; geotechnical, earthquake, mechanical and materials engineering; dredging technology; planning and system analysis; and structural designs.

Japan Marine Science and Technology Center (JAMSTEC)

The Japan Marine Science and Technology Center (JAMSTEC) was founded in 1971 through the cooperative efforts of the government, academia, and the private sector. The center was founded to promote marine sciences and technology in Japan in response to social needs.

JAMSTEC High Pressure Test Facility

JAMSTEC has conducted various research and development projects, including undersea habitat experiments at depths of 30, 60, and 100 meters; wave power generation tests; diving technologies to depths of 300 meters using mixed gases; construction of the research submersible, "Shinkai 2000" and its support vessel "Natsushima"; and construction of the research vessel "Kaiyo," and the remotely operated vehicle, "Dolphin 3K." JAMSTEC has also begun construction of a deep-sea manned research submersible that will operate at depths of 6,500 meters.

JAMSTEC Hyperbaric Test Chambers

Tsukuba Science City

Located 60 km north of Tokyo, Tsukuba Science City is a product 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 conceived in 1963 as a way of meeting Japan's technological needs of the future through coordinated high-level research and educational facilities. Three of the facilities visited on this study tour included the Electrotechnical Laboratory (ETL), the Mechanical Engineering Laboratory (MEL), and the Tsukuba Institute of the Japan Foundation for Shipbuilding Advancement (JAFSA), described below.

Electrotechnical Laboratory (ETL)

The ETL is the largest national research organization in Japan. Since its founding in 1891, ETL has contributed to the advancement of science and technology as well as to the development of Japanese industry in the field of electrical engineering and electronics.

ETL is concerned principally with four fields of basic technology: 1) basic electronics, 2) information processing, 3) energy technology, and 4) standards and measurements. The Energy Division conducts R&D on ocean energy through its experimental OTEC Power Generator that is capable of simulating real sea conditions.

Mechanical Engineering Laboratory (MEL)

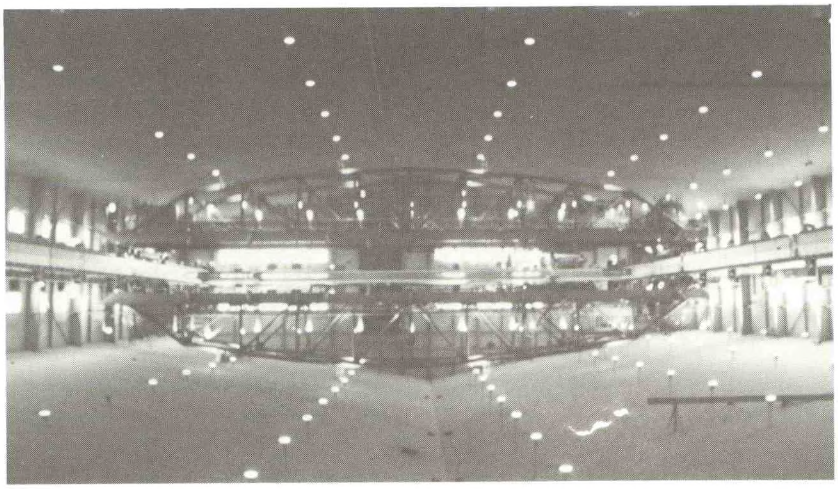
The MEL was founded in 1937 to conduct mechanical engineering research in both applied and basic fields. Current research activities include: energy and nuclear energy engineering, industrial standards, materials and production engineering, space technology, biomechanics and medical engineering, environmental protection, robotics, and machine tools.

Robotics demonstration at the MEL

Japan Foundation for Shipbuilding Advancement (JAFSA)

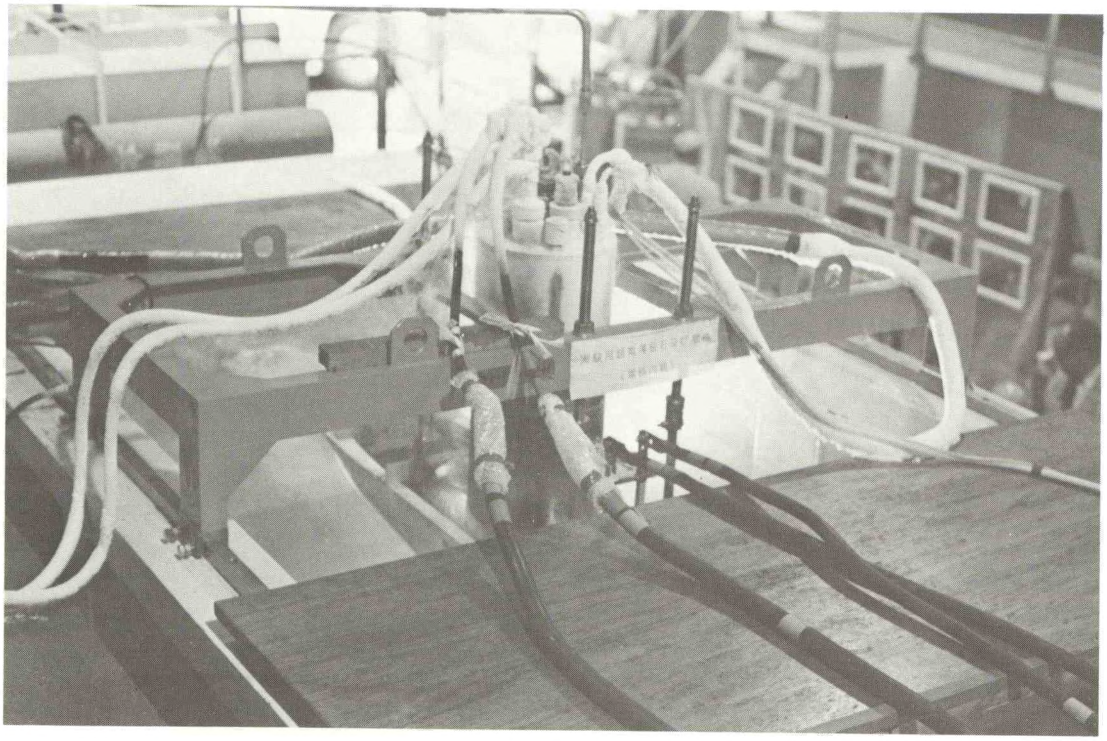
The JAFSA is a public utility organization authorized by the Ministry of Transport. JAFSA was established with a subsidy from the Japan Shipbuilding Industry Foundation (JSIF) with revenue from motorboat races. Mr. Ryoichi Sasakawa is chairman of both the JAFSA and the JSIF.

JAFSA carries out various research projects to promote the development of advanced technology and improved performance. One major project has been the research and development of the first screwless experimental ship with a superconductive electromagnetic propulsion system. JAFSA has built a laboratory for the project at the Tsukuba Institute.



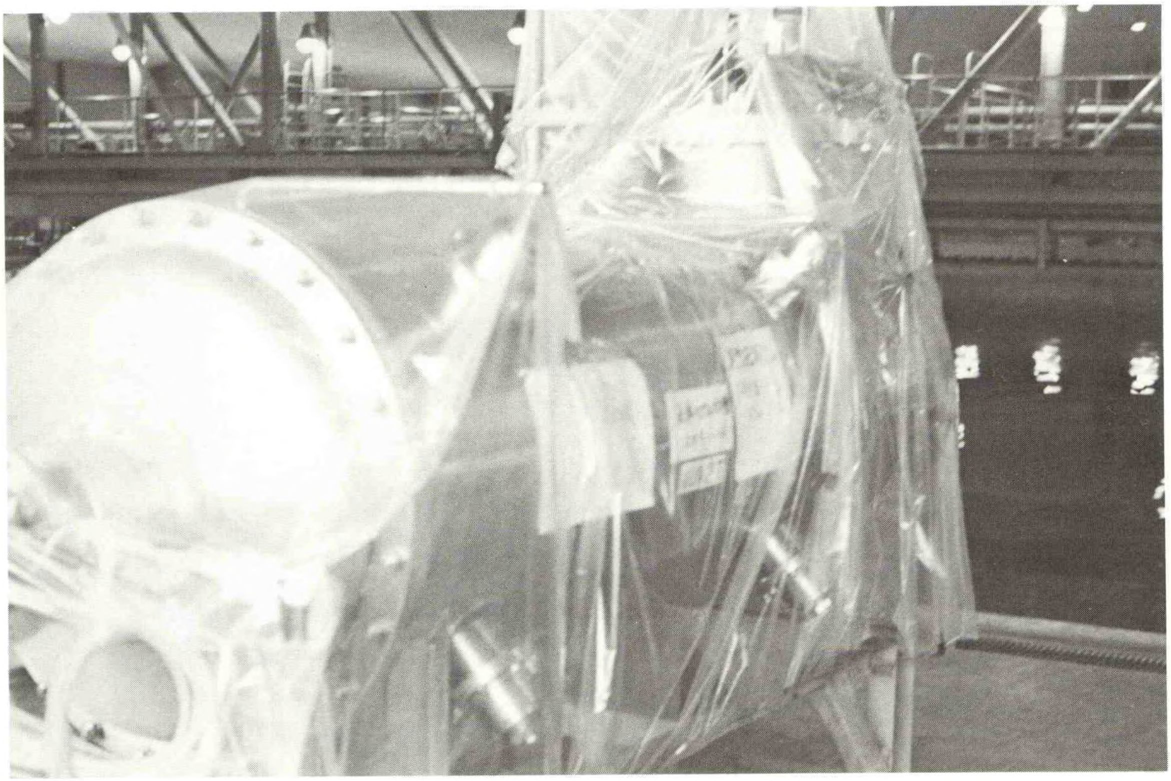
JAFSA test facilities

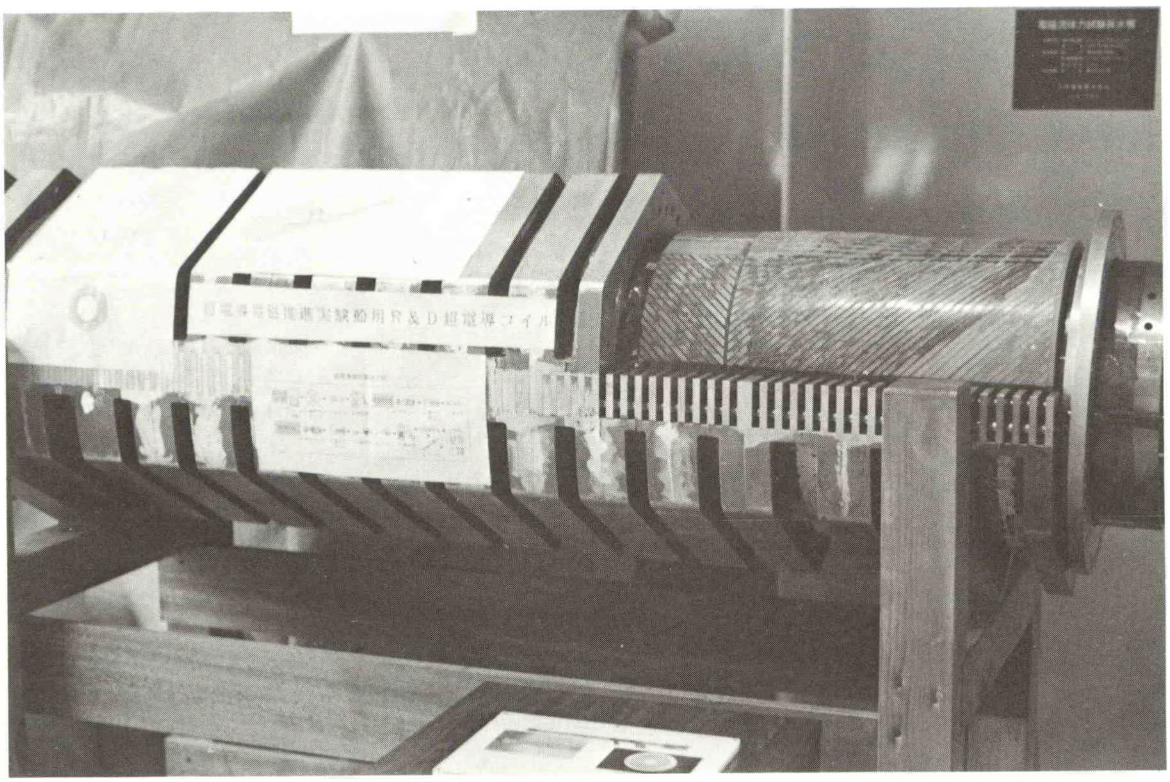
JAFSA magnetohydrodynamic propulsion demonstration



Experimental magnetohydrodynamics system

JAFSA magnetohydrodynamic propulsion demonstration





Experimental hydrodynamic systems

Port of Tokyo

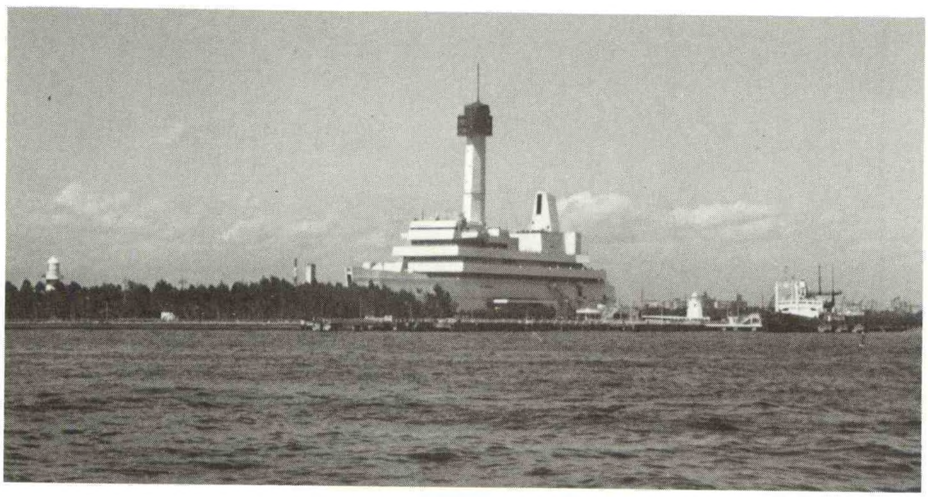
The Port of Tokyo, the ocean gateway to Japan's capital, plays a vital role as the distribution center for commodities essential to the livelihood of the 30 million metropolitan residents, including the nearly 12 million citizens of Tokyo.

Equipped with up-to-date terminals for containers, ferries, and specialized cargoes, the Port is firmly linked with ports in other countries and around Japan. It is one of Japan's most important ports for international trade. The Port has a sister-port affiliation with the Port of New York and New Jersey, and a friendship relationship with Tianjin, China.

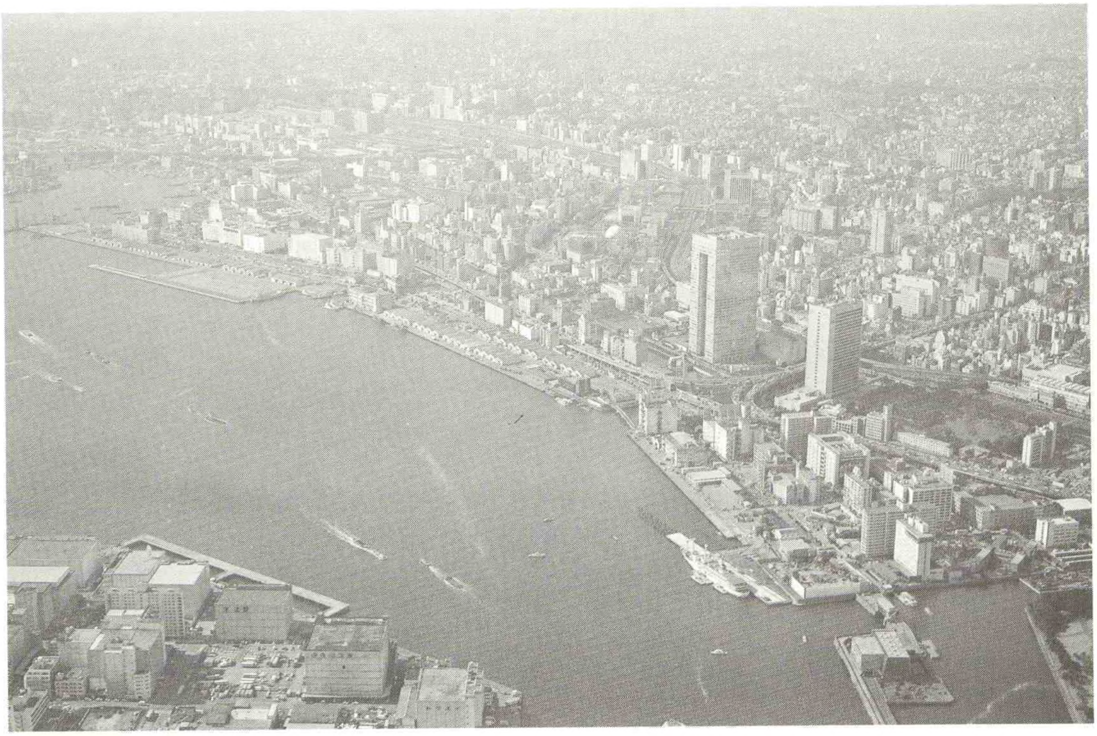
During 1986, over 57,000 ships entered the Port and about 62 million tons of cargo was handled, including nearly 20 million tons in foreign trade. Container cargoes in this category amounted to about 14 million tons, placing Tokyo among the world's leading container ports.

The Tokyo Metropolitan Government has implemented a program to improve its port facilities by 1990. The program includes the entire Port area and is using reclaimed land to help solve urban problems. Plans are also underway to revitalize the coastal area in preparation for the increased demands of the 21st century.

Located in the Port of Tokyo park, the Museum of Maritime Science was created as a comprehensive and modern institution to display ships and other maritime matters. Mr. Ryoichi Sasakawa, chairman of the Japanese Foundation for the Promotion of Maritime Science, is president of the museum. The museum's exterior is patterned after a 60,000-ton passenger liner and functions as the symbol of the port of Tokyo. The museum has an observation tower 70 meters high that looks out over the Port of Tokyo and the metropolitan area.



Museum of Maritime Science

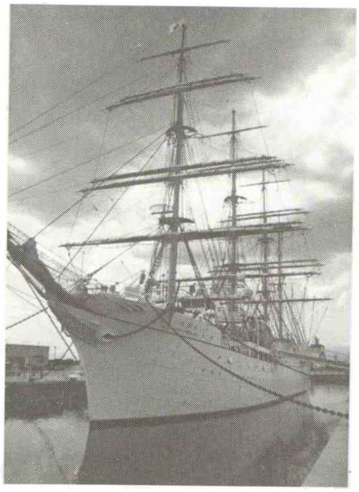


Aerial view of Tokyo Bay

Marine Facilities Panel at Tokyo Bay

Port of Yokohama

The Port of Yokohama is located in Japan's largest metropolitan region—the Keihin industrial area and the cities of Tokyo and Yokohama. Yokohama is Japan's oldest international trade port, having opened in 1859. Its 98 public pier births, 22 public buoy berths, and 149 private berths help Yokohama to serve more than 150 nations.



Nippon Maru sailing ship, Port of Yokohama

Since 1968, Yokohama has also served as a container cargo port. Honmoku Pier is one of the most famous container operating piers in Japan. Completed in 1974, the pier is about 200 ha wide and consists of four jetties each having four container berths. Anew pier, Minami Honmoku Pier, will be constructed on reclaimed land near the industrial zone of Honmoku Pier. It will serve as a distribution center for container cargos and will include deeper berths for larger container ships.

Briefing on the Port of the 21st Century, Yokohama

Minato Mirai 21 (MM21)

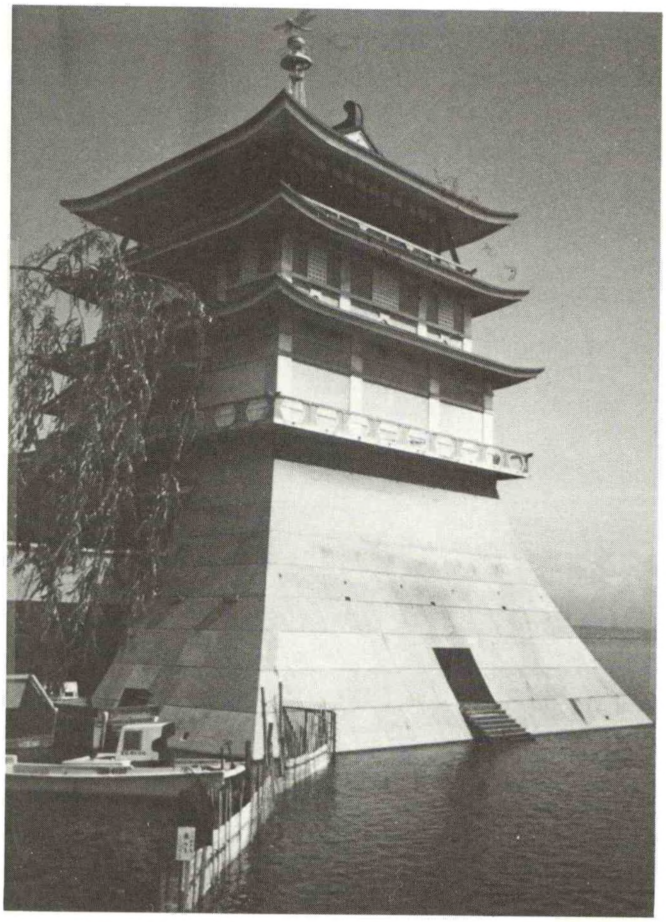
Minato Mirai 21 (MM21)is the name given to Yokohama City's huge, 20-year, urban planning project scheduled for completion in the year 2000. ("Minato" means port, "mirai" the future, and "21" the 21st century.) Extending over 186 ha of existing and reclaimed land, MM21 will become a new port city designed to provide business, cultural, and commercial facilities. In short, it will be a multipurpose cosmopolis.

In principle, the private sector will construct the business and commercial buildings, and the public sector will build the public facilities. A third sector, the Yokohama Minato Mirai 21 Corporation (a combination of public and private sectors), will construct the facilities that have a major impact on the area, such as the international convention center and the railway line.

Model of Yokohama, Port of the 21st Century

Lake Biwa Research Institute

Lake Biwa Research Institute was established to conserve the natural beauty and water resources of Lake Biwa. Existing research results relating to the lake and its watersheds are being collected, analyzed, and classified into different fields of study. Current research areas include: 1) circulation studies, 2) rate of sedimentation on the lake bottom, 3) water quality of tributary rivers flowing into the lake, 4) biochemical activity of ecosystems, 5) denitrification and nitrifying activity in and around the lake, 6) distribution of benthos and zooplankton, and 7) distribution and trends of industrial activity in the watershed.



Lake Biwa Research Institute

Disaster Prevention Research Institute (DPRI), Kyoto University

Affiliated with Kyoto University, the Disaster Prevention Research Institute (DPRI) was established in 1951. The Institute conducts scientific and engineering research on various problems concerning the prevention and reduction of natural disasters. Specific research areas include: 1) earthquakes and volcanoes; 2) atmospheric environments causing disasters; 3) earthquake and wind resistant structures; 4) urban earthquake hazard reduction; 5) flooding, sediment transport, and waves; and 6) water pollution studies.

One of many temples in Kyoto

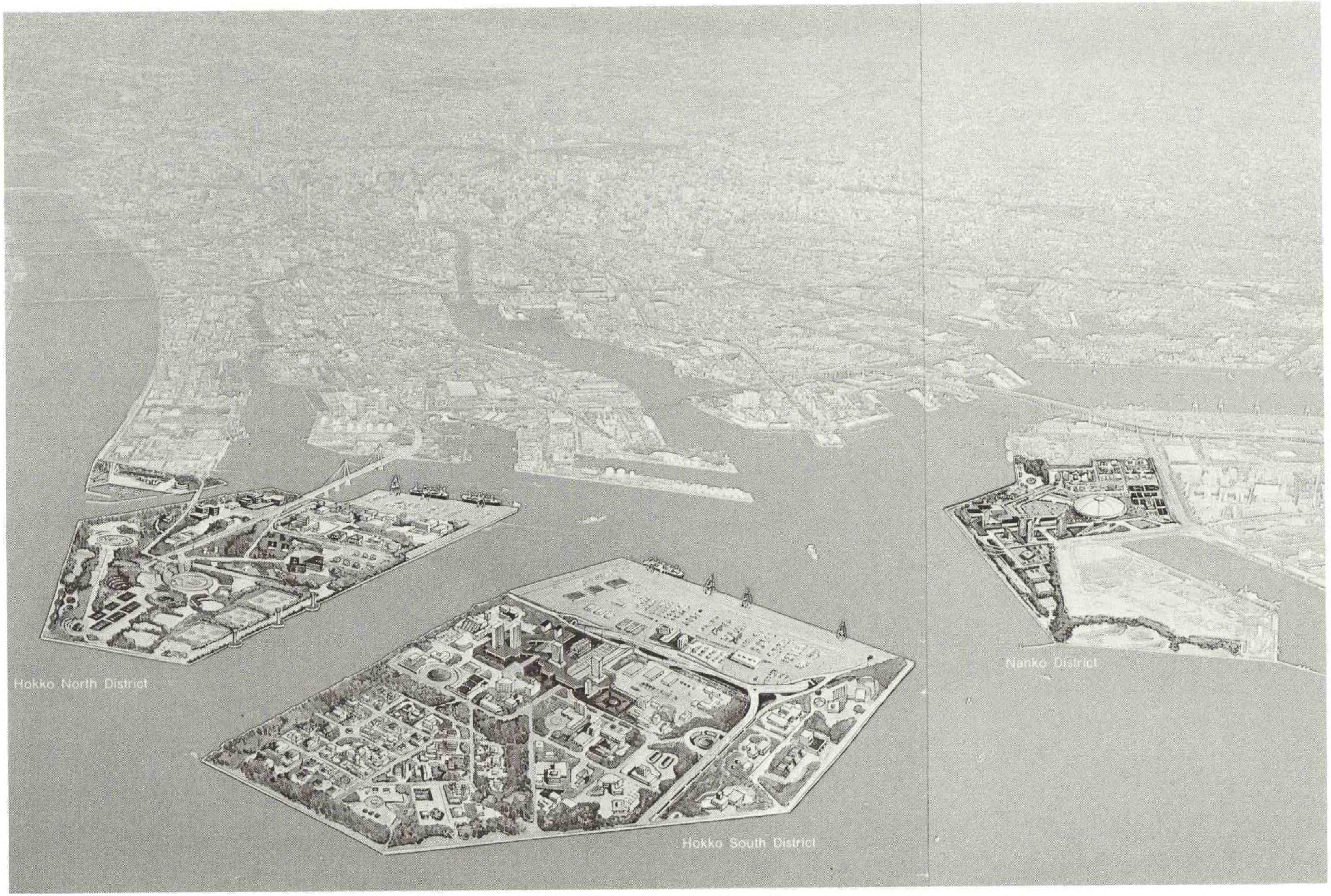
The Technoport Osaka Project

The Greater Osaka Region constitutes Japan's largest production and consuming center with a population of 15 million. The region covers an area radiating out 50 km from the center of Osaka City. With the Tokyo Metropolitan Region it shares the fame of being one of Japan's socioeconomic cores, having many industrial and commercial facilities. With a geographical advantage of being located at the hub of Seto Inland Sea and of having up-to-date port facilities, coupled with an easy access to every corner of the Greater Osaka Region by a highly developed road network, the Port of Osaka supports the region as a main distribution center.

As the gateway to Osaka, the Port of Osaka plays an essential role in the industrial and commercial activities of the Greater Osaka Region. The port is connected with 420 ports in 107 countries and visited by 6,000 foreign ships a year, 1,500 of which are container ships.

The Technoport Osaka Project is an ambitious plan for an ultra-advanced urban complex to be constructed in Osaka Bay on a group of newly created islands comprising Hokko (north port) and Nanko (south port). The core functions of Technoport Osaka will be chiefly three: 1) information communication, 2) advanced technological development, and 3) world trade. Technoport Osaka will be much more than just an imdustrial park. It will be a place where people can live and work, a community with excellent living facilities, both cultural and recreational. Technoport Osaka will comprise Osaka Teleport, Office Park, Research Park, and World Trade Park.

With optical fiber networks and satellite communications bases, Technoport Osaka will play a key role in communicating information around the world. All resident companies will have a tremendous advantage in their access to this superior communications infrastructure. Research Park will provide spacious siting and the ideal environment for research activities, with communal-use mainframes, seminar houses, and recreational facilities.



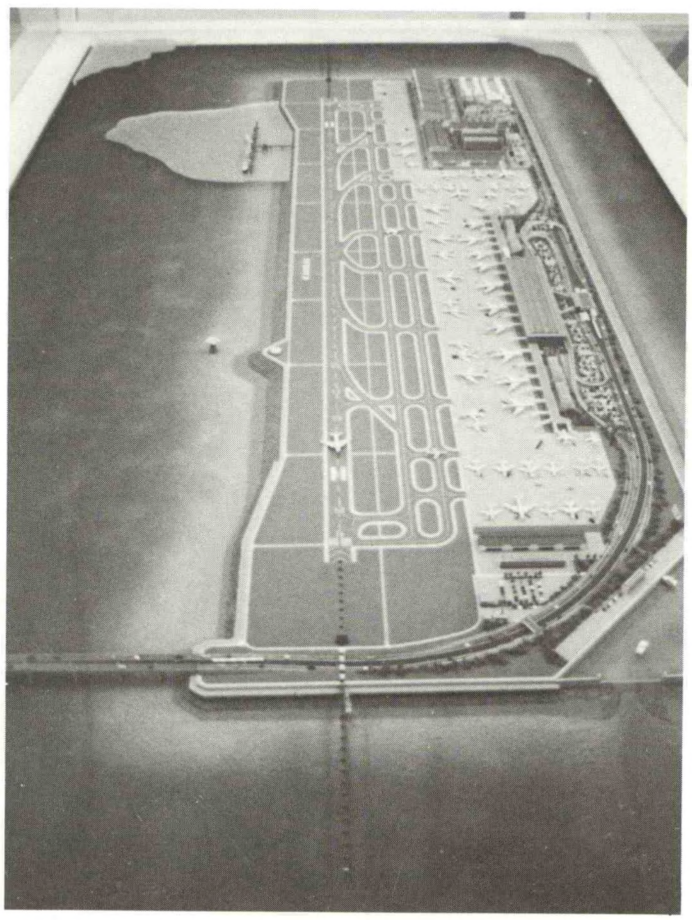
Technoport Osaka Project

Kansai International Airport

In 1993, Japan's second major international airport, the Kansai International Airport, will open in Osaka Bay, five km offshore and approximately 300 miles southwest of Tokyo. The new, 24-hour operational international airport will be located in the cultural heartland of Japan and will provide direct access to Japan's second largest urban area. The location of the airport will also change conventional air traffic patterns in Japan and reduce some of the existing noise pollution problems over urban areas.

The airport island will consist of 511 ha of reclaimed land contained by an 11 km seawall. Construction will be completed in a relatively short period under the adverse conditions of deep water and a soft, alluvial clay foundation.

An Environmental Research Center for the Projects of Kansai International Airport will be constructed largely for conducting environmental monitoring and keeping the public informed of significant changes.



Model of Kansai (offshore) International Airport

Boat tour of Kansai (offshore) International Airport

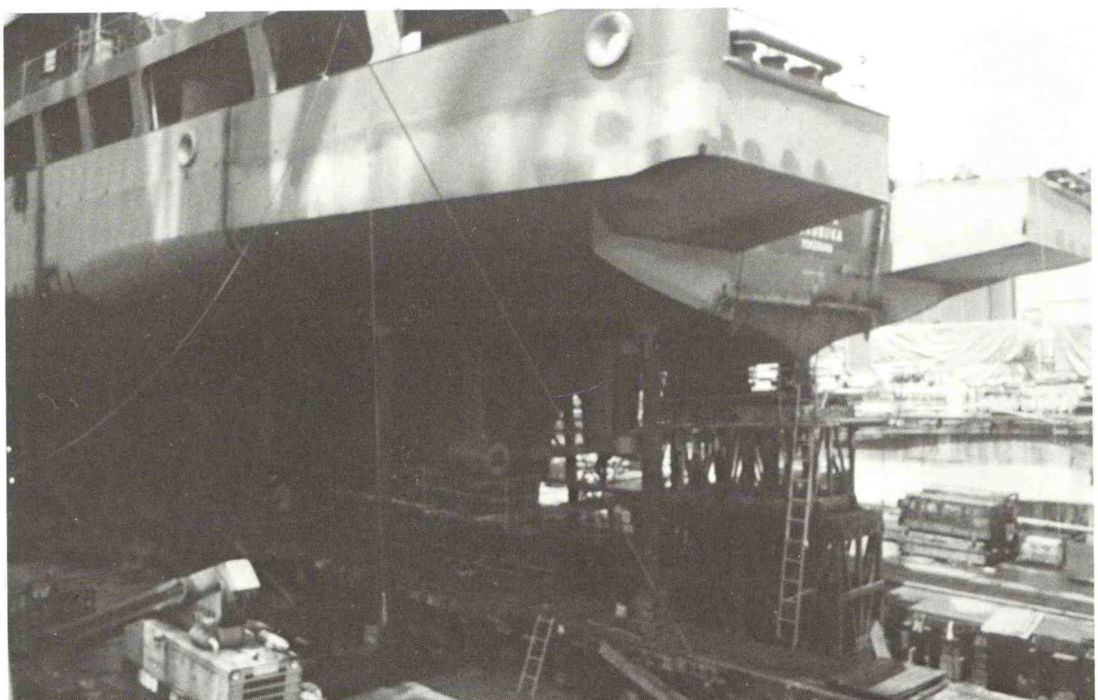
Heavy lift barges, Kansai (offshore) International Airport

Kawasaki Heavy Industries, Ltd.

Kobe Works, located west of the international Port of Kobe, was the birthplace of Kawasaki Heavy Industries, Ltd., over 100 years ago. Since that time, approximately 900 ships of all kinds have been constructed at Kobe Works. Today, Kobe Works consists of three main production departments: Shipbuilding, Ship Repair, and Prime Mover.

Aerial view of Kawasaki Heavy Industries, Ltd.

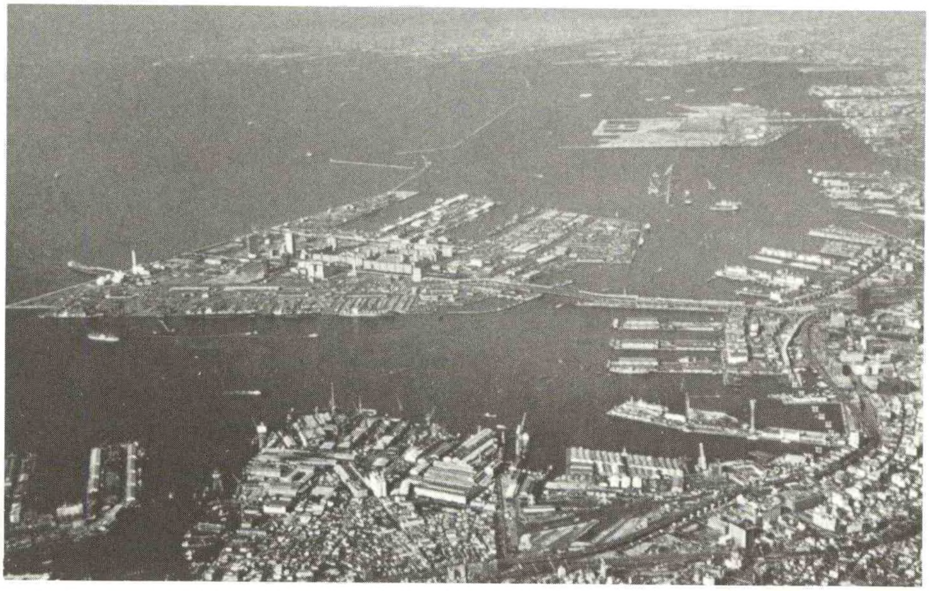
Visit to Kawasaki Heavy Industries, Ltd.



Shinkai 6500 support ship Yokosuka at Kawasaki Heavy Industries, Ltd.

Port of Kobe

The Port of Kobe, with its fine natural harbor and strategic location to industrial centers, has been in operation since 1868. Today, the Port of Kobe is Japan's leading liner port and the world's leading container port. The port is linked to 122 nations and over 500 ports by 26 liner routes.



Artificial islands: Port Island and Rokko Island

Port Island, completed in 1981, is the most ambitious man-made island in the world. Completed after 15 years of work, at a cost of $2.2 billion, it is a modern, cultural city, as well as a busy port, that meets the daily needs of its 20,000 inhabitants. Port Island covers an area of over 4 million square meters; as much as 80 million cubic meters of earth was used in the reclamation work. The wharf areas on the outer edge of the island contain 12 container berths, 15 liner berths, and one chemical cargo berth.

Entrance to Port (artificial) Island

Port Of Kobe, cont'd.

Rokko Island, the second man-made island, east of Port Island, is scheduled to be completed by 1990. A part of the island has already started functioning; there are already 2 container berths, 7 preferential berths for cargo by type, 4 multi-purpose berths, 2 tramper berths, 1 domestic feeder berth, and 1 ferry terminal. The island covers a larger area of 5.8 million square meters and landfill requirements will be in the area of 120 million cubic meters of earth. The island will be equipped with the latest wharf facilities with deeper water and greater wharf length than existing facilities. The island is expected to be equipped to house 30,000 people.

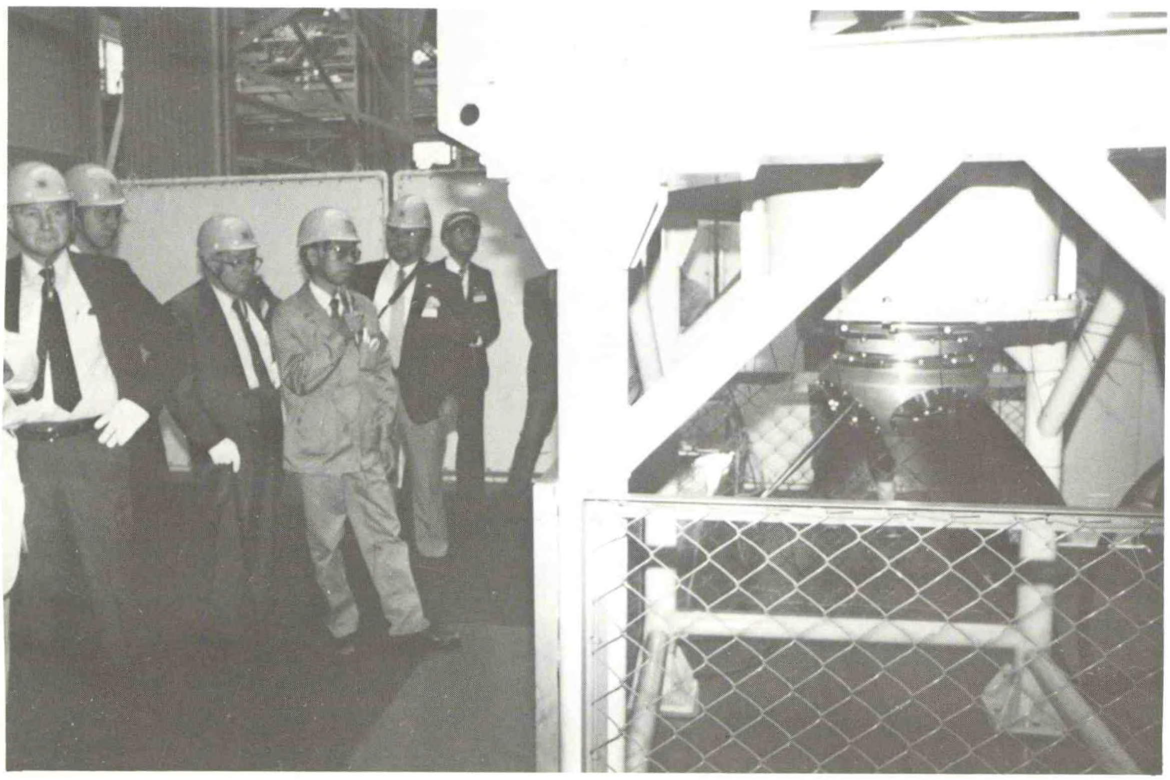
Maya and Shinko Piers. The Maya Piers are two-and-a-half times larger than conventional piers, containing a total of 21 berths. Large transit sheds feature pillarless construction plus a wide apron width, allowing smooth operation of large cargo-handling machines. Shinko Piers number 12 in all and are capable of mooring 36 large vessels at one time. Pier No. 4 houses the Port Terminals, the largest passenger-ship terminal in the East.

Rokko (artificial) Island under development

Mitsubishi Heavy Industries, Ltd., Mitsubishi Kobe

Founded in 1905, Mitsubishi Kobe is known for its shipbuilding, ship repair, steel structures, nuclear power plants, steam generators, diesel engines, construction machinery, and environmental control equipment.

Of special interest, is the company's work in deep submergence research. In 1933, Mitsubishi Kobe built the "Kaiyo," the world's first deep sea submarine. This was followed in 1964 with the deep sea submersible, "Yomiuri," and in 1981 with the deep submergence research vehicle, "Shinkai 2000." Currently, Mitsubishi Kobe is working on a next-generation 6,500 meters deep submergence research vehicle, scheduled for completion in November 1989. The vehicle will enable investigation of 98 percent of the world's seabeds and the sinking behavior of the Pacific plate at the Japan Trench. Mitsubishi Kobe is also currently working on the design and production of an unmanned, tethered submersible with a diving depth of up to 2,500 meters for the inspection and maintenance of submarine cables used in international communications.



Cycloidal propeller demonstration at Mitsubishi Heavy Industries, Ltd.

Ishikari Bay New Port

Development of Ishikari Bay New Bay was begun in 1972 and completed in 1982. Located 15 km from Sapporo, at the center of the Ishikari coast, the port covers approximately 3,000 ha, 6 km of coast, 2.5 km of offshore, and 2 km of land. It has great potential to support the growing industrial development of the Ishikari Bay area. The port has 29 berths.

Ishikari Bay derives its name from Japan's second largest river, which feeds into the bay. "Ishikari" means "Big Bending" in the Ainu language (the language of the aborigines of Hokkaido).

The Institute of Low Temperature Science

The Institute of Low Temperature Science at Hokkaido University is involved in a variety of research activities, from physics to biochemistry. In the realm of oceanography, the institute specializes in studies of sea-ice conditions.

Briefing at Hokkaido University Institute of Low Temperature Science

Hokkaido Prefectural Government

Hokkaido is the second largest and nothernmost of Japan's four major islands. It faces the Sea of Japan on the west, the Sea of Okhotsk on the north, and the Pacific Ocean on the south. The coastline of Hokkaido is about 2500 km long. The population is about 6 million, or about 5 percent of Japan's total, but the land size is about 20 percent of the total.

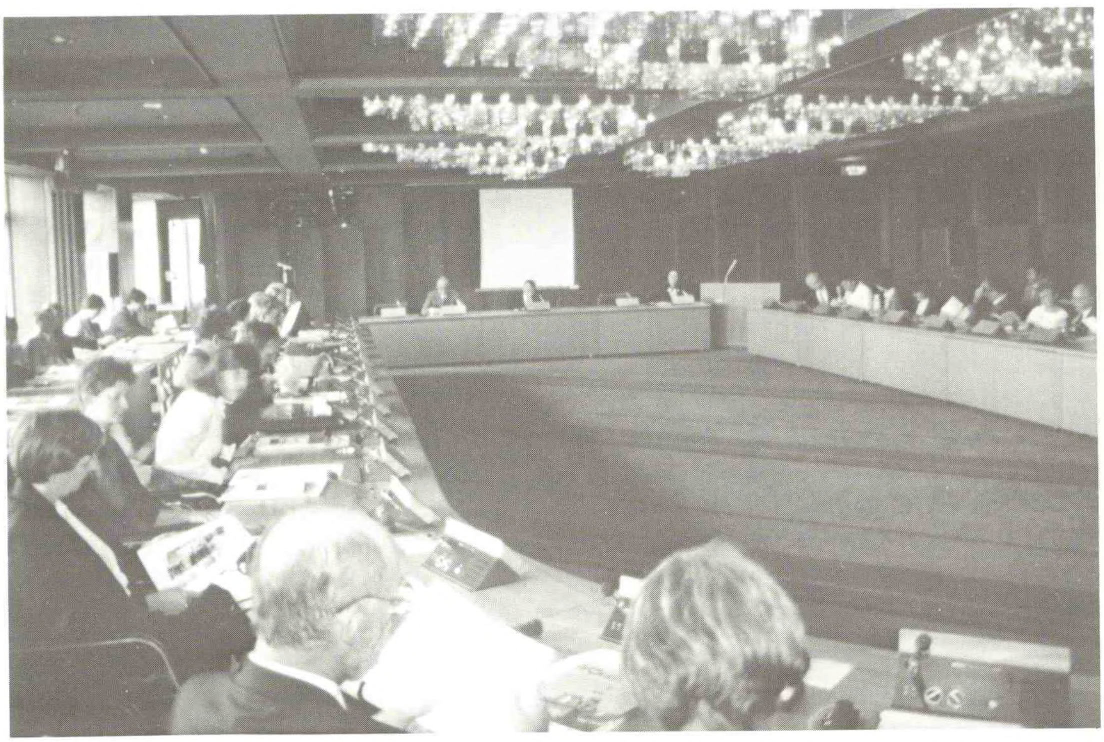
Hokkaido is the major food supplier of Japan, providing an abundance of agricultural, dairy products, and livestock farming. The area is one of the most productive fishing grounds in the world — rich in fish, shellfish, and seaweed — producing 26 percent of Japan's fishery production. Most of the industry has concentrated on natural resources, but is now expanding to automotive and electronic manufacturing.

The largest coastal project is the construction of the industrial port and complex in eastern Tomakomai. Also in progress is the development of a commercial port in Ishikari Bay to serve as a new distribution center. A recent major accomplish-ment is the completion of the Seikan Undersea Tunnel that was begun in 1971 and now links Hokkaido with the main island of Honshu. The tunnel, a major engineering achievement, is 54 km long with about 24 km under the Straits of Tsugaru. The tunnel was constructed to pass 100 meters under the straits, which had a depth of 140 meters.

Of special interest to the ocean science and engineering community is the Okhotsk Program — a plan to build a research tower in the Okhotsk Sea at a water depth of about 30 meters and located about 3.5 km offshore of Mombetsu City. The goal of the plan is to conduct scientific research of the ice-covered sea to obtain basic information on marine resource development and to develop sea climate fore-casting models and measures for environmental protection. It also plans technological research of sea-ice structure interactions and ice loading; low temperature materials; marine transportation; sea-ice biological studies; and fishery resource development.

The Okhotsk Program will enable scientists and engineers to live and work at sea among environmental extremes, and thereby, to conduct real-world experimentation. The program provides an excellent opportunity for international cooperation in scientific and engineering research projects of mutual interest.

Visit to Hokkaido Prefectural Government House



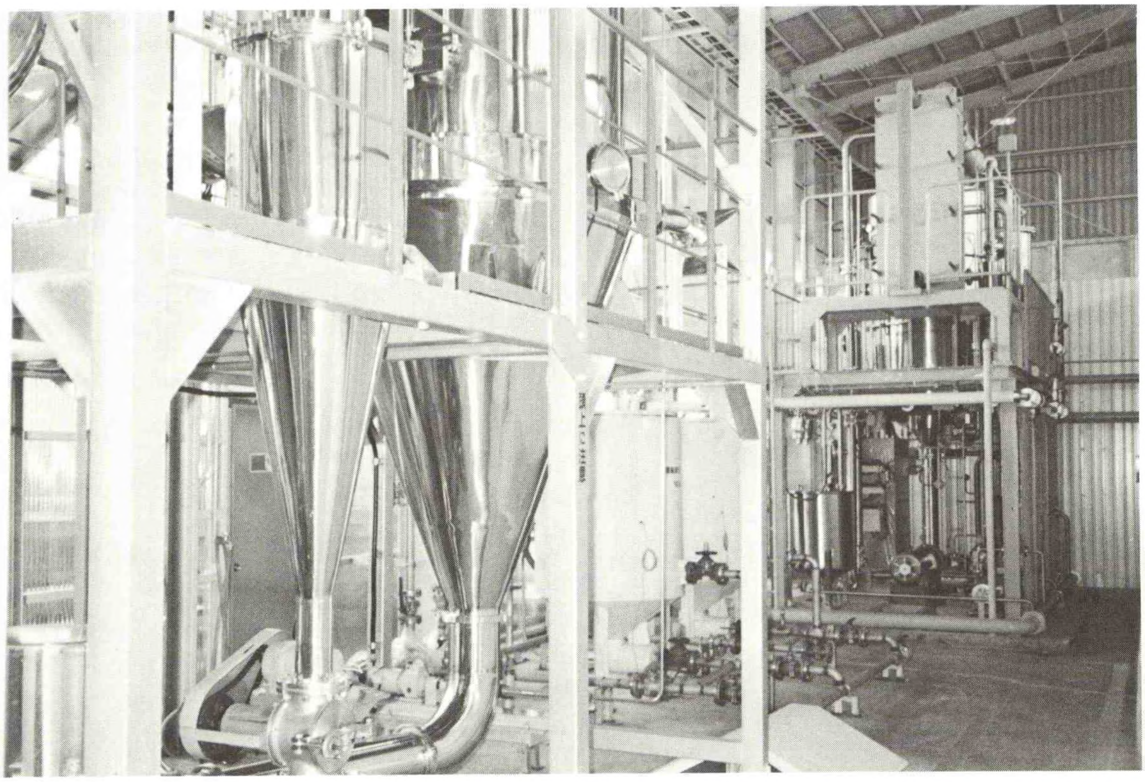
Briefing by Lt. Governor Ueda on behalf of Governor Yokomichi, Hokkaido Prefecture

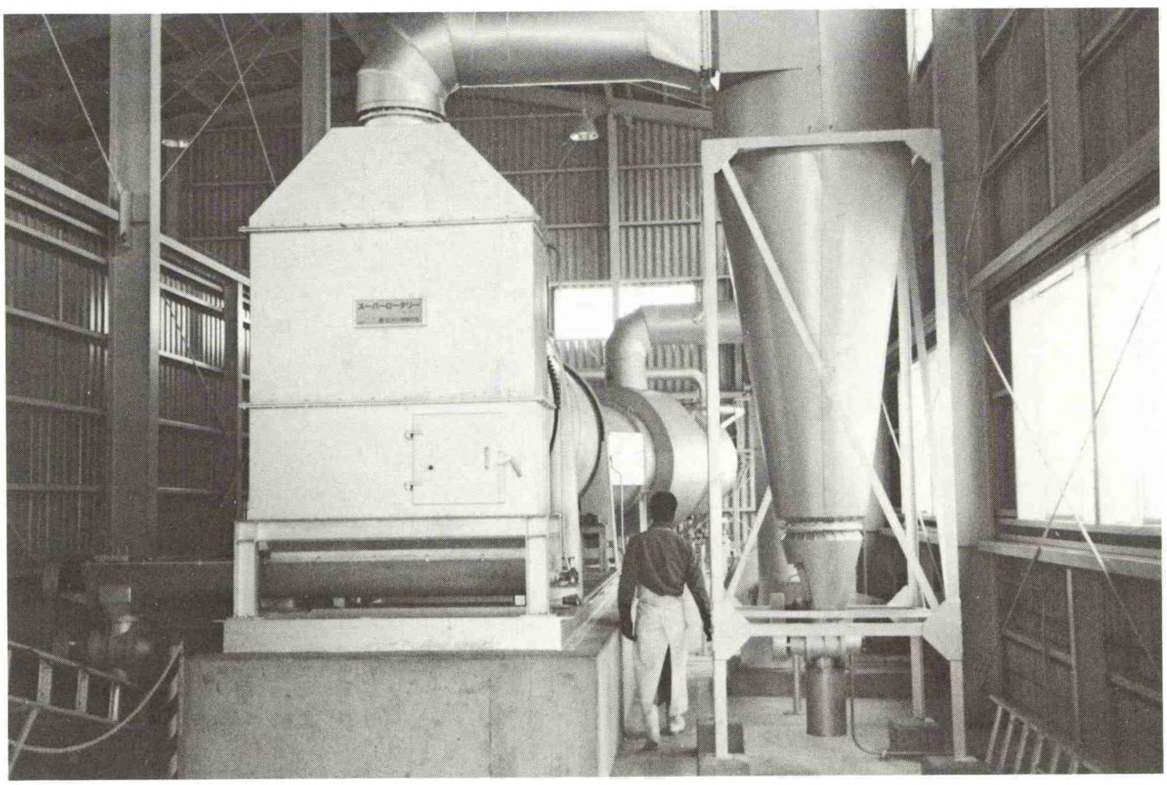
Marine-Bio Company, Ltd.

The Marine-Bio Company, located in Data City, Hokkaido, is a leading company in marine biotechnology. It is involved in a number of marine projects in the Bio-Topia 2000 Program. One project is the development of marine biomass that involves growing and harvesting kelp. Valuable products are extracted from kelp, including natural flavor (seasoning), animal feed, and chemicals. Another project involves accelerating the growth of fish and shellfish using thermal discharge water from the local thermal power station.

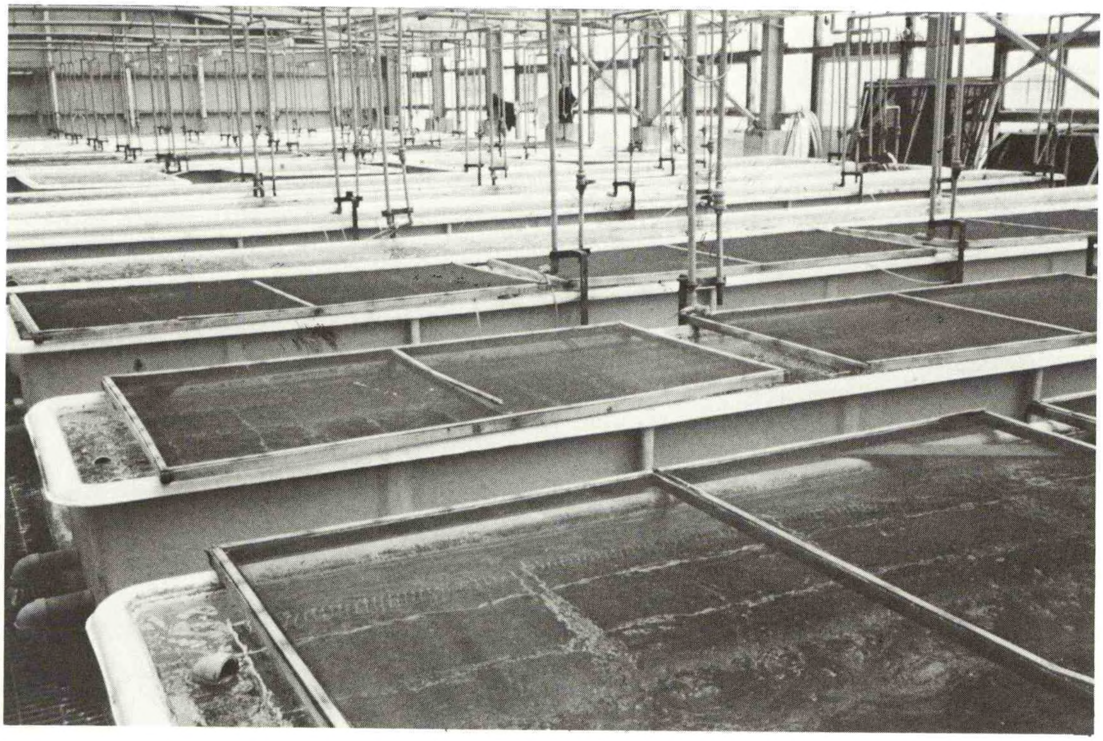
The Marine-Bio Company has great prospects for developing new marine-bio products for the 21st century.

Kelp project at Bio-Marine Co.

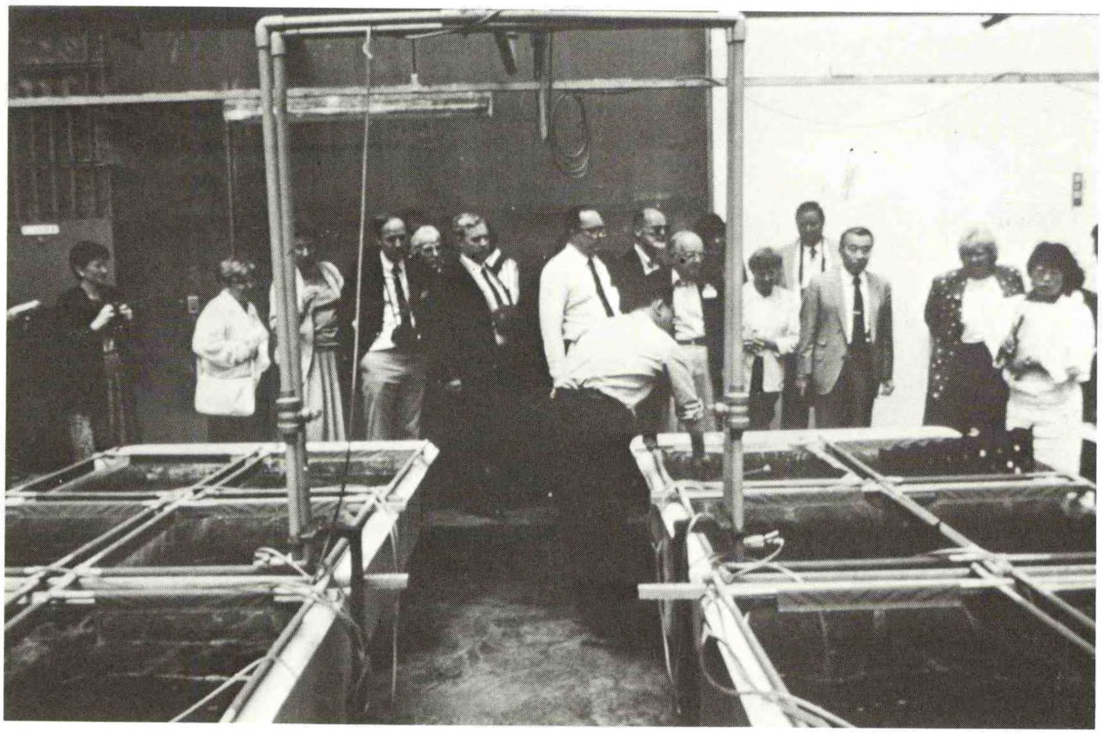




Processing facilities at Bio-Marine Co.



Aquaculture facilities at Bio-Marine Co.

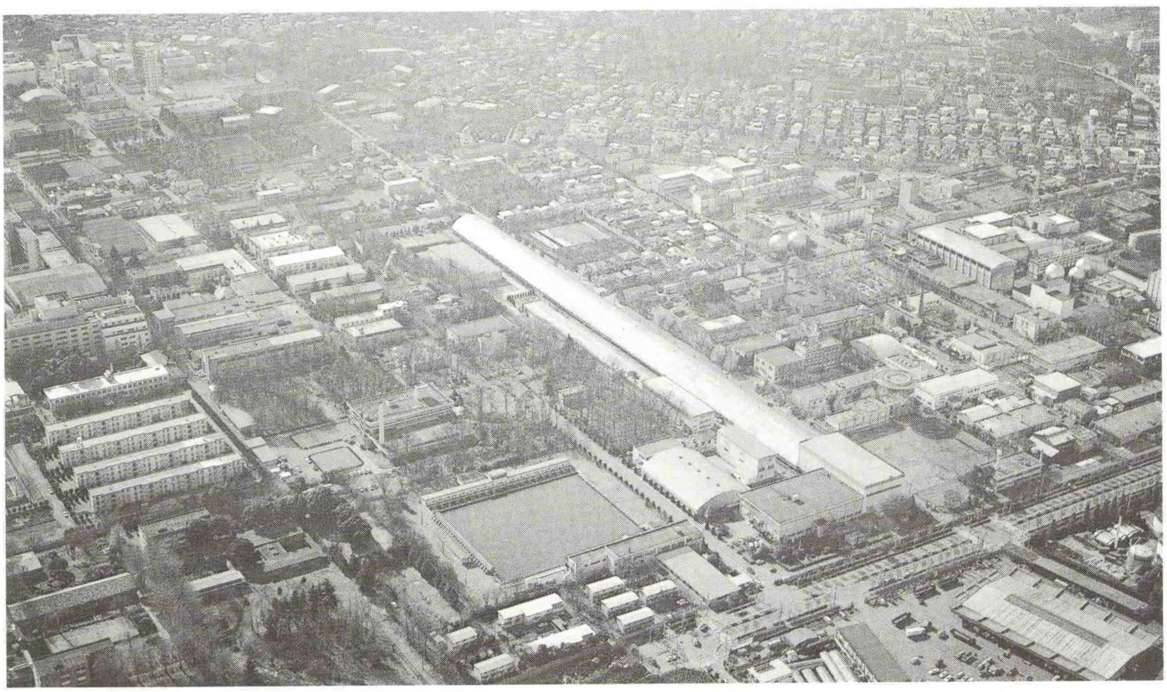


Aquaculture facilities at Bio-Marine Co.

Ship Research Institute
Ministry of Transport

The Ship Research Institute was founded in 1963 as a research arm of the Ministry of Transport. The institute conducts research in shipping propulsion and dynamics, structure and material processing, and the effects of severe climate on ships and structures. Research projects include: 1) fundamental techniques for the construction of floating offshore structures; 2) studies on the development of reliability evaluation techniques for structural materials; 3) special projects for ships; 4) special projects for pollution prevention; and 5) research and development for transport.

The ice model facility was completed in 1981 to seek solutions to ice engineering problems encountered in the design of ships and structures to be used in arctic conditions. The Open Basin Test Facility allows waves to be produced simultaneously from two directions. Radio controlled ship models can be used with pitch, roll, and acceleration data telemetered to the control station.



Aerial view of the Ship Research Institute

Japan reception at the Ship Research Institute Following the Final Meeting

Members of the Study Tour on the bus

FINAL MEETING

A summary of the 15th UJNR-MFP Joint Meeting was prepared by Dr. Sugai and Mr. Vadus and presented by Dr. Sugai, as follows.

1. Overview

At the closing session of the15th UJNR-MFP Joint Meeting, I would like to summarize our activities since the opening session May 9th.

From May 9-10 we held the plenary sessions at Sasakawa Memorial Hall. Total MFP attendance was 64; 20 from the U.S. (11 members and 9 advisors) and 44 from Japan (20 members and 24 advisors). Other attendees included various speakers and guests, such as Dr. Richard Getzinger, Science Counsellor, U.S. Embassy; Mr. Masato Chijiya from the Science and Technology Agency; and Mr. Takashi Yamamoto from the Ministry of Transport. Mr. Watanabe and I were pleased to be honored by the U.S. Panel's bestowal of testimonial plaques. During the afternoon coffee break on May 10, Mr. Vadus and four U.S. members, together with Dr. Sugai and two Japan members, made a courtesy visit to Mr. Sasakawa.

From May 11-23, we made a study tour from the Kantoh area through Kansai to Hokkaido, visiting about 20 facilities operated by goverment, industry, and academia. We visited various laboratories, factories, port and harbor facilities, and construction sites. In the Northern District Center of Hokkaido, the vice governor and assistant to the president of Hokkaido Tokai University gave the status and plans for activities in the Hokkaido prefecture.

Today, May 23, we have the final meeting. Attendees (members and advisors) total 42; U.S. 12 and Japan 30. I am pleased to welcome you here to the Ship Research Institute after a full study tour.

The15th UJNR-MFP Joint Meeting was quite informative and successful. Valuable informal discussions and exchanges of ideas took place during the meeting, especially during coffee breaks, lunches, receptions, and during the study tour.

2. Plenary Session

The U.S. and Japan chairmen presented opening keynote addresses that were well received: Dr. Sugai, "Ship Technology for the 21st Century" and Mr. Vadus, "Marine Facilities and Systems for the 21st Century." Both were futuristic themes that provided a broad basis for the presentations.

There were a total of 50 papers prepared for the meeting, 16 of which were reference papers. A total of 34 papers were presented (U.S., 18 and Japan, 16) and two keynote addresses. The following five categories were covered:

1. Marine Facilities for Resource Development;
2. Advanced Ship Technology Development;
3. Offshore and Undersea Technology and Systems;
4. Coastal Ocean Space Utilization; and
5. Ocean Measurement Systems.

All of the papers were well prepared and the presentations were smooth and punctual. Most of the U.S. speakers had prepared colorful slides that were clear and attractive. Discussions following the papers were informative. Many of the reference papers were discussed and explained during the study tour. The proceedings of the 15th UJNR-MFP Joint Meeting will be published and forwarded by the Secretary of the Japan Panel and the Editor of the U.S. Panel in about three months.

3. Proposal for the Next Joint Meeting

Mr. Vadus proposed that the 16th Meeting in 1989 be held in Seattle, Washington, during the last two weeks of September in conjunction with Oceans '89. A study tour will be arranged to visit marine facilities in Alaska, Seattle, San Francisco, Los Angeles, and Hawaii.

4. Future Activities

Regarding continued cooperation, Dr. Sugai stated: "It is important to continue the Joint Meeting and Study Tour regularly for exchange of technical information and ideas; for cooperation on projects of mutual interest; and for technical correspondence and visits during the year. In the future, we expect information exchanges to emphasize new trends and future projects in research and development.

As a result of discussions at this meeting, it was decided that plans for more specific cooperative research projects between the U.S. and Japan should be considered. It is not easy to initiate research projects involving many international organizations necause of the problems of multi-organization coordination. However, it is desireable to arrange a few modest U.S./Japan cooperative research projects under the same themes among a few organizations. For instance, the Shipbuilding Research Institute (SRI) now has two international cooperative research programs involving the exchange of researchers: 1) research with Canada on experimental techniques using an ice tank and 2) research with West Germany on ship stability. Furthermore, the Science and Technology Agency (STA) has recently established a new fellowship system to invite young foreign reserachers to Japanese national laboratories such as SRI, Port and Harbor Institute, etc. This system should be useful for some future cooperative research activities."

Mr. Vadus shared Dr. Sugai's views that the Marine Facilities Panel must promote opportunities for cooperative projects and information exchange on topics of mutual interest. Several areas of interest for possible cooperation sponsored by the U.S. side are described below.

Mr. Norman Caplan of the National Science Foundation (NSF) indicated that the NSF is interested in conducting ocean engineering research to develop new technology for characterization of the Exclusive Economic Zone (EEZ). The U.S. and Japan have national interests in the EEZ and can benefit from cooperative research projects. At NSF, the engineering and geoscience organizations have agreed to support new developments in ocean technology for ocean science. The NSF program encourages international cooperation. Mr. Caplan indicated that he and Mr. Vadus would meet with the Japan Science and Technology Agency (STA) after the UJNR meeting to explore possibilities for establishing a cooperative ocean engineering research program between STA and NSF. The initial effort would involve conducting a program definition workshop in the U.S. or Japan to identify technical areas of mutual interest. Topics for consideration would include autonomous undersea vehicles and new sensing devices that would be integrated for automated operation.

Mr. Charles Ehler of NOAA offered three brief proposals for areas of cooperation and information exchange between the two panels: 1) coastal ocean space utilization; 2) marine recreational facilities; and 3) marine pollution assessment and monitoring. In the area of ocean space utilization, the U.S. Panel can learn from Japan's experience in implementing offshore development programs, especially its institutional arrangements for cooperation between the national and prefectural governments and industry. The Japan Panel can learn more about the U.S. coastal states' program plans for the development and conservation of ocean resources, especially when it visits Alaska, Washington, California, and Hawaii in September1989 for the 16th meeting.

Marine recreation is one of the fastest developing coastal industries in the USA and probably in Japan, too. Each year, the U.S. spends about $8 billion to provide recreational opportunities for Americans; this is higher than the value of commercial fisheries in coastal areas. Mr. Ehler suggested that the U.S. and Japan could exchange information on requirements for recreation and compatibility with other users of the coastal ocean.

Mr. Ehler also emphasized the importance of marine pollution assessment and monitoring in the U.S. and Japan in the course of development and utilization of the coastal ocean and its resources. Both the U.S. and Japan have large polluting industrial activities in coastal areas. For example, during our study tour in Japan, we saw pulp and paper industries, chemical industries, iron and steel manufacturing, and agriculture located along the coastal areas. Maintenance of the health of the marine environment is an important national objective in Japan and the U.S., especially for developing coastal fisheries and recreation. At the time of the 16th meeting, in September 1989, the first comprehensive marine pollution assessment of the U.S. will be available. Mr. Ehler offered to provide a summary of that assessment at the next plenary session.

Two other potential areas of cooperation were raised after the meeting. One was proposed by Richard Krahl, U.S. Department of the Interior, Minerals Management Service, and pertains to cooperative research activities on sea ice - offshore platform interactions and the containment and recovery of spills in icy waters. Another proposal was made by Mr. William Andahazy, David Taylor Naval Ship R & D Center, and pertains to cooperative efforts to improve magnetohydrodynamic propulsion performance and efficiency.

All of the above proposals were offered for consideration as cooperative efforts. As a minimum, each of the topics associated with the proposals should be included in the 16th meeting plenary sessions in September 1989.

5. Acknowledgments

We thank all of the U.S. and Japan members for their valuable technical contributions and for the generosity of their employers. Appreciation is extended to NOAA, the Ministry of Transportation (MOT), and STA for their support. Special recognition is given to the U.S.-Japan secretariat who assisted in arrangements for this meeting and study tour, especially to Mr. Obara and Mr. Narita on the Japan side and Ms. Mary Leach on the U.S. side. Special thanks to Mr. Sasakawa and the Japan Foundation for Shipbuilding Advancement.

Boat four of Marine Facilities

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KEYNOTE ADDRESSES

SHIP TECHNOLOGY FOR THE 21ST CENTURY

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1. Preface

The 21st century is coming soon beyond our expectation, as only twelve years are left hereafter. It is thought that almost all things in the century can be predicted by extrapolating the trends at the most present. However, the most difficulty is expected in predicting how the Japanese shipbuilding industry will be in the 21st century, because there are too many indefinite factors at present. Demands for new building vessels in the world will change up-and-down toward the next century, and then the amount in the early century is anticipated to be somewhat on a plateau. However, the amount shared to the Japanese shipbuilding industry will strongly depend upon the qualities of these vessels which should be governed by the situation of trade and industries in the world. Apart from such uncertain factors, future prospects of research and development in science and technology for ships in the 21st century shall be dealt with here as no one doubts necessity of that R&D, though they may be deduced from the author's personal point of view.

2. Future Prospects of the World Industries in the 21st Century

2.1 Changes in the Structure of Trade and Industries in the World[1),2)]

How will the structure of trade and industries in the world change toward the 21st century ? Before we get to work on the prospects, two conditions should be promised ourselves on that the predictions are restricted to the science and technology problems in the early century and an unexpected radical innovation in social and economical circumstances is ignored, because too far and wide predictions likely lose their practical meanings.

In the first place, it is said that the present day is an innovation age from the industrialized society to the information-oriented society. Characteristics of the latter society are represented by the light weight products with higher added value. Quantitative expansion in the economical activity will lose an importance there and qualitative change into higher cultivation in the human living will progress further.

In the second place, an important point we have to pay attention is the change in the structure of energy supply in the world. From a view point of long term tendency, the present structure like that almost all energy resources depend on fossil fuel coming from the earth and are transported massively from supplying spots to consuming places will abate the importance. Opinion on what kind of new energy will replace the fossil fuel is not in agreement among the experts concerned. At least, the weight of energy consuming industry will decrease comparatively, accordingly, the weight of the fossil fuel trade in the world will also decrease in the coming new society.

In the third place, we know that the one which has supported a rapid expansion of the industry and an improvement of the standard of living in this century was so-called basic row material such as steel, nonferrous metal, cement, wood and pulp etc.. Massive transportation of them was a symbol of the industrializing society. After twice oil crises, the situation changed drastically and comparatively small and light weight products have become more popular than large and heavy products. The trade for the former kind of products will flourish more in the coming century than it is now. However, this tendency does not necessarily mean a decline of the large and heavy industry, because still expansion of demands for the heavy products will be expected among new industrializing countries and under developing countries.

2.2 Predictions about a new Trend of the World and Japanese Shipping Industries

What will be the world and Japanese shipping industries in the next century ? Massive transportation such as energy and basic row materials for the industry will not increase so much and the trade of products will increase rapidly as mentioned in the above. These tendencies will be remarkable in advanced countries, however, they will also appear in the new industrialized countries which should aim at further processed manufactures.

In the 21st century, the leading part of the trade will transfer rationally from the North Atlantic Ocean to the Pacific Ocean and further to other local areas surrounded by the new industrialized countries. In the other hand, the diversification of the transportation at sea will advance and a composite transportation service through land and sky will become prospering, though there should be hard competition with the air-transportation. The shipping industry seeks consistently for faster and more versatile service. It is believed that the Japanese shipping industry will keep her leading position, taking advantage of her geographical best position.

The other factors we can not ignore are the growth of the leisure industry at sea and the development of water front areas. These will open a new world for the Japanese shipping industry.

2.3 Anticipation of a new Progress in the related Technology Fields[3)]

A new progress on the related technology fields with the shipbuilding is anticipated here.[4)]

(1)The total energy consumption in the world has changed its trend after twice oil crises and the amount does not enlarge as we expected before, owing to the energy saving technology. The situation will change further from the extreme dependence on fossil fuels to the coexistence of a wide variety of fuels such as alcohol, hydrogen and so on.

(2)Innovation of the computer technology will still progress toward the 21st century and improvement on not only the quantity like memory size and speed but the quality, for instance, like the 5th generation computer with neuro function will be made continuously. Another remarkable progress will be achieved on the application of artificial intelligence and information based on the data base concerned.

(3)The role of the sensors is changed toward the 21st century and then the one more feasible to the high intelligent computer system and more convenient for the communication net work should be admired. Further advanced sensors including bio-sensors will be expected in the near future.

(4)The fields where robot plays conspicuous part extend over not only manufacture field but also non-manufacture and advanced technology fields in the 21st century. We can not image even now an automated factory without robots. In the non-manufacture field, the robots for supporting the handicapped, dangerous work and maintenance or repairing works will become popular. In the advanced technology field, the robotics, for instance, for space and ocean development, working in radioactive ray or very high temperature atmosphere are desired. For the last two fields, more sophisticated robots with high intelligence than they are now will be looked for.

(5)A lot of new materials will be created until the 21st century. Among them, remarkable materials expected the application into the shipbuilding industry are considered to be a fine steel, a super conductive material, a multi functional new material such as ceramics coated metal and so on.

(6)We are scheduled to conduct the experiments on the Japanese first nuclear powered ship "Mutsu" at sea in 1989-1990, that schedule was postponed awfully due to a small accident. After finishing the experiments, we step into the 2nd generation ship, however, we have not agreed yet on what kind of ship will be the 2nd nuclear ships in Japan. Only an investigation into the further nuclear ships has been done recently and the report says that three types of ships, viz. a very high speed container ship, an arctic merchant vessel with ice breaking capability and an under sea research vessel or power station are taken as the candidates.

The heavy industry like shipbuilding should watch the new technical progresses in the related fields incessantly, because it is standing on the syntheses of those technologies basically.

3. Anticipation of the Japanese Shipbuilding Industry for the 21st Century

Fig.1 shows anticipated amount of new vessels to be built in Japanese shipbuilding yards in the future.[5] It is predicted that the world shipbuilding industry, once escaped from the long and deep slough, will recover to some extent in the early 1990s. That will be caused mainly by the replacement of VLCC's and bulkers. After a small depression in the end of 1990s, the demand will maintain the stable growth toward the 21st century. During this 1990s, a Korean expert [6] said that the market share of Japan is expected to decline as it moves into more sophisticated industries and services, while the share of the new industrialized countries such as China should steadily increase. This remark is considered to be right on the whole. There are two ways for us to survive the severe competition among the world shipbuilding industry. The one way is to cut off the building cost drastically, as we will be attracted to build still simple ships such as oil tankers and bulkers. Another way is to develop so further advanced technology ships that the new industrialized countries can not catch up with us. Our opinions have not coincided yet in the point which way we should take. In any way, application of computer technology will play a very important role there. If the computer aided and integrated manufacturing system which we are now developing is completed, the both ways will be satisfied at the same time, because the system should be very versatile. We can expect about 30% share of the new shipbuilding in the early 1990s by utilizing the system. Of course, endeavors to cut off our shipbuilding facilities to an appropriate scale and to cooperate internationally with the other shipbuilding countries in order to keep order of the industry.

On the second swell of the new shipbuilding demand in the early 21st century, whether the Japanese shipbuilding industry can keep her leading part or not will depend strongly upon the quality of ships demanded there. The higher performance demanded for the ships will bring us the larger amount of share probably. Besides, the amount will be governed by the situation of shipping industry in the world and in additions the situation of the human activities as mentioned before.

4. Technology necessary for the Shipbuilding in the 21st Century [4]

The shipbuilding industry was formerly proud of her most advanced technology among many industries in the last century. A lot of technical advancement has been accomplished continuously even in this century, though the emphasis has been laid mainly on the mass production of merchant ships, particularly after the 2nd world war. The industry and the technology are originally in the reciprocal relation. Need for high performance ships always stimulates the progress of science and technology. On the other hand, high technology often reclaims a new shipping world. This kind of mutual reaction sometimes leads to dramatic change in the transportation at sea, when it acts in phase. Generally speaking, the technology in the naval architecture does not progress now so rapid as that in electronics or bionics. However, it may play an important role still to improve the shipping and shipbuilding industries gradually as we can see an example that our technical endeavor in reducing the fuel consumption could overcome the oil crises.

Now let us consider upon the technology which may be necessary for the shipbuilding in the 21st century. If we assume that the situation of shipping industry will not experience any large change until 2000 A.C. and the conventional ships will keep their majorities, the circumstances surrounding research and development in the naval architecture will require still further high performance ships. The ships with faster speed, less fuel consumption and crews than they are now should be appreciated. In additions, maintenance free ships should be admired. These kinds of research and development may contribute greatly to the economical advancement in the shipping. On the other hand, rationalization of the ship production technology will advance further by utilizing the computer technology throughout. We are now going on some big research projects which are the research on an advanced automatic ship operating system, the research on numerical ship hydrodynamics, an advanced design method by analysis and a computer integrated ship manufacturing system and so on. These projects are considered to be on the same direction in the extension of technology at the present.

Safety at sea is another very important research problem for which international cooperation, for instance, through the International Maritime Organization is considered to be inevitable. We are also thinking that the cooperation with the under developing countries on this problem is necessary, because many disasters are happening there.

Secondly, if we assume that the situation of maritime industries reform radically due to the factors as follows;

1) change of the shipping industry from massive energy and row materials transport to products transport, and besides from across the ocean voyage to intermediate distance or triangle voyage,

2) diversification of the energy for ships into nuclear and alcohol or hydrogen, though they will not be in the majority yet in the early 21st century,

3) prosperity of the combined transportation system through sea, land and air,

4) expansion of the water-front development and the leisure industry,

5) extension of human activities to wider and deeper sea space,

then, new demands for the unconventional vessels should come about. These vessels will have always much incentive to studying the new science and technology in which at least a few break through items may be included. On the contrary, the accomplished technology opens a new maritime world, for instance, if an appropriate hydrogen storing metal is discovered, the hydrogen powered ships probably will become very popular at sea.

Thirdly, unexpected discovery in science and technology is apt to lead to an innovation in marine facilities and consequently in the industries. For instance, if a super conductive material working under usual temperature is discovered, the electro-magnetic propulsion ship will bring the innovation into the shipping industry.

Table 1 shows anticipation for the realization time of a various kind of marine vessels and items of the technology necessary for them.

5. Conclusions

Changes in the structure of trade and industries in the world, particularly of the shipping and shipbuilding industries in the 21st century were predicted first. Then, the technology necessary for the shipbuilding was considered and the following conclusions were deduced;

(1)The conventional shipping industry still need more high performance ships at some reasonable prices. Incessant effort should be made for developing the new technology by utilizing the advanced computer technology to the full.

(2)The demands for the unconventional new vessels are expected due to the reformation of the maritime industries. Much emphases should be laid upon the development of extremely advanced technology on material, energy and information.

(3)Endeavors should be made for innovating a new technology applicable to the shipbuilding such as the super conductive electro-magnetic propulsion method.

No one believes that the role of shipbuilding technology has ended. We have to make an effort continuously to develop the new technology, in order to contribute to the better life of humankind in the 21st century.

References

1) "Sea and Ship in the 21st Century" la mer No.50(1985)

2) H. Muto:"The Structure of Japanese Industries in the 21st Century" Steel Design No.298(1988)

3) M. Nakamura:"Basic Technology Power of Japan in the 21st Century"(ditto)

4) "Items of the Technology Development related to the Shipbuilding toward the 21st Century" Report of the Future Technology Research Committee, the Society of Naval Architects of Japan(1985)

5) Report of the Council for Rationalization of Shipping and Shipbuilding Industries, The Ministry of Transport(1986)

6) Suk Chang:"The Performance of the Korean Shipbuilding Industry during 1987 and Future Prospects" Machinery Korea VOl. X No.2(1988)

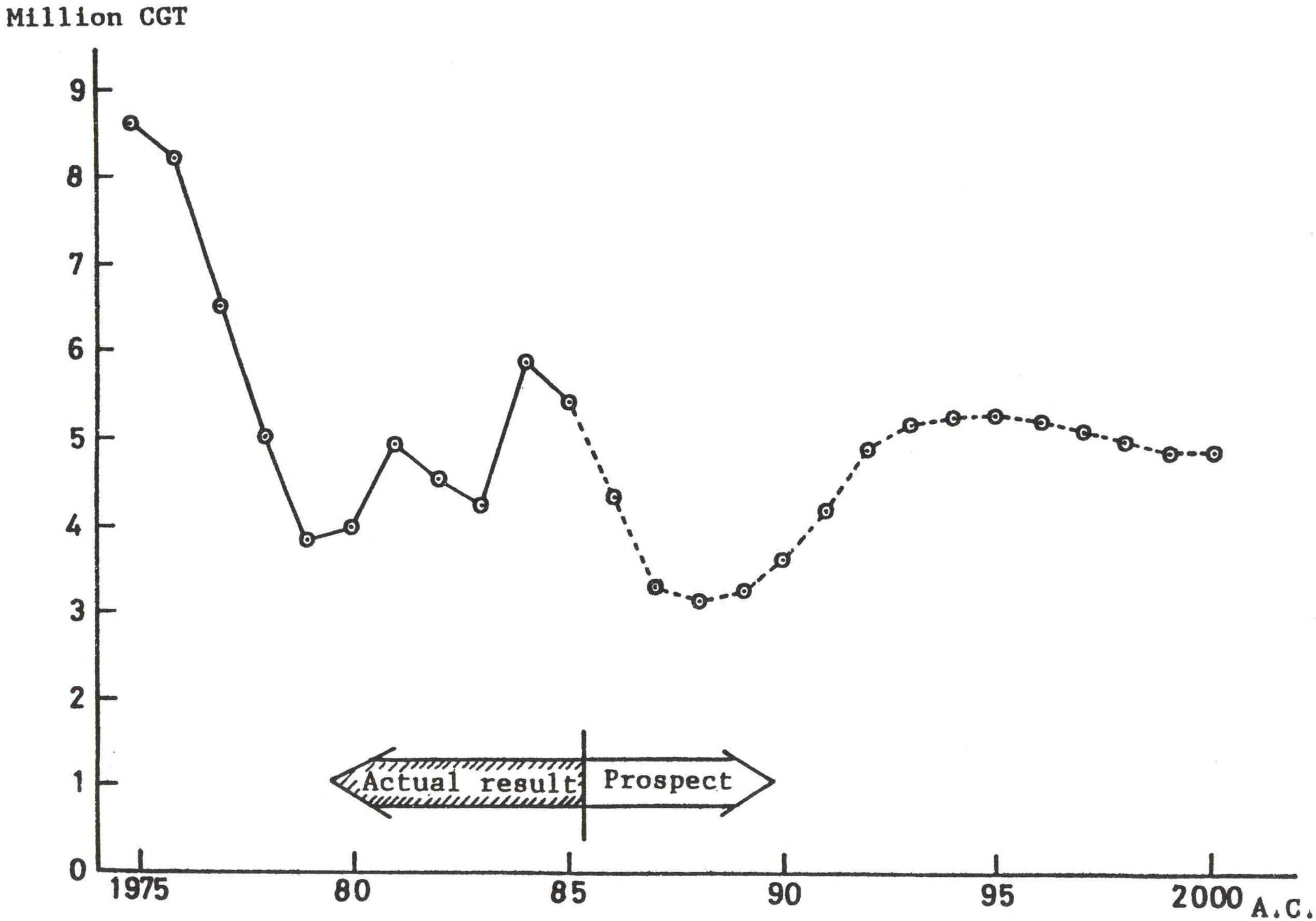
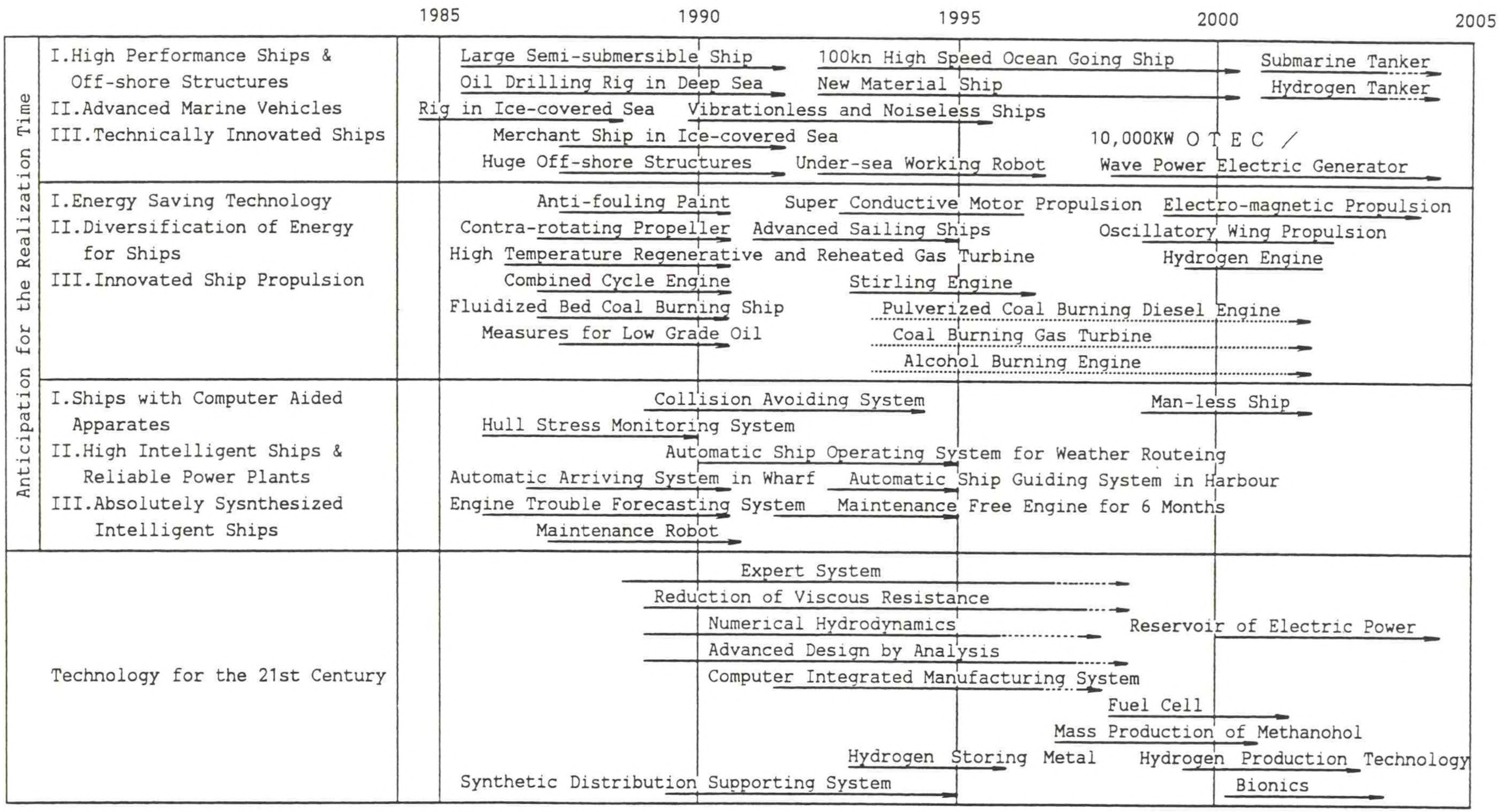


Fig.1 Actual Result and Prospect of New Ships Building in Japan

Table 1 Anticipation for the Realization Time of the Technology Advancement



Marine Facilities and Systems for the 21st Century

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Introduction

Increasing societal demands and greater dependence on development and utilization of the world's oceans and their resources provides a driving force for future research and development of marine facilities and systems for the 21st century and beyond. The overriding goal for all future endeavors in the ocean will be to contribute to the maintenance and improvement of the quality of life on earth.

To achieve this goal, we must provide basic needs of food, energy, protection of the environment, and a comfortable living standard with all the amenities. Technical, economic, environmental, social, and political factors affect these basic needs and will influence future directions for ocean science and engineering and the resultant marine facilities and systems. Some of these factors are noted below.

World population has been growing exponentially over the last 40 years and is expected to almost double over the next 40 years from over five billion to about 9 billion. This steady increase equates to less land per person, and doubling the need for food, energy, and material resources, and a significant impact on our environment. Even without doubling the population, most of the present world population (located mainly in developing nations) are in need of basic resources of food and energy.

The oceans cover almost three-quarters of our planet, contain a major portion of our untapped resources, and provide an extension of our land space. Recent declarations of 200-mile EEZ's have significantly expanded jurisdictions of ocean-bordering nations. The major beneficiaries in the near term will be the developed nations that have the technology and resources to exploit these vast new domains. For example, declarations of EEZs can expand the territorial jurisdictions of Japan by over a factor of 11, the United Kingdom by almost five, and Canada and the United United by about two.

Energy Utilization

At present, the main sources of energy are hydrocarbons and nuclear power. There are about 370 nuclear reactors that supply about 15 percent of the total energy worldwide. The percentage ranges for individual countries' totals range from 16 percent in the U.S., to 23 percent in Japan, to 65 percent in France. For the U.S., the rate of increase in the 1980's was cut approximately in half from the 1970's. The general slowdown is mainly due to public concern about environmental hazards, the remote possibilities of catastrophic failure, and the increasing costs associated with installing a new plant. The "not-in-my-backyard" syndrome will remain a major opposing factor. Nuclear fusion technology may provide a major breakthrough for safe nuclear power by the year 2030.

Today, production of offshore oil and gas from the U.S. EEZ is valued at $26 billion annually. Offshore oil production accounts for about 11 percent of total U.S. production, while offshore gas accounts for about 24 percent. Ninety percent of the oil and almost 100 percent of the natural gas produced in Federal waters in recent years have come from the Gulf of Mexico. Estimates indicate that about 35 percent of all domestic oil and 30 percent of all domestic gas is in offshore undiscovered deposits. Estimates of oil and gas reserves indicate that world supplies could extend to 2030. This includes arctic and deepwater operations. It is not well known to what extent these reserves will be, or can be, profitably extracted. Currently, oil and gas production platforms are capable of operating in depths of 300 meters. By the end of this century, platforms in the Gulf of Mexico are expected to operate in depths of 600 meters, at a pricetag on the order of $500 million at today's prices.

Major oil and gas deposits have been discovered along the northern perimeters of Alaska, Canada, and the Soviet Union, with prospects for more. Exploitation of land areas has begun, but development of remote land areas and offshore areas will require large investments and new advances in technology. The combination of extreme cold, wind, permafrost, and sea ice will greatly increase costs of exploration, production and shipping, and only very large deposits will justify development. Economic considerations will influence significantly the extent of oil and gas development in deep waters and arctic frontiers.

Large reserves of coal will be available beyond the 21st century. However, as we continue to burn oil, gas, and coal at increasing rates, the cumulative effect of building up carbon dioxide layers in the atmosphere is a major problem. The ability of our environment to assimilate carbon dioxide is being reduced because expanding urban development is resulting in increasing losses of trees and plant life, the natural assimilators of carbon dioxide. The processes and capacity of our oceans to assimilate or release carbon dioxide is not well known at this time. (CO_2 layers cause heating of the earth's surface be cause of the "greenhouse effect," resulting in melting ice caps.) Over the past 50 years, global sea levels have been rising at about 3.0 millimeters a year; three times the rate of the previous 50 years. If this trend continues, it is possible that sea levels could rise as much as one or two meters by the middle of the 21st century, inundating some coastal cities and villages. This will be a concern in designing and installing future marine facilities.

Solar-Derived Energy

After examining hydrocarbons and nuclear power, it appears reasonable that alternate energy sources should begin phasing in by the end of the 20th century. Solar energy has great potential as an alternate source of energy for the future. It can be processed directly through thermal and photovoltaic methods, as currently being applied to solar-heated and powered homes. Solar energy can also be processed indirectly by converting the dynamic motion of wind, waves, and currents induced by solar winds; converting ocean thermal and salinity gradients; and converting biomass energy derived through photosynthesis.

At present, the greatest area of soalr-derived ocean energy development is in ocean thermal energy conversion (OTEC). The resultant OTEC electrical energy can be transmitted to shore by cable or used offshore for various purposes—desalinization, ammonia production, hydrogen liquefication, and for energy-intensive industries such as alumina processing. The combination of a nearshore, or land-based OTEC plant, with an aquaculture or biomass facility and a desalinization plant is a compatible arrangement that can provide multiple benefits. Cold, deep water is a valuable resource rich in nutrients and has been successfully used in aquaculture and biomass production. The natural phenomenon of high biological productivity in upwelling areas, while representing only 0.1 pecent of the ocean's surface areas, produces about 40 percent of the world's fish. Pumping large amounts of cold water from depths on the order of 1,000 meters is analogous to upwelling.

Aquaculture facilities can receive nutrient-rich cold water into large basins onshore or into lagoons, where the sun can generate photosynthesis. The production of phytoplankton is multiplied and forms the first link in the food chain for culturing shellfish or fish. Sea farming can also be developed using natural geographical features, such as bays or large breakwaters, and developing a conditioning program for fish feeding and gathering for harvest. This may include genetic selection and development of the most suitable species of fish.

The growth of world population, accompanied by industrial and agricultural development, creates heavy demands on water resources. By the year 2000, the world's total annual water demand is estimated to double. The search for development of new water sources will become increasingly important in the 21st century. Desalinization of sea water will continue as one means of generating fresh water. Also, OTEC systems can provide fresh water as a by-product in primary production of electricity.

In addition to OTEC, there is considerable wave energy resource that can be extracted in many coastal areas throughout the world. Though it can provide power to produce energy-intensive products nearshore, it does not have the energy storage capacity or the number of by-products associated with OTEC. However, wave energy systems may be combined with OTEC to extract energy from the perimeter around an OTEC site. In this way, wave energy conversion can contribute some power and can also serve to minimize the wave loading forces on the OTEC platform. In the same way, perhaps a wave energy conversion system could surround a biomass farm at sea. By the end of this century, OTEC (with its multiple by-product capability) is expected to be cost competitive with present forms of energy.

In the U.S., current energy conversion techniques have been examined for harnessing the Gulf Stream off the Florida coast. This stream carries 30 million cubic meters of water per second—more than 50 times the total flow in all of the fresh water rivers of the world—and the surface velocity sometimes exceeds 2.5 meters per second. The extractable power is about 2,000 watts per square meter and would, therefore, require extremely large, slow-rotating blade turbines operating like windmills. The total energy of this Florida current is estimated to be about 25,000 megawatts, and extracting about four percent is not expected to disrupt climatic conditions. This would be 1,000 megawatts or the equivalent of one nuclear power plant. The amount of current energy resource is not as abundant as the ocean thermal resource. Hence, development of technology for constructing and installing only a few systems must be considered in cost-benefit analysis. A huge energy extraction system in the Gulf Stream could have a dual role of providing energy and perhaps some coarse control of severe weather in the local region by disrupting the flow of the stream. Technology for such possibilities will be the subject of scientific investigation and may be realizable late in the 21st century.

Salinity gradients provide an enormous resource worldwide, comparable to ocean thermal gradients. The present major limitation is the inadequacy of osmotic membranes. Since sea-based salinity gradient conversion systems must be near fresh water sources such as estuaries, they could present a constraint to navigation and other uses in such areas. Also, since estuaries are becoming more polluted, which in turn, causes salinity levels to rise, the performance of osmotic membranes is greatly reduced. Desirable improvements include: better efficiency, less susceptibility to clogging, easier cleaning, and longer life.

Solar pond technology, using high salinity water to absorb the sun's heat and extract it by means of a rankine cycle heat engine, has considerable promise and does not require osmotic membranes. Israel has developed a 150-kilowatt pilot plant on 1.5 acres of land at a location near the Dead Sea. It may be possible to apply this technique by modifying a naturally formed coastal area such as a bay or lagoon.

Future Energy Sources

Based on the above discussion, it is my opinion that by the year 2030 oil and gas reserves will be substantially reduced, forcing development of less accessible and more costly sources in polar and deep ocean regions; coal development should increase, depending on its environmental suitability; nuclear power by fission should increase depending on its environmental suitability and public acceptance; nuclear power by fusion may provide an acceptable alternative, depending on successful development; there will be wide application of solar energy; and solar-derived ocean energy sources such as OTEC will increase at a steady pace. Solar and solar-derived ocean energy is ideally suited for the 21st century because it is an abundant, inexhaustible, nonpolluting resource. For example, OTEC can provide electric base-load power and offer considerable by-products such as ammonia for fertilizer use, hydrogen and oxygen for fuel cell use, and alumina for aluminum products. Technology associated with each of these products such as aquaculture, marine biomass development, and energy-intensive product processing needs to be developed and refined to yield greater efficiencies and reduce production costs.

Deep Water Facilities and Technology

Offshore structures for oil and gas development are expected to operate in water depths of 600 to 1000 meters by the end of the 20th century. Floating OTEC systems will require platforms and structures in over 1000 meters depth. These large deep-water structures will require new techniques for construction, transportation, and installation. Candidate structures or platforms will include guyed towers, single anchor leg spar systems, and tension anchor leg moors. Special considerations will be required for deep ocean foundations and mooring systems, including piling and anchoring to ensure stability over periods measured in decades. Future deep water platforms will be larger, more complex, and of different configurations. Structures and components that are relatively inaccessible will require special design considerations for inspection, maintenance, and repair, including some redundancy in design. It is likely that many oil and gas production platforms of the future will be located on the seafloor and designed for automated operations. A remotely operated vehicle can be incorporated into the system design to perform visual monitoring and inspection, and manipulative tasks for nondestructive testing, maintenance, and repair.

Many OTEC plants will be shelf-mounted or land-based, especially for island applications. In many cases, shelf slopes could be very steep, up to 45 degrees and more. This will require research and improved techniques to allow the installation of foundations and cold water pipes on steep slopes and to ensure long-term stability. Materials for deep-water platform legs and foundations, cold water pipes and deep ocean risers, and deep ocean mooring systems need to be assessed and rated for long-term stability based on cyclic fatigue.

Many of these large-scale platforms and deep ocean platforms will require new materials, new fabrication techniques, computer-aided design techniques and new handling and assembly techniques. The technology for platform development in the nearshore may also be applied to extending our shore boundaries into the contiguous "sea space."

Polar Marine Facilities and Technology

Development of offshore oil resources in polar regions, mainly the Arctic, will require an understanding of the physical properties and dynamic behavior of ice forces. In general, technology associated with ocean resource development in the temperate zones will have to be adapted or changed to meet the environmental extremes of polar regions. Construction, transportation, and installation of offshore structures in polar regions will be a major factor. Because of ice forces, platforms and structures with minimum surface in the ice plane will be preferred. Oil and gas production platforms installed on the seafloor under the ice and designed for automated operation can avoid the Support equipment and systems to operate on or under the ice will be required for site survey, measurement of environmental forces, installation, inspection, maintenance and repair.

Antarctica has been referred to as the "continent of the 21st century." There is great potential for mineral and fisheries resources. However, the Antarctic Treaty has for 27 years barred commercial development, while scientific research continues. Antarctic ice cores have provided records of human effects in the atmosphere by leaving samples in the annual layers of ice sheets that trace back some 150,000 years. In addition to the CO_2 problem, there is the formation of an ozone hole (twice the size of the continent and increasing), believed to be caused by industry-generated chlorofluorocarbons. The hole enables ultraviolet radiation to penetrate the atmosphere causing potential damage to crops, marine life, and human health. Ocean scientists and engineers of the 21st century must strive to maintain a balance between resource development and protection of the land, sea, and atmospheric environment, especially to minimize major damage that may be irreversible in the 21st century.

Robotics/Autonomous Undersea Vehicles

Development of ocean resources over the next 50 years will require progressive use of robotics and automation to perform a variety of tasks including resource assessment; bottom survey and mapping; ocean system operations monitoring; and inspection, maintenance, and repair (IMR). Automated operations of offshore energy systems will greatly reduce manning requirements, and human factors must be considered in system design. Operations in deep water and under ice present new risks and hazards for manned systems, but are ideally suited for remotely operated undersea vehicles (ROV) and autonomous undersea vehicles (AUV). These will be used for oil and gas completion systems and pipelines located in deep water and under the ice for operations, monitoring, and IMR. These vehicles will be used at great depths to perform ocean surveys for resource assessment and charting, and environmental monitoring. Future improvements for these vehicles include control telemetry; navigation and maneuverability; optical and acoustic viewing; and telemanipulation. Advanced sensors and the extensive application of microprocessors programmed with knowledge-based/artificial intelligence systems will enable ROV/AUVs to achieve high levels of performance that closely duplicate man's visual and tactile skills.

Marine Mining

There are vast amounts of minerals on the sea bed as well as constituent elements of sea water itself. Uncertainties still remain about the distribution and abundance of minerals that are of economic interest. The marine mining industry has remained relatively undeveloped because of the high cost of offshore production relative to land production. For the U.S. EEZ, sand and gravel resources on the continental margins are estimated to be in the hundreds of billions of cubic meters; placer deposits on the Pacific Continental margins are estimated at over 2 billion cubic meters; the Blake Plateau off Florida is estimated to have more than 2 billion tons of phosphorites, and the areas off Georgia and the Carolinas may have even larger deposits; and about 100 seamounts located in the EEZ of the Hawaiian Islands have potential yields of 4 million tons of manganese oxide crusts rich in cobalt. Most land deposits appear to be in abundant supply for the next 30 years, but as world economics become increasingly unreliable, there is a growing concern for potential disruption in the supply of imported hard minerals, especially strategic minerals such as cobalt, chromium, manganese, and platinum group metals. From a strategic point of view, it is essential that the Federal Government promotes continued deep ocean mining technology development by industry to enable recovery of deep ocean strategic minerals within an acceptable time frame. Present technology is capable of high resolution sonar imaging and underway sampling and assay techniques.

However, data retrieval is very slow and costly. Bottom survey operations in the next 10 to 20 years could employ a number of reliable high-endurance AUVs that can be pre-programmed to conduct long duration surveys using survey and in situ assessment systems such as neutron activation analyses, x-ray florescence, or atomic absorption techniques that provide underway assays along the seabed. These vehicles would be controlled from a mother ship or a submarine serving as the central control and data collection assessment and mapping center. Once a field of manganese crusts or nodules high in strategic mineral content is located and mapped, it is envisioned for the future that a remotely operated robotic, rock crushing and hydraulic dredging unit be deployed for selective recovery. Dredged materials would be conveyed to an on-site separation and processing ship and from there, transported to other processing facilities onshore.

Seafood

In the U.S., coastal fisheries yield over 10 billion pounds of food each year, or nearly 50 pounds per person, contributing more than $23 billion dollars yearly to the Nation's economy and providing employment for more than a million people. No other nation has the diversity and abundance of fish and shellfish, with 15 percent of the world's living marine resources located in the U.S. EEZ. Still, the U.S. is only fourth among fishing nations of the world (behind Japan, the USSR, and China). As population continues to grow, so too will the demand for the harvest of living marine resources, and consequently, the demand for mariculture, aquaculture, and artificial reefs located in protected areas of estuaries and coastal waters. Japan continues to make major strides in this area and serves as a model for others to follow. Improvements in fish farming will also be made by applying marine biotechnology, i.e., molecular genetics and genetic engineering to create faster growing and better quality products protected from diesease.

Regarding the fishing industry, improvements are needed in fish finding and classification for resource assessment and harvesting. For the future, high resolution, multi-frequency sonar systems, using acoustic signature techniques from ROVs or AUVs controlled from a mother ship, will be needed for resource assessment. Use of electric fields or other conditioning methods will also be needed for catching and harvesting. Automated fish processing ships will be needed to improve operating efficiencies. Also, capabilities need to be developed for harvesting underutilized fish to make fish analog products such as surimi that provide fish-derived nutrition and simulate the taste of more costly seafood. This can easily develop into a several billion dollar-a-year industry by the 21st century. Advanced marine facilities for fish hunting, farming, aquaculture, and at-sea processing will be required.

Waste Disposal

As the costs of land-based disposal options have increased, interest has grown to use the seafloor of the EEZ for waste disposal. Growing international restrictions on deep sea disposal and state government opposition to near-coastal dumping leaves the EEZ as the only ocean regime for the disposal of many types of materials, including hazardous wastes and dredged materials. The seabed of the EEZ should be considered along with land-based alternatives with a view to selecting the most environmentally sound solution. Surveys of the EEZ, including information on habitat, will be needed to locate suitable potential sites for specific classes of wastes. Comprehensive studies with due regard for interactions between overlying water and sediments will be necessary. Subseabed disposal of radioactive waste is another option being considered. For example, seabed areas outside the EEZ, in the mid-Pacific, have been geologically stable for millions of years. This is an important factor when considering radioactive materials with half-lives in the tens of thousands of years. Deep ocean subseabed surveys will be required to determine site acceptability and means for seabed penetration. Should the international community decide that such options are viable and acceptable, this will require special marine facilities for transporting and making deep ocean subseabed deposits of special shielded and vitreous-lined containers. Disposition of municipal waste and dredging material has been a growing concern that has reached critical stages for many large coastal cities. This problem will be even greater as population increases. Options other than using existing land sites to extinction must be considered, such as incineration at sea, artificial islands, and seabed disposal. New marine facilities and systems for these options will be required.

Marine Transportation/Ship Technology

This subject is of major importance to the marine community, with many current advances projecting into the 21st century. This topic is covered in great detail in the 15th meeting of the U.S. - Japan Marine Facilities Panel. Dr. Kazuo Sugai, Japan Panel Chairman and Director General of the Ship Research Institute, provided the paper "Ship Technology for the 21st Century," and Dr. Noboru Hamada, President of the Japan Marine Machinery Development Association (JAMDA), provided the paper "Proposals on Ship Technology for the 21st Century." Dr. Hamada has pioneered the development of the sail-assisted, ship propulsion concept that has been incorporated into 15 ships, and he has made great strides in automated ship operation, reducing manning requirements to a bare minimum. Other important advances covered in the 15th meeting pertain to ship propulsion and include magnetohydrodynamics (MHD), superconducting electric propulsion, and closed cycle undersea propulsion. Inter-modal transport, automated container cargo handling and routing systems will be important to maritime commerce in the 21st century.

Facilities for Scientific and Engineering Research

Ships, offshore platforms, buoys, submersibles, ROV's, AUV's, and satellites are marine facilities and systems used in a wide variety of scientific and engineering research including oceanographic, meteorological, geological ocean measurements, and environmental monitoring to obtain a better understanding of the ocean, its resources, and the influence of the oceans in climate research and global environmental change. One major advancement for the 21st century will be the deployment and control of several fully automated, instrumented, long endurance AUV's that can be controlled by a mother ship or via remote satellite using the AUV with a companion surface buoy for telecommunications. Future AUV's could be cost effective in conducting surveys, especially in hazardous areas, deep ocean, under ice, and for long endurance.

Fixed offshore research platforms and towers in the EEZ, especially the coastal ocean, can provide multi-purpose research facilities. An excellent example is the proposed Okhotsk Program and Tower Project that would be located in the Sea of Okhotsk off the northeast coast of Hokkaido. This tower can be used to conduct a wide variety of scientific research mentioned above as well as engineering research including development and evaluation of fish technology, ocean energy conversion techniques, and resource assessment techniques. The proposed tower is a fixed cylinder shape to be located offshore in 50-meters water depth and fully equipped with living and laboratory facilities.

Coastal Ocean Space Utilization

In the U.S., as well as in other ocean-bounded developed nations, population and industry are seeking closer location to the coast, and the trend is increasing. For example, presently in the U.S., over half the population lives within 50 miles of the coast; by the year 2000, it could be as high as 75 percent. In Japan, because of the steepness of the mountains, only 30 percent of the land is habitable, most of which is along the coast where 70 percent of the people live. As a result, development of ocean space in estuaries and coastal areas, including revitalization of ports, harbors, and coastal communities, is gaining momentum. This will be the coastal renaissance of the 21st century.

In Japan, the need for additional coastal real estate has resulted in the development of artificial islands in estuaries and coastal areas for a variety of dedicated uses such as power stations, recreational facilities, and a new municipal airport; and for integrated uses providing high-quality living, working, educational, and recreational facilities. All of the coastal prefec-ures are developing revitalization plans to integrate coastal communities. In the U.S., a number of major port and harbor communities such as Los Angeles, Long Beach, Baltimore, and New York have begun, or are planning, large-scale ocean space revitalization projects.

Even though inland space may be available, there is strong desire and a steadily increasing need to provide more coastal space for the coastal-oriented public seeking the ocean view, fresher air, and marine recreation. This will further spur the need for artificial islands and floating cities. An artificial island can be designed and constructed in an environmentally sound manner to serve as an initial repository for municipal waste and dredge spoils and later converted for other uses. An offshore location would be selected so as not to affect inland ground water tables. Also, construction of the containment, treatment of the deposited material, and environmental monitoring will ensure environmental protection. Future advances in marine biotechnology will minimize the problem through applicaton of genetic engineering to create bacteria that can break down harmful compounds so that they are environmentally suitable.

Concept studies conducted in Japan include mega-size floating islands that would be located in 100 meter-depth waters and would consist of a water plane area of about 10 square miles, roughly half the size of Manhattan Island in New York City. By providing four decks, the useable space would be 40 square miles and would be able to accommodate as many as 500,000 people. The floating island would include living facilities, business centers, university and research centers, and municipal facilities such as hospitals and an airport. This conceptual design would be supported by 10,000 floating columns that would be anchored to the seabed. Buoyancy would be controlled via column sensors that would feed data to a central computer. This type of project — a floating city—may carry a pricetag on the order of 100-200 billion dollars.

Future floating cities could be designed using a modular approach. As the city grows, new blocks could be floated in and attached, making a suburb, or a park, or a simulated mountain with built-in ski slope. The modular floating factory, or processing plant, has already been demonstrated by Japan with the construction in Japan of a wood pulp processing plant that was then towed to a pre-determined pile-anchoring site along the Amazon River. The floating city also provides an interesting concept for a naval base that ideally should be located offshore, and perhaps could be relocated as needed.

Another interesting experiment for a prototype floating city would be to place it in the Gulf Stream and see if mooring and station keeping could be assisted by using the sub-surface counter current flows to cancel the surface currents. In this case, large-ducted "windmills" could be incorporated to extract energy from the Gulf Stream.

Environmental Protection

Significant environmental problems will continue to persist during the accelerated future development of the world's oceans, especially the coastal ocean, and its resources. Ocean scientists and engineers must always consider and weigh the environmental implications of development. The coastal ocean is especially affected in varying degrees by man's impact, including sewer outfalls, land run-off, ocean dumping, sand and gravel mining, dredging, oil and hazardous materials spillage, disposal of plastic debris, and contaminants from chemical and industrial waste products. The increasing multi-use of coastal ocean space will continue to raise many potential environmental problems and will require careful long-term monitoring and assessment to ensure adequate protection. Some of the problems that must be averted or ameliorated include overenrichment/oxygen depletion of coastal waters, physical modification of seabed habitats; pollutant damage to fish and shellfish; and mitigation of natural hazards and coastal erosion.

Each coastal nation is responsible for the health of its coastal environment, a fact that has national, international, and global implications. This will be of great concern in the 21st century. Hence, each coastal nation must establish and maintain a comprehensive environmental program within its EEZ. Such a national program must develop a comprehensive understanding of its ocean environment and its resources and provide environmental information products and services to multiple users in the public and private sectors. The heart of the program requires establishing and maintaining environmental baselines followed by continuous long-term monitoring for the detection and assessment of low-level changes that may affect the environmental health of the coastal ocean, and in turn, have an impact on its living resources, the food chain, and man's well being. Environmental research and application of advanced technology are integral to any comprehensive and adaptive environmental program.

Most present methods of sampling in the water column and sediments and performing analyses in the laboratory are slow and cumbersome. Future needs for rapid, in situ, and real-time measurement and monitoring systems are obvious. For example, optical fibers can transmit laser light to a desired depth with the back-scattered radiation then transmitted back to a spectrometer to detect and quantify various substances. Other systems that take water or sediment samples underway, followed by in situ measurements, analyses, and automated geographical charting will be needed. This is another future application for AUV's, automated, bottom-mounted monitoring stations, and advance surface craft, to provide large area synoptic coverage to acquire data for developing, validating, and using environmental models. Satellite data transmisssion systems coupled with surface and subsurface measurement systems, and satellite-borne ocean measurement systems all coupled together will be integral to programs monitoring coastal environmental change as well as global environmental change.

Conclusions

Ocean science and engineering and the resultant marine facilities and systems will contribute substantially to the maintenance and improvement of the quality of life in the 21st century by providing for the basic needs of food, energy, and a habitable environment for a rapidly growing population. Technical, economic, environmental, social, and political factors will influence the extent to which these needs can be met. Many new marine facilities and advanced systems will be introduced in the 21st century.

Solar-derived ocean energy will provide an inexhaustible, non-polluting energy source and other important by-products such as deep ocean nutrients for aquaculture and fresh water.

Marine mining in shallow coastal waters will continue and new deep ocean mining facilities and systems need to be developed soon to meet future potential strategic metal crises.

New fish hunting and farming facilities and systems will be needed to satisfy the increased demands for seafood and other fish-derived products such as surimi.

The staggering problems of coping with vast quantities of municipal and industrial waste, dredged materials, and radioactive waste will require supplementing conventional land-based disposal methods with new facilities and systems for environmentally safe disposal in the ocean, on the seabed, and in the subseabed.

Advances in technology including robotics, AUVs, ocean measurement systems, biotechnology, environmental monitoring techniques, new materials and construction techniques for deep ocean systems and large floating cities, ocean energy conversion techniques, undersea viewing and survey techniques, application of knowledge-based systems, and computer-aided design and manufacturing will all contribute substantially to the development of the marine facilities and systems in the 21st century.

Expanded exploitation of the EEZ will be a major undertaking by the developed, seafaring nations of the world. A coastal region renaissance will be the main emphasis for the 21st century, including revitalization of coastal port and harbor complexes and ocean communities; increased use of artificial islands, introduction of floating cities, and the attendant problems of multiple users. In view of the accelerated pace of development in the EEZ and especially the coastal ocean, multiple-use conflicts will be a prime concern of regulators, designers, developers, managers, and users. It will be crucial in the 21st century to maintain a balanced outlook in the development of the ocean and its resources with due concern for the protection of our precious, vulnerable natural environment, while maintaining and improving the quality of life for all.

BIBLIOGRAPHY

Artunc, Sadik C. 1987. Recreation planning and design for floating cities. In: Coastal Zone '87: Proceedings of the 5th Symposium on Coastal and Ocean Management, Volume I. NY: ASCE. pp. 138-146.

Broadus, John M. 1987. "Seabed materials." Science 235:853-860.

Compass Publications. 1987. "Special Report— Ocean engineering and resource development in the Exclusive Economic Zone." Sea Technology 28(6):10-41.

Corell, Robert. 1987. The U.S. Global Ocean Science Program.

Craven, John P. 1987. Technology milestones in ocean space utilization. In: Oceans '87: Conference Proceedings. Volume II. pp. 730-736.

Ehler, C.N., D.J. Basta, T.F. LaPointe, and M.A. Warren. 1987. "New oceanic and coastal atlases focus on potential EEZ conflicts." Oceanus 29(3): 42-51.

Freund, John F. 1986. New technologies in U.S. Navy undersea vehicles. In: Proceedings of the 14th Meeting of the U.S.-Japan Marine Facilities Panel. pp.41-48.

Hamada, Noboru. 1988. "Japanese advances in transport technology." In: Sea Technology 29(2): 25.

Hill, G. and M. Lockwood. In press. Seafloor exploration and characterization: Prerequisite to ocean space utilization. Volume II. Proceedings of the Oceans '87 Conference.

Hotta, Kenji and Kato, Wataru. 1987. Socioeconomic effects of offshore artificial Islands. In: Oceans '87 Conference Proceedings, Volume II, pp. 747-751. Halifax, Nova Scotia.

Kato, W. (ed.). 1986. Ocean space utilization '85, Proceedings of the International Symposium. Tokyo: Springer-Verlag.

Kester, D.R., W.V. Burt, J.M. Capuzzo, P.K. Park, B. Ketchum, and I.W. Duedall (eds.). 1985. Deep-sea waste disposal. In: Wastes in the ocean, Volume V. New York, NY: John Wiley and Sons.

Kondo, Takeo. 1987. Macro oceanic and atmospheric management project. In: Oceans '87 Proceedings. Volume II, Oceans '87 Conference. Halifax, Nova Scotia.

Lockwood, M. and G. Hill (eds.). 1986. The Exclusive Economic Zone symposium—Exploring the new ocean frontier. Symposium Proceedings.

Manheim, F.T. and A. Vine. 1987. Options for radioactive and other hazardous waste siting within the U.S. Exclusive Economic Zone. Tech. Rep. WHOI-87-12. Woods Hole, MA: Woods Hole Oceanographic Institution.

Marine Technology Society. 1985. "Marine mineral resources." Special issue of the MTS Journal 19(4): 72.

Matsumoto, T. 1985. An analysis of offshore man-made islands. In: Ocean space utilization '85, Volume II. W. Kato (ed.). Tokyo: Springer-Verlag. pp. 7-14

Muller, Gerhardt. 1987. Ports and artificial islands: Development of a new relationship. In: Oceans '87: Conference Proceedings. Oceans '87 Conference. Halifax, Nova Scotia.

National Marine Fishery Service. 1987. The marine recreational fishery statistic survey: Atlantic and Gulf Coast. 1986. National Fishery Statistic Program. Washington, DC.

National Marine Fishery Service. 1987. The marine recreational fishery statistic survey: Pacific Coast. 1986. National Fishery Statistic Program. Washington, DC.

Okamura, Kenji. 1987. Future ocean space utilization in Japan. In: Oceans '87 Proceedings. Volume II, Oceans '87 Conference. Halifax, Nova Scotia.

Prior, D.B. and E.H. Doyle. 1984. Geological hazards survey for exploratory drilling in water depths to 2000m. Offshore Technology Conference Paper No. 4747, pp. 311-318.

Robinson, Sid. 1987. 2020 plan: Utilizing ocean space for port development. In: Oceans '87 Conference Proceedings. Volume II, pp. 752-756. Halifax, Nova Scotia.

Seymour, R.J. and J.R. Vadus. 1986. Real-time information systems for improved port operations. Ports '86 Conference. Oakland, CA. May 1986.

Soh, T. 1985. Conception of offshore fishery base. In: Ocean space utilization '85, Volume II. W. Kato (ed.). Tokyo: Springer-Verlag. pp. 15-22.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration. 1986. U.S.-Japan cooperative Program in Natural Resources, U.S.-Japan Marine Facilities Panel. Conference Record of the 14th meeting.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration. 1988. U.S.-Japan cooperative Program in Natural Resources, U.S.-Japan Marine Facilities Panel. Conference Record of the 15th meeting.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration. 1986. Gulf of Mexico strategic assessment data atlas. Washington, DC: Government Printing Office. 165 maps and text.

U.S. Congress, Office of Technology Assessment. 1987. Marine Minerals: Exploring our new ocean frontier. OTA-0-342, Washington, DC. 347 pp.

University of Hawaii/National Science Foundation. 1987. Ocean engineering technology in the Exclusive Economic Zone. Results of a workshop on engineering solutions for the utilization of the Exclusive Economic Zone resources. October 19-23, 1986

U.S. Global Ocean Science Program Working Group. National Science Foundation. Report on "U.S. global ocean science program."

Vadus, Joseph R. 1982. Ocean technology in the 21st century. U.S.-Japan Symposium. Nihon University. Tokyo, Japan.

Vadus, J.R., C.N. Ehler, A.J. Silva. 1987. Information needs for seafloor and seabed utilization. 1987. Exclusive Economice Zone Symposium. U.S. Geological Survey. Reston, VA.

Van Dyke, Kay. 1985. Status of floating city technology. In: Oceans '85: Conference Proceedings. Volume II. Oceans '85 Conference. San Diego, CA.

Waki, S. 1985. The port island development in Kobe City as and urban complex artificial island. In: Ocean space utilization '85, Volume II. W. Kato (ed.). Tokyo: Springer-Verlag. pp. 131-142.

Walsh, Don. 1987. Pleasure in the ports: Can recreation and shipping live together? In: Oceans '87: Conference Record, Volume II. Oceans '87 Conference. Halifax, Nova Scotia.

Woods Hole Oceanographic Institution. 1987. Special Issue on Japan and the Sea. Oceanus 30 (1): 90.

World Commission on Environment and Development. 1987. Our common future. Oxford: Oxford University Press.

Yabe, Y. and T. Maeda. 1985. Prerequisites for ports and harbors in the 21st century: Case study of Beppu Port. In: Ocean Space Utilization '85, Volume II. W. Kato (ed.). Tokyo: Springer-Verlag. pp. 143-150.

Yokoi, R. and T. Noguchi. 1985. Some technical problems of the sea-plane airfield and floating airport. In: Ocean Utilization '85, Volume I. W. Kato (ed.). Tokyo: Springer-Verlag. pp. 723-727.

MARINE FACILITIES FOR RESOURCE DEVELOPMENT

FUTURE PROJECTIONS IN ARCTIC AND DEEPWATER TECHNOLOGY FOR OFFSHORE OIL AND GAS STRUCTURES

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ABSTRACT

Much of the United States' future domestic petroleum supply is expected to come from the areas offshore Alaska and the lower 48 states. Areas of highest potential are in the deep waters of the Gulf of Mexico (GOM), seismically active areas off southern California, and the ice-infested waters of the Arctic. Operations under any of these conditions are severe, with high development costs, and immense financial risks. This paper addresses some of the technological breakthroughs proposed to develop oil and gas operations in these frontier areas, as well as recent activities relating to the U.S. Arctic Research Commission, and the concerns expressed for the installation of platforms in seismically active areas.

INTRODUCTION

As the pace of exploration increases in the frontier areas of the Outer Continental Shelf (OCS), questions arise continually about technologies needed to safely and efficiently develop oil and gas operations in such severe environments. The engineering categories listed in Figure 1 entail some of the items requiring special attention. Each of these categories has its unique problems and constraints which must be addressed. Experience derived from numerous installations in nonfrontier areas coupled with extensive research sponsored by both industry and Government provides a solid basis to move operations into the less benign regions.

Technologies that will be used to develop, produce, and transport oil and gas in the Arctic are constantly being updated, and although some systems are well proven, others are not. Design criteria must include provisions for very low temperatures, sea ice, permafrost, seismicity, waves, and bottom scouring by ice ridges. Environmental issues which must be addressed are impacts from a major oil spill, effects due to marine structures as well as shore-based facilities, and the consequences of dredging, ice breakers, excess noise, and other possible hazards. Industry, however, has demonstrated its capability to use new technologies for exploration in the Arctic, and this insight will prove of great benefit for developing future production facilities.

Engineering Categories

- Well Control
- Structural Dynamics
- Structural Inspection and Monitoring
- Geotechnical
- Ice Mechanics
- Materials
- Risk Assessment
- Oil Spill Containment and Cleanup

Figure l. *Engineering categories requiring special attention for the development of oil and gas operations in frontier areas.*

Industry is of the opinion that the technology exists for developing and producing oil and gas in water depths out to at least 3,000 feet. This does not imply that all potential engineering and operational problems have been solved. Uncertainties still exist and will continue to exist until facilities in these water depths become operational. Areas of concern for deepwater operations relate to well-control procedures, laying and operating pipelines, strumming of risers because of high ocean currents, inspection techniques, and the use of novel structures. All of these areas must be addressed from a technological standpoint to bring deepwater operations into the same realm of reliability as current operations.

Over the last several years, millions of dollars have been invested in designing equipment, developing analytical tools, and conducting model and full-scale field tests in preparation for frontier operations.

To illustrate the technological developments that have occurred or are anticipated for operations in the deep ocean, seismically active regions, and the Arctic, the following information is provided.

Deepwater Technology

Ten years ago the term deepwater referred to water depths greater than 600 feet; now this has been extended to water depths greater than 1,000 feet. In two recent lease sales in the Gulf of Mexico, 33 percent of the tracts leased were in water depths greater than 3,000 feet, and four tracts were leased in water depths of 10,000 feet. While it is unlikely that a significant number of projects will be carried out in these water depths over the next few years, the industry has retained a strong interest in continuing to acquire deepwater tracts for future development. Deepwater exploration has not been limited only to the Gulf of Mexico. Brazil is currently conducting exploratory drilling at two sites, one in 3,660 feet of water and the other at a depth of 3,690 feet. Other countries with deepwater activity are Norway, Australia, Indonesia, Italy, Spain, Thailand, and the U.S.S.R. Table 1 shows the total number of deepwater wells drilled worldwide during each of the past 10 years.[1]

A variety of structural concepts are available for deepwater development as shown in Figure 2. These include conventional fixed jackets, compliant towers, tension leg platforms, and floating production platforms. Many complex technical problems have been solved in developing workable systems, and each system has its own unique advantages and limitations. However, what may prove to be technically feasible may not be economical, that is, the size of the recoverable resource is a key component for the economic feasibility of deepwater development.

Table 1. *Chronology of Deepwater Drilling*
(Taken from Reference 1)

	600-1,000 ft.	1,001-2,000 ft.	2,001-3,000 ft.	Over 3,000 ft.	Total
1978	21	13	7	3	44
1979	39	35	3	10	87
1980	40	32	8	6	86
1981	31	44	4	0	79
1982	58	37	1	5	101
1983	64	36	2	3	105
1984	64	63	13	8	148
1985	66	74	12	10	162
1986	46	42	16	12	116
1987	33	41	16	11	101

The current record for a fixed platform is held by Shell's Cognac Platform located in 1,025 feet of water. However, Shell is constructing a new platform, Bullwinkle, that will become the world's tallest deepwater fixed platform. It will be located in 1,350 feet of water and will stand 1,615 feet tall from the ocean floor to the top of the drilling rig. The platform will consist of a single-piece steel jacket with a weight of approximately 50,000 tons. The massive structure, too large for conventional launching equipment, required construction of a specially designed 853-foot by 253-foot launch barge that is being built in Korea.[2]

Recent studies indicate that steel-jacket platforms could be technically feasible up to a water depth of approximately 1,600 feet. However, these giant structures are subject to motions and stresses amplified by resonant vibration, which results in an unacceptable fatigue life. New designs are being developed to eliminate this problem, but it is reasonable to state that conventional jacket structures are not feasible beyond this depth.[3]

A new type of structure is being developed to extend platform depth capabilities significantly. Known as compliant platforms, these structures are allowed to move in response to waves and currents, thus reducing the magnitude of the load to be resisted. Figure 3 indicates the relative sway periods of fixed and compliant platforms and how each compares with typical wave-energy spectra.

Compliant platforms may be classified in two ways. The first is designated as bottom-founded. This would be typical of guyed towers and compliant towers. Exxon has installed a guyed tower, Lena, in 1,000 feet of water in the GOM, and the technology is such that guyed towers may be an efficient system down to a water depth of

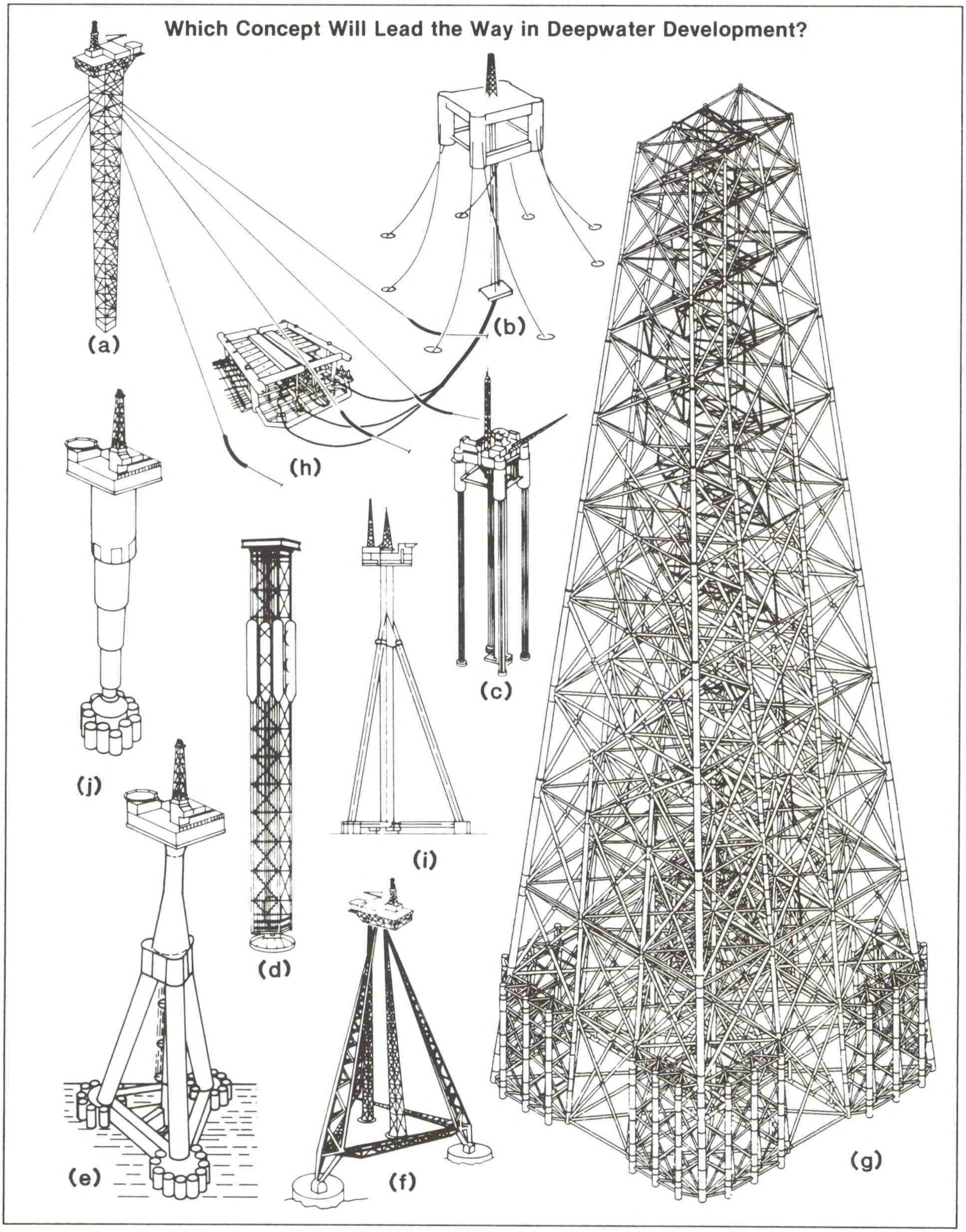

Figure 2. *Structural concepts for deepwater platforms: (a) Guyed Tower, (b) Floating Production System, (c) Tension Leg Platform, (d) Articulated Compliant Tower, (e) Rigid Concrete Tripod Structure, (f) Steel Tripod Structure, (g) Rigid Steel Jacket, (h) Subsea Production System, (i) Steel Box Tripod Structure, (j) Solid Compliant Tower (figure courtesy of McDermott International).*

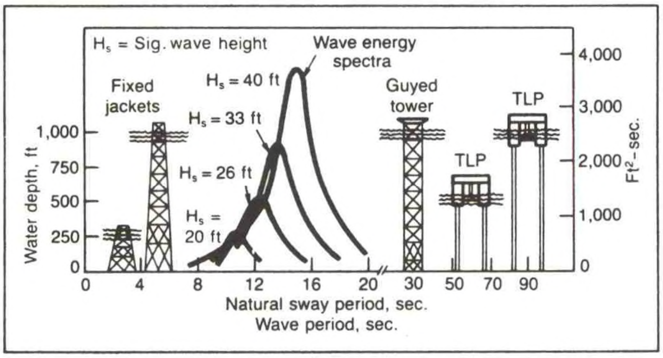

Figure 3. *Comparison of the natural sway period between a fixed jacket platform and a compliant platform and their relationship to the wave energy spectra for different significant wave heights.*

2,000 feet. The compliant tower differs from the guyed tower in that it eliminates the cable system that serves as the support for the tower. Stability is maintained by the flexibility of the frame as well as buoyant chambers built into the frame. These types of structures could be economical down to 3,000-foot water depths. Both of these compliant platforms are rigidly attached to the seafloor with piles and are designed with relatively slender flexible steel frames that have a natural period significantly higher than the high-energy wave periods.

The second class of compliant platform is basically floating structures. The tension leg platform (TLP) is typical of this type of structure for which the technology has been developed. The TLP makes use of excess buoyancy, which places the mooring legs or tendons under a very high tensile load. This in turn restricts the motions of the platform such as heave, pitch, and roll, while it allows movement in the horizontal direction. The first commercial application of a TLP was the Hutton Platform in the North Sea in 485 feet of water. The first deepwater application in the U.S. OCS will be in 1,760 feet of water on a Conoco tract in the GOM. This will be a lightweight version of the TLP and will be known as a tension leg well platform. It will have a displacement of only 18,000 tons, will not support a drilling rig, will have limited processing capabilities, and thus will serve primarily as the support for the well heads. Production will take place on a remote platform location in relatively shallow water.[4]

The TLP concept does suffer from a payload limitation. The larger the deckload, the larger the hull required to provide necessary buoyancy, and the larger the moorings and foundation requirements. With increased water depth, longer tendons and risers are required which add substantially to the deckload, and in turn increases the hull displacement.[3] It is this weight interaction that increases the cost of TLP's and keeps them from being the most economical choice for the deeper tracks. They are expected to be economical down to a water depth of approximately 4,000 feet.

To overcome the disadvantage of the TLP's, Floating Production Systems (FPS) technology is receiving increased attention as an option for deepwater oil and gas operations. An FPS facility is a floating platform held in place by catenary mooring lines. In a typical FPS, the production facility is coupled with a subsea completion system where well control is provided on the seafloor. Wells are usually predrilled through templates, and production is brought to the surface through a compliant riser system connected to the floating vessel. Satellite well production units may be placed at different locations with manifolds located on the template. Currently, some 22 FPS installations are operating worldwide involving converted or purposely built semisubmersible drilling rigs.[3] Placid Oil Company's FPS, being installed in the GOM, will be the world's deepest facility in 1,500 feet of water. This unit is designed to support a total of 24 template and satellite wells with the satellite wells located in water depths varying between 1,500 to 2,000 feet. Since other systems become economically unattractive with increased water depths, FPS's are considered to be the choice for future deepwater developments beyond 4,000 feet.

The compliancy of the production platform resolves the problem of resisting large loads due to the action of waves and currents, but complicates the design and operation of marine riser systems. This is the area of most need for future technological developments. The complications arise from the fact that marine risers are a critical and delicate component of a floating production system and must be designed and analyzed with the hull as a unified system. Regardless of the type of platform deployed or riser configuration used, the array of risers has distinctly different physical properties and tension requirements, and the platform will move relative to the various components. Therefore, interference between risers, risers and platform, and risers and mooring lines becomes of paramount importance in the design and operation of floating platforms.

Arctic Technology

The technology for Arctic oil and gas development is still in its infancy, even though great strides have been made since the Prudhoe Bay oil discovery in 1969. The capability to conduct exploration operations in this area has been demonstrated, and the first offshore oil production from the American Arctic, the Endicott Oil Field, has begun. However, year-round operations in other than nearshore areas are still a few years in the future. The industry's technical capability to explore and produce in the Arctic varies with a number of factors, but mainly with water depth.[5] Figure 4 indicates some of the numerous structural concepts that have been used, to date, for exploration. By using water depth as the limiting factor, current and future technological developments are more easily related.

For water depths between 0 to 100 feet, the current technology is adequate for both exploration and production. The basic types of systems used include earth-filled islands, caisson-retained islands, and submersible drilling vessels. Submersible drilling vessels, such as the Concrete Island Drilling System (CIDS), are typical of structures developed for these depths. The same three basic structural types may be used as well for production; however, the design loads will be larger because of the longer expected structural life and the probability of being subject to greater loading events.

The technology for water depths between 100 to 200 feet is less defined and is currently being developed. Two types of drilling concepts are possible for this water depth depending on the ice thickness to be encountered. The first type would be a large conical gravity structure, such as the Arctic Cone Exploratory Structure (ACES), and the second type would be a floating drilling vessel, such as the Gulf Canada's Kulluk.[5] For production, a large fixed structure will be required, but towing it to the site and installation may present a new set of problems.

For depths greater than 200 feet the only currently available technology would be a floating drilling system, and because of large ice forces possible at these depths, this system may not be feasible. If it is possible to use a floating system for exploration, then a subsea production system would be an option for producing the field. The industry is gaining experience with subsea production systems, but a significant amount of work and field use outside the Arctic will be required before deploying such a system in the Beaufort Sea.

Arctic subsea soils present yet another environmental problem for both structures and pipelines. Structures and pipelines that rest on the sea bottom must have a firm foundation, and because of the presence of permafrost in the Arctic, the soils are much more difficult to work with. New technologies are being developed to keep the soil frozen to maintain a firm base for the massive structures necessary to withstand the large ice forces and to protect pipelines required to transport the product from offshore sites to shore facilities by encasing them in a protective frame.

U.S. Arctic Research Commission

Because of the vast potential for mineral recovery in the Arctic Region, the Congress of the United States created the Arctic Research Commission (ARC) under the Arctic Research and Policy Act of 1984. This Act assigned a number of responsibilities to the Commission. These include (1) recommending an Arctic research policy and priorities, (2) cooperating with the Interagency Arctic Research Policy Committee (IARPC) on development of an integrated 5-year plan for Arctic research, (3) recommending ways to improve logistic support of Arctic research, (4) handling of the information and data resulting from Arctic research, and (5) coordinating U.S. Agency programs on Arctic research.[6]

In the 4 years since passage of the Act, considerable progress has been achieved in meeting the Commission's goals. A comprehensive 5-year Arctic research plan has been prepared by the IARPC and steps are currently being taken to implement the plan and the priority research it recommends.[7] By autumn 1988, a document, "Five-Year Implementation Plan," is to be published. This document will further discuss and amplify the recommendations and will describe the efforts of the Government to carry them out. The IARPC Plan consists of three major technical sections. The Atmospheric and Oceans section emphasizes initiatives on sea ice and biological productivity. The Land section focuses on natural resources, engineering challenges, and research to improve understanding of how land environments respond to natural variation and human-induced changes. The section on People relates to their health, economics, and social environment and history.[8]

The IARPC, in consultation with the ARC, has developed and adopted a U.S. Arctic Research Policy, which includes an identification of U.S. interests and a statement of goals to carry out these interests. This research direction was used to put forth the 5-year Arctic research plan, and a matrix of the research priorities are shown in Figure 5.[9] The preparation and publication of the Research Policy and the Plan are only the beginning on an implementation process. The IARPC is conducting meetings on a regular basis to coordinate the research being conducted by Agencies within the U.S. Government, and are encouraging the focus to be placed on the priority subjects.

A dominant theme that has emerged from the Committee's efforts, thus far, is the need for long-term baseline data. While the collection of such data is not generally considered to be research, it forms a needed base for future research efforts and is essential to understanding global change. Stable funding and logistics support is

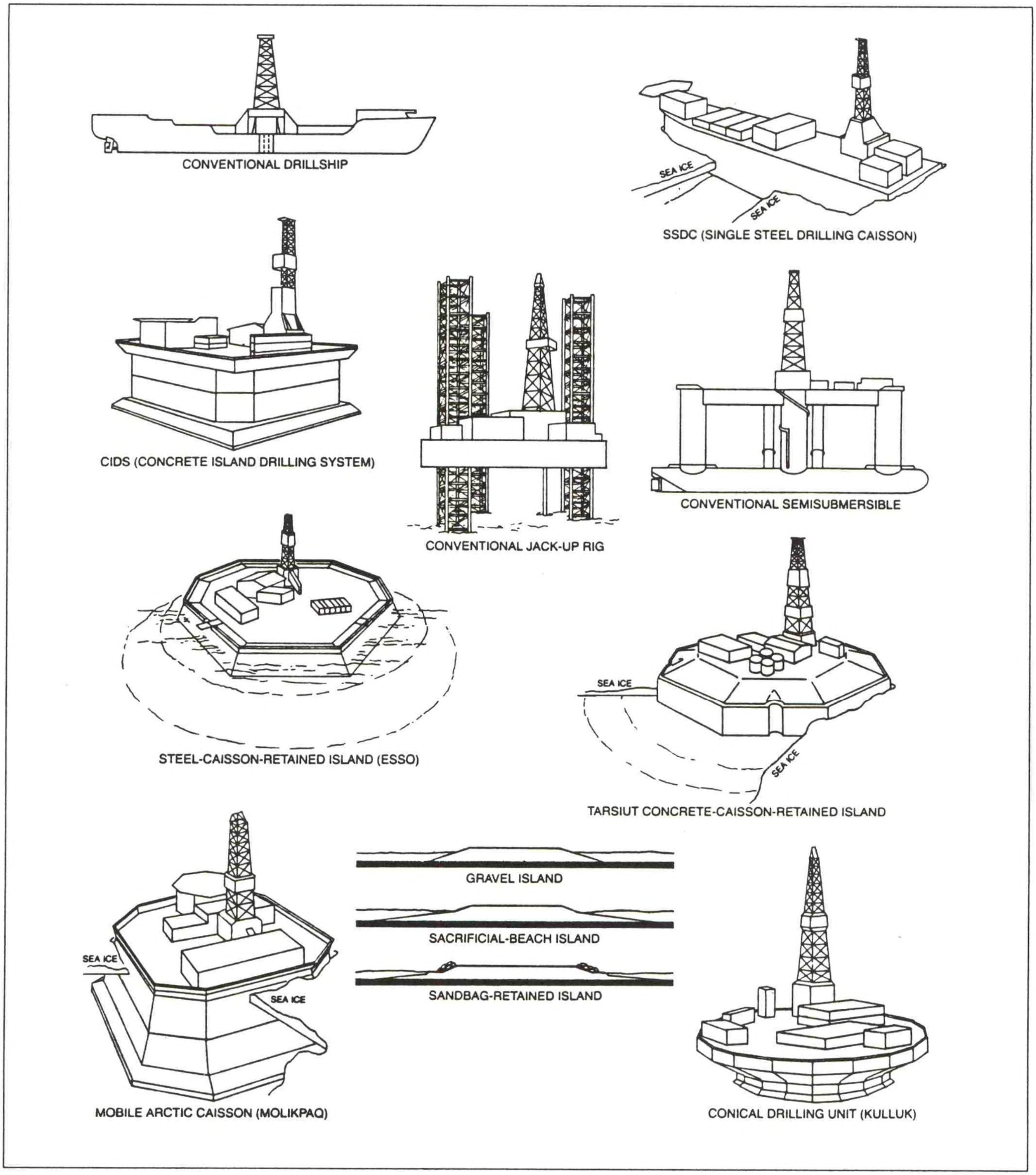

Figure 4. *Offshore exploratory drilling structures used in the Arctic.*

required if these long term data bases are to be acquired and maintained. A workshop on Arctic data requirements necessary to address long-term needs is scheduled for this spring (1988) by the IAPRC.

Earthquake Hazards

The occurrence of earthquakes poses a hazard to offshore facilities unless appropriate engineering countermeasures are employed. To provide an adequate degree of safety at an affordable cost requires a knowledge of the energy properties of earthquakes, the influences of soil conditions on ground motion, and the dynamics of structures that are moved by ground shaking. In verifying the design of platforms that may experience seismically-induced loadings, the Minerals Management Service (MMS) requires that dynamic analyses of the structure be performed using earthquake motions appropriate to the site in question. Joint and member stresses from a "strength level" analysis must remain within allowable limits. The motions can be described by applicable ground motion records or by response spectra consistent with the recurrence period appropriate to the design life of the platform. For design purposes, preferably, site-specific studies are performed to determine the intensity and characteristics of seismic ground motion. Factors considered in the studies include the active faults existing in the region, the type of faulting, the maximum magnitude of earthquake that can be generated by each fault, the regional seismic activity rate, the proximity of the site to the potential source faults, the attenuation of the ground motion between these faults and the platform site, and the soil conditions at the site.

In lieu of a lengthy site-specific determination of the intensity and characteristics of seismic ground motion, the MMS permits the use of defensible standardized spectra applicable to the region of the installation site when such spectra reflect those site-specific conditions affecting frequency content and energy distribution.

When using the "time history" method for structural analysis, the MMS requires that at least three sets of ground motion time histories be used. These may consist of recorded or constructed (synthetic) earthquake time histories. The manner by which they are used must account for the potential sensitivity of the structure's response to variations in the phasing of the ground motion records. Ground motion descriptions are required to consist of three components corresponding to two orthogonal horizontal directions and the vertical direction.

As a second level of verification, some platform designs are required to demonstrate sufficient reserve capacity to prevent collapse, though not local failure, of the

RESEARCH TO ADDRESS NATIONAL ISSUES	NATIONAL ISSUES IN THE ARCTIC											
	ARCTIC AS A NATURAL LABORATORY	NATURAL HAZARDS	NATIONAL DEFENSE	CLIMATE AND WEATHER	ENERGY AND MINERALS	TRANSPORTATION	COMMUNICATIONS	RENEWABLE RESOURCES	POLLUTION	ENVIRONMENTAL PROTECTION	HEALTH AND ADAPTATION	NATIVE CULTURE
UPPER ATMOSPHERE AND NEAR EARTH SPACE PHYSICS	✓		✓				✓					
ATMOSPHERIC SCIENCES	✓	✓		✓					✓			
PHYSICAL AND CHEMICAL OCEANOGRAPHY	✓	✓	✓	✓	✓	✓		✓		✓		
MARINE LIFE SCIENCES	✓			✓	✓			✓	✓	✓		✓
GLACIOLOGY AND HYDROLOGY	✓	✓		✓	✓			✓	✓			
GEOLOGY AND GEOPHYSICS	✓	✓		✓	✓							
PERMAFROST RESEARCH	✓	✓	✓	✓	✓	✓		✓		✓		
ARCTIC ENGINEERING	✓	✓	✓		✓	✓	✓	✓		✓	✓	
TERRESTRIAL AND FRESH-WATER BIOLOGY	✓			✓				✓	✓	✓		✓
MEDICINE AND HUMAN BIOLOGY	✓								✓		✓	✓
SOCIAL AND CULTURAL RESEARCH	✓				✓		✓	✓			✓	✓
ECONOMICS	✓				✓	✓		✓		✓		✓

Figure 5. *Matrix of major research priorities. The tick marks indicate which research fields have high priority in relation to the national issues. They are arranged with the physical sciences on the top and the biological and social sciences at the bottom. This does not imply any order of priority.* (Taken from Reference 8)

platform under a rare, intensive earthquake. One of the most difficult factors to be considered in designing or verifying offshore platforms in an active seismic area is the effect of earthquake loading upon both the structure and the soil. For deepwater facilities, the soils are subject to high hydrostatic pressure, which affects their seismic response. Therefore, data from instruments that record seismic ground motion onshore cannot be used directly for predicting offshore structural responses. However, seismic offshore ground motion records are scarce, and lacking a better alternative, onshore data are often used without consideration of their applicability to the offshore environment.

The MMS has initiated two research projects to better understand the effects of earthquake loading on the dynamic response of an offshore platform. The Seafloor Seismic Data Study project is being conducted by the Sandia National Laboratories to obtain and analyze seafloor earthquake motion data for seismically active areas off southern California. The program is focusing its efforts on the use of the Seafloor Earthquake Measurement System (SEMS) to collect and store seafloor seismic events.

Figure 6 is a diagram of the SEMS concept and illustrates the major subsystems and their interfaces. The Data Gathering System (DAGS) collects data from the Sensor Package, which contains the seismic sensors (accelerometers) and magnetometers. The Command and Recording System (CARS) is a portable shipboard unit that provides the operator interface with DAGS. The CARS records the data sent from DAGS on a digital cassette tape recorder for subsequent analysis. The Buoy Repeater Station (BRES) is a portable acoustic transmitter/receiver station that interfaces CARS with DAGS. The BRES takes commands from CARS and relays them to DAGS. Conversely, BRES receives data from DAGS and transfers them to CARS. All three subsystems are controlled by similar microcomputers.

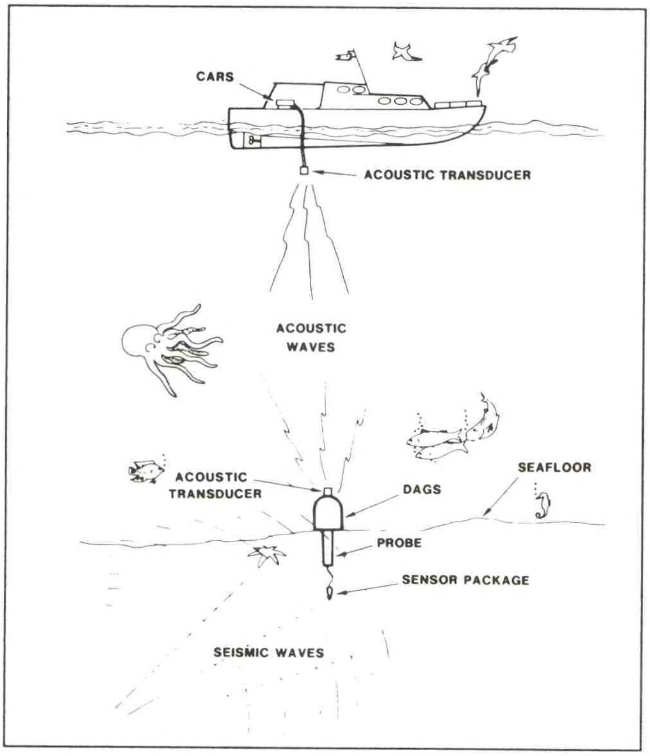

Figure 6. *Subsystems of SEMS concept for obtaining and recording subsea seismic events.*

As an adjunct study, a project entitled "Seismic Response Analysis of Offshore Pile Supported Structures" is being conducted by the University of California, San Diego, to assess the reliability of current state-of-the-art computational pile/soil interaction models used to predict the amount of energy transmitted to a platform. Seismic accelerograms will be obtained from SEMS units located on the seafloor and from onboard adjacent instrumented platforms. Data that Tokai University recently obtained from an instrumented structure offshore Japan will also be used in the study. It is hoped that these studies can attest to using the ability of present day standards to accurately predict platform responses and, if necessary, to propose changes to the standard to make them more reliable.

CONCLUSION

This paper has highlighted the major technologies that have been or are currently being developed to open the deep ocean and Arctic to offshore oil and gas operations. It has not been possible to present a complete account of all the technologies, such as subsea production systems, well control procedures, or oil spill and containment procedures that must supplement platform developments in order to proceed in a reliable manner; however, developments are progressing in these areas as well. Industry has historically demonstrated the ability to develop required technologies to meet the needs arising from a need to move into new areas of resources. Because of the extensive research being conducted by both Government and industry and the continual accumulation of frontier area experience, the future holds much promise for the development of these areas.

REFERENCES

[1] Offshore Rig Newsletter: Vol. 15, No. 2, Offshore Data Services, Houston, Texas, February 1988.

[2] Tubb, M., "Gulf of Mexico: Recovering from a Year of Inactivity," Ocean Industry, October 1987.

[3] Langewis, C., "The Gulf of Mexico--Newest Proving Ground for Deepwater Technology," Ocean Industry, May 1987.

[4] "Resurgence Seen for Gulf of Mexico," Petroleum Engineer International, February 1988.

[5] Utt, M. E., "Sea Ice Forces and the State of Technology of Offshore Arctic Platforms," Journal of Petroleum Technology, January 1985.

[6] The United States: An Arctic Nation, Report of the U.S. Arctic Research Commission to the President and Congress of the United States of America, U.S. Arctic Research Commission, National Science Foundation, Washington, D.C., January 31, 1987.

[7] United States Arctic Research Plan, Report prepared by Interagency Arctic Research Policy Committee, Washington, D.C., July 1987.

[8] Arctic Research of the United States, Vol. 1, Interagency Arctic Research Policy Committee, National Science Foundation, Washington, D.C., Fall 1987.

[9] National Issues and Research Priorities in the Arctic, Polar Research Board, National Research Council, Washington, D.C., July 1985.

Strength Evaluations of TLP Tendons

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1. Introduction

The tension leg platform (TLP) is one of the most practical concepts for petroleum production strtuctures in deep sea fields. The floating platform is anchored by vertical legs (tendons or tethers) which suppress heave, pitch and roll motions of the platform.

In the design stage of the TLP, it is important to confirm the structural integrity of the tendons, because they are responsible for the safety of a whole system of the TLP. Since the tendons are subjected to high stresses due to the pre-tension and pulsating stresses due to the motion of the hull, a carefull consideration on the strength of the tendon must be taken.

Many studies have been performed on the strength of the tendons, especially on the fatigue strength. Sakaguchi et al.[1] studied the fatigue life of the prototype TLP in South China Sea considering the axial stresses on tendons. Nordgren[2] treated the high frequency vibration probrem and pointed out that fatigue problem arises from high frequency resonance of the TLP in heave, pitch and roll modes of motions. Kitami et al[3] undertook the analysis of the TLP with the mechanical damping system comparing with tank tests, and conclude that the linearized theory is applicable to the fatigue life estimation of the tendons.

There are many sorts of stresses acting on the tendons, such as tensile stresses due to the hull motion having the same frequency as waves, tensile stresses due to the slow drift or setdown, stresses due to the resonanse response and bending stresses.

The stresses due to the hull motion are focused on in this study assuming that the linearised theory is applicable for the estimation of the fatigue strength. This paper describes the preliminaly study on the strength of the tendons which includes following items.

1) Tank tests to verify the varidity of the calculation.
2) Stress analysis on the connectors of the tendon.
3) Fatigue test results of the tendon materials.

2. Tendon Behavior in Regular Wave

2.1. Experimental Study

To verify the tendon response characteristics of a TLP in waves, the experiments were carried out in the ship model basin of NKK in Tsu, JAPAN. The basin is 240 m long, 18 m wide, and 8 m deep. The assumed full scale water depth is 543 m, and the scale ratio of the model is 1/67.9. Table 1 shows the principal dimensions of the prototype TLP and the model.

Table 1 Principal dimensions of TLP

Item		Actual TLP	Model TLP
Scale Ratio		1	1/67.9
Deck Size (Length x Breadth m)		89.0 x 89.0	1.311 x 1.311
Column Height	(m)	58.1	0.918
Column Dia.	(m)	22.4Φ x 4 sets	0.33Φ x 4 sets
Pontoon Dia.	(m)	13.0Φ	0.192Φ
Draft	(m)	34.7	0.511
Displacement	(ton)	80,000	0.256
Water Depth	(m)	543.2	8.0
Tendon	(mm)	1016Φ x 33t x 16sets(X-70) Steel make	30Φ x 1.4t x 4 sets Polycarbonate make

Although the prototype is a 4-column TLP with four tendons in each corner, the model was made to have hydrodynamicaly equivalent one tendon for each corner. The displacement was approximately 80,000 tons, and the total pre-tension was about 20,000 tons in full scale respectively. An outline of the experimental setup is shown in Fig.1.

The model was instrumented for measurements of 6 degrees of freedom motion and the tensile force of the tendon. The motions were measured at the center of the platform deck, and the tensile force at the attachment points. The specially prepared tendon model made of polycarbonate pipe was used to simulate a hydrodynamic force affected mooring member. Behavior of tendons in water was observed by an under water TV camera.

Tests were conducted in both regular and irregular waves with the variation of wave headings. To examine the non-linear properties, regular wave tests were repeated with different wave heights.

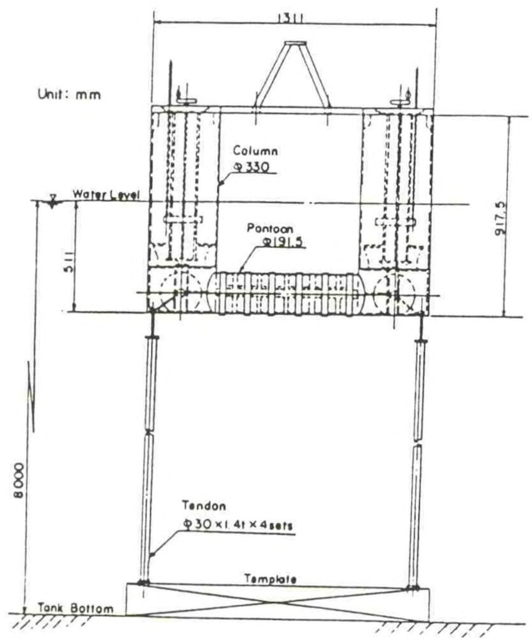


Fig. 1 Experimental Setup

2.2 Theoretical Study

The relevant features of the theoretical prediction method used in this study are as follows.

1) 3-dimensional potential theory was employed to calculate first order wave forces and responses.
2) Restoring characteristics of the tendons were approximated as linear springs.

The surface of the TLP was shaped by about 400 facets. The subdivision of the TLP surface is shown in Fig.2.

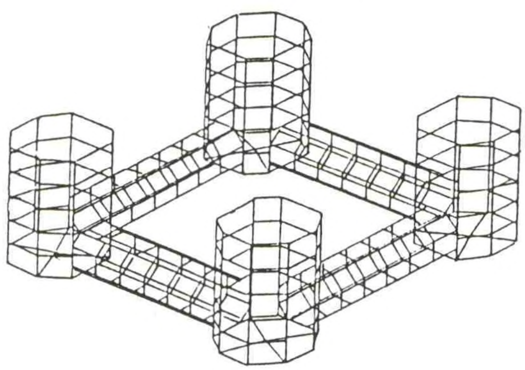


Fig. 2 Facets subdivision of TLP

2.3 Comparison Between Theoretical and Experimental Results

Comparison between calculated and measured linear transfer functions are carried out for motions and tensile forces of the tendons. Although the behavior of the tendons in waves shows strong non-linear characteristics, only the linear characteristics is discussed in this paper. Non-linear properties will be reported in a separate paper. Among a huge number of the experimental data, the response amplitude operator (RAO) of tendon forces in 45 degrees heading are given in Fig.3. In this figure, the abscissa gives non-dimensional wave length compared to the column spacing. The calculated results give good correlation to the experiments.

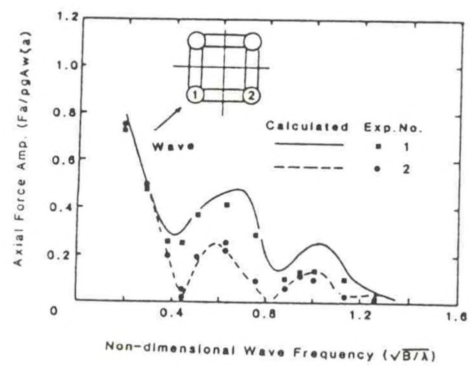


Fig. 3 R.A.O. of Tensile Force of Tendon in 45 deg. Heading

Figure 3 shows that the linear calculation gives sufficient prediction of tendon characteristics.

By using the aforementioned calculation program, the directional variation of the tendon tension RAO was surveied. The results of the calculation for aft starbord tendon is shown in Fig.4. Both calculation and experiment show that the hind tendon were exposed to the severest variations.

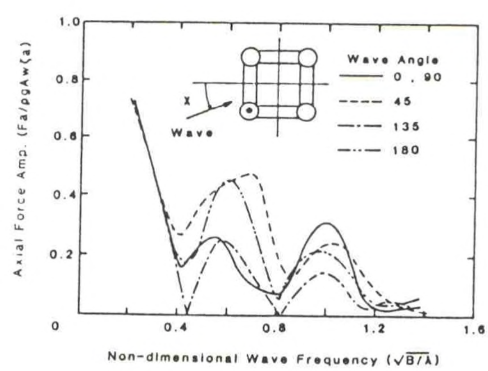


Fig. 4 Directional Variation of R.A.O. of Tendon Tensile Force

2.4 Long-term Stress Distribution

There are several mthods to estimate the long-term stress distribution on tendons. Since the stress response of tendons may have some non-linearities, it is better to adopt the method using the nonlinear analysis in the time domain. The use of the method, however, makes the problem complicated, then the linear method is adopted in this paper.

The short-term prediction is performed by using a spectrum analysis. The modified Pierson-Moskowitze type (ISSC) spectrum is used here. Using the wave spectrum and the R.A.O. shown in Fig. 3, the response spectrum can be calculated. Assuming that the probability distribution of the tendon stress is Rayleigh distribution, the short-term prediction can be performed. The long-term statistical distribution of the response is calculated by using the wave scatter daigram of South China Sea as an example. The results are shown in Fig.5. The ordinate expresses the tensile force amplitude of tendons devided by quasi-static variable buoyancy per 1m wave amplitude for each tendon. The abscissa shows the probability of exceedance.

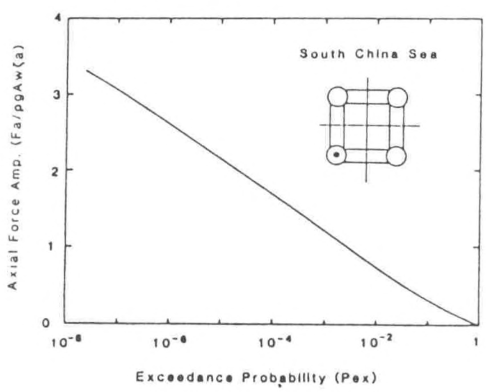


Fig. 5 Long-term Distribution of Tensile Force Amplitude of Tendons

3. Strength of Tendon Connector

3.1 Stress Analysis of Tendon Connector

Two different procedures are generally used to connect the pipes. One is the threaded joint, and the other is the butt welding. In this section, the stress analysis of the threaded joints is presented.

The finite element analyses are performed to the tendon connector in order to evaluate the strength and the effectiveness of the internal and external shoulder seals. One of NKK's structural analysis systems THANKS is used for FEM analyses. THANKS is based on ADINA[4]. To simulate the contact and friction phenomena, the contact element based on a penarty method is developed and implemented into THANKS[5].

Figure 6 shows the mesh subdivision of the newly developed tendon connector. The nominal diameter of tendon pipes is 28 in. Figure 7 shows the fine meshes at the threaded parts. The contact and friction elements are located at the contact region of the threads and both shoulder parts. The elements used in the analyses are isoparametric axisymmetric elements. In the analyses, Coulomb's frictional coefficient is assumed as 0.018. Load conditions described are the make up, TN25, TN50, TN75 and EP. TN25, TN50 and TN75 mean the load conditions of 25%, 50% and 75% yeild stress tensile load of a pipe body, respectively. EP is the external water pressure equivalent to 600m water depth.

Table 2 shows the stress amplitude ratio(S.R.A.) of the connector excluding the threaded parts. The maximum S.R.A. is observed at points 2 and 8 and the value is 1.148. In the

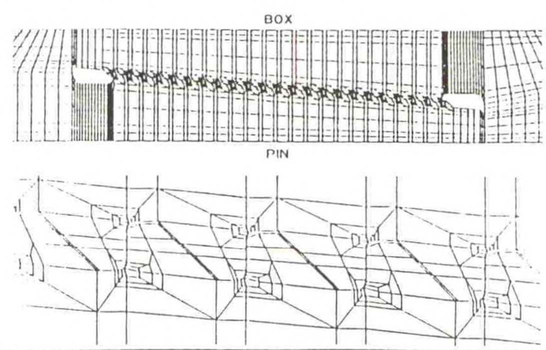


Fig.7 Mesh Subdivision of Threaded Parts

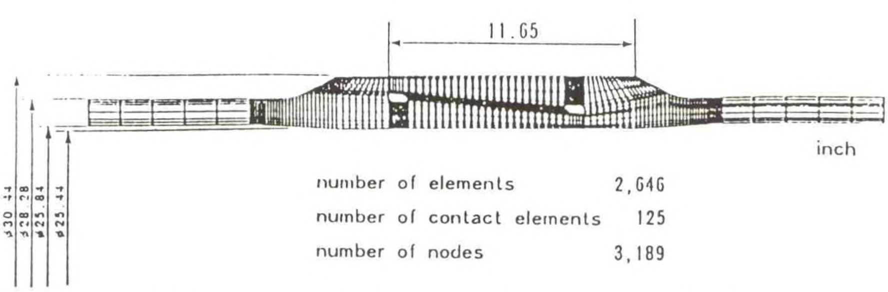
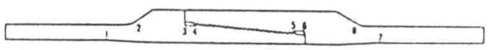


Fig.6 Mesh Subdivision of Tendon Connectors

threaded parts, the maximum S.R.A. is occured at the box end and the value is 1.10. Figure 8 shows the contact pressure distributions at both shoulder seals in various load conditions. The pressure decrease under tensile loads. However the pressures are sequred under TN75+EP condition which is the most strenuous condition.

Table 2 Stress Amplitude Ratio at the Connector



point / constant load	1	2	3	4	5	6	7	8
TN25	0.718	1.145	0.535	0.721	0.664	0.721	0.721	1.148
TN25+EP	0.727	1.131	0.596	0.764	0.661	0.753	0.722	1.147

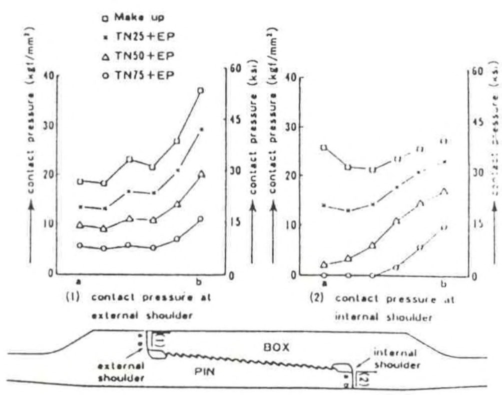


Fig.8 Contact Pressure Distributions

3.2 Results of Fatigue Tests

In order to find out the fatigue performance of the pipe materials, fatigue experiments are performed by using various types of specimens.

API X-70 is selected for the tendon material here. Test specimens are cut from the UOE pipes whose diameter is 711.2mm and thickness is 23.8mm. The specimens are as follows: 1) Hour glass type specimens from the base metal, 2) Hour glass type specimens form girth welding parts, 3) Round bar type specimens with a circular notch from the base metal whose Kt(stress concentration factor) is 1.5 or 3.0 and 4) As-welded butt joints by SAW.

The second and the fourth specimens are included in this study to confirm the applicability of the butt welded joints for tendon joints instead of the threaded connectors.

The results of fatigue tests are shown in Fig.9. No significant difference exists among two hour glass specimens. It is confirmed that the

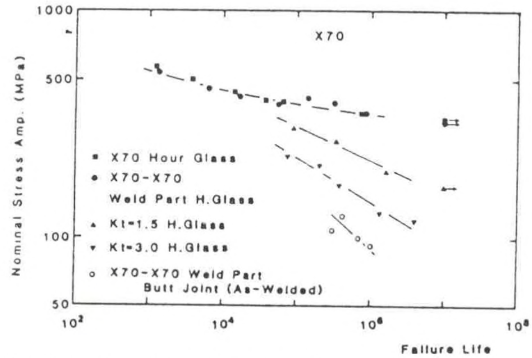


Fig.9 Fatigue Test Results of X-70

welding joints are applicable to the tendon joints. On the other hand, the strength of as-welded butt joints is lower than the specimen of Kt=3. These results suggest that it is effective to dress or finish the weld bead.

4. Conclusions

In order to evaluate the strength of TLP tendons, the tendon behaviors in regular waves, the stress analyses of tendon connectors and the fatigue strength of the pipe materials were discussed. The following conclusions are reached.

1) According to the comparison of the model test results with calculated results of the linear theory, the linear theory is applicable for the estimation of the long-term stress distribution of tendons.
2) Stress analyses of newly developed connectors of tendons were carried out using contact elements. It is confirmed that the connector has a sufficient strength reliability.
3) According to the fatigue tests results, the butt welded joints are applicable to the tendon joints instead of threaded connectors.

REFERENCES

1] Sakaguchi, I. et al.:"Dynamic Response and Fatigue Life Prediction of TLP tension legs", OMAE, 1986.
2] Nordgren, R. P.:"Analysis of Dampers for Fatigue Reduction in Tension Legs" OMAE, 1987.
3] Kitami, E. et al.:"Response Characteristics of Tension Leg Platform with Mechanical Damping System in Waves", OTC, 1982.
4] Bathe, K. J. :"Static and Dynamic Geometric and Material Nonlinear Analysis using ADINA", MIT Report, 1977.
5] Sato T. et al. :"Finite Element Analysis and Fatigue Evaluation of the Threaded Marine Riser Connector", ESTC, 1988.

OCEAN MINING: STATUS AND FUTURE ACTIVITIES
Including a Brief Review of Deep Ocean Mineral Resources and Placer Mining in US Federal and State Waters

Clifford E. McLain, President, Oregon Resource Exploration, Inc.

Introduction

Ocean mining has been an area of developmental interest within the US over the past 30 years. With the discovery of the manganese nodules on the deep ocean floor, and the subsequent formation of several consortia for the exploration and development of these mineral deposits in the 1960's and early 70's, interest in the practical economic potential of ocean minerals assets has remained in a prominent position in the ocean policy of the US. Under the Carter Administration, this interest among others motivated the US to work closely with the Law of the Sea Treaty organization. Under the first years of the Reagan administration, this same interest was one of the key reasons cited by the US in refraining from becoming a signatory to the actual Treaty and for the later declaration by the US of its own Exclusive Economic Zone, in March of 1984.

However, the world hard metals markets has been a depressing factor on the development of new hard minerals prospects throughout the world, and particularly on seabed hard mineral deposits, both known and potential. In the current US national and world situation, the idea still appears bright and promising, but the reality is that few practical immediate opportunities exist for the development of actual operating undersea mines at this time. The number of opportunities is not zero, however. This paper is an attempt to review these opportunities, and the state of technology and policy of concern to their immediate development within the US. The views are entirely those of the author, and are the result of his work, and that of his associates, in the attempt to establish working ocean mining operations over the past several years.

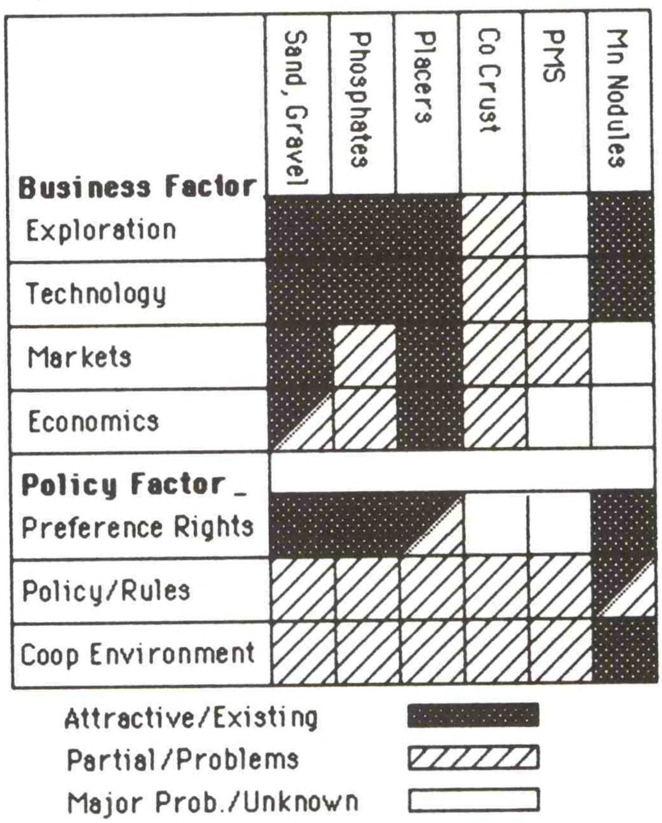
Status of Ocean Mining in the US

There are currently six active or potential ocean mining areas of interest to the US economy at the present time:

- o Sand and Gravel
- o Metal ore bearing placers
- o Phosphates
- o Cobalt rich crusts
- o Polymetallic sulfides (hydrothermal)
- o Manganese Nodules

The first three in the list are essentially shallow water deposits and as may be expected these are the areas in which some economically practical business now exist. The last three areas are still either in the exploration phase, or are awaiting a more suitable economic environment, or both. This situation is briefly summarized in Figure 1, which is adapted from a recent paper by Mr. James Wenzel[1] an associate of the writer.

Figure 1: Ocean Hard Minerals Devel. & Policy



Referring to Table 1, it is suggested that in the case of the three shallow water mineral areas, the exploration of known deposits is within the capabilities of technology, and is completed or able to be well defined for deposits suspected but not yet characterized. The technology for recovery is well in hand. Markets for these minerals are in most cases attractive. In some cases, the US phosphates may not compete with those of other areas. The placer minerals of ilmenite, chromite, and precious metals and gemstones, all have a reasonable economic value, as to most sand and gravel deposits, and some phosphates, depending upon transport and local markets.

In a policy sense, most of these shallow water minerals are supported by a working set of development regulation and policy within the US and State waters (in the US jurisdiction, the States control the seacoast waters out to three miles from land). Preference rights or development claims can be obtained for each of these areas through lease payments to the appropriate jurisdiction. In a recent case, which will be referenced as an example in the latter portion of this paper, a new policy has been developed granting right of preference at the State level during the exploration phase. However, in most cases, the development of the shallow water deposits do have problems, both environmental and in policy, and are faced with the need to generate a situation of "cooperative environment" within the operating area of the proposed development before it can proceed. Basically, the shallow water resources have been and will continue to be developed by the private sector, as a practical and economically rewarding business area.

In the deep ocean area, there are more problems, and much less likelihood of near term economic development, even though some of these resources may be vast in extent and may hold valuable minerals even in todays rather poor market in the base metals. Referring again to Table 1, the manganese nodules have themselves been rather thoroughly explored and characterized as a deposit and the technology for their recovery has received heave support in the past. Demonstration units have been build and tested. Interestingly enough, under the US Deep Seabed Hard Minerals Act, the preference rights have been well established for this particular mineral deposit in US law. Policy and rules for the most part tend to favor development and a reasonably cooperative policy and viewpoint exists for the development of this resource within the US. Unfortunately, the world economic market is such as to preclude any practical investment in the development of the nodules[2].

The cobalt rich crusts, which have been of great interest in the Pacific, and which are well represented within the US EEZ areas of the Central and Northern Pacific (around Hawaii, for example), have recently received a significant amount of exploration and are moderately well characterized. The technology for their efficient extraction has not yet been developed, although the general techniques for their recovery and processing are understood[3]. World markets for the principal metals, and the economics of their recovery, even for the valuable cobalt content, do not now appear to be such as to encourage private investment. In addition, no suitable basis for preference or claim rights has been developed in the US. Although signatories of the Law of the Sea Treaty would have an operating basis for development, the provisions of the Treaty for deep seabed mining, which were one of the major reasons the US did not sign, are not such as to encourage investment.

The relatively recent polymetallic sulfide deep ocean hydrothermal deposits have attracted renewed interest in deep ocean mining, because of the relatively high concentration of metals such as copper, tin, silver, and zinc. These deposit discoveries are a by-product of the exploration of the great spreading zones of the sea floor of the past 10 years. Only the first stages of exploration have been completed. New technology is required even for the exploration itself, as well as for any potential recovery operations. The economic practicality of these deposits is as yet largely unassessed, since the recovery costs have not yet been determined, nor can they be until these deposits are more fully characterized. As in the case of the cobalt rich crusts, there is no adequate basis for an assertion of claim within US law.

In summary, in the area of deep ocean deposits, There may be expected to be a continuation of research and exploration within the US EEZ areas in which the cobalt rich crusts and the hydrothermal polymetallic sulfide deposits are found. There will probably be little additional US government sponsored work on the manganese nodule deposits, but it should be noted that in 1986, NOAA did issue exploration licenses for the Clipperton fracture zone area in the Pacific to commercial interests, indicative of come continued interest in this form of deposit. Considering all of the possible technical and policy development which is still required, and the possible market conditions over the next ten years, the writer suggests that of the three types of deep ocean deposit, the cobalt crusts are perhaps the most likely to see commercial development first.

The picture in the shallow, coastal waters, is quite different. There are, and have been, profitable commercial enterprises operating on these types of minerals, and this type of development will continue, but increasingly under a more careful and often more demanding level of control by State and US Federal agencies. The deep ocean deposits are not in any case found within the current US State coastal waters jurisdiction. However, the shallow water deposits are found in both State and Federal waters and the jurisdictions are often overlapping. The resolution of State and Federal conflicts represents one of the more difficult features of commercial development. Another factor is the increasing awareness of "other coastal ocean users" of the impact of near shore ocean hard minerals development. Nevertheless, over the next ten years, this is where the action is and where it will continue to be.

Incentives for Coastal Ocean Hard Mineral Development

Within the US, there has been a continuing search by the ocean hard minerals community, for an appropriate way to encourage private sector participation in the exploration and development of promising mineral resources on the ocean floor. The current and seemingly chronic US trade deficit argues for the development of more exportable resources. In addition, with a tightening Federal budget in order to reduce debt, the individual States are feeling the pinch in terms of fewer Federal dollars to support State and local needs. Since most of the shallow water ocean mineral assets of the US lie at least partially within State territorial waters, the coastal States can look upon the development of these assets as a valuable additional source of income. Finally, many coastal regions around the US have only a narrow economic basis, and would benefit from the development of an additional industry.

Against these incentives, however, lie another set of problems which appear to be common to all coastal developments, and that is the perceived risks to the environment and what might be termed the "lifestyle" of the coastal community. In many coastal areas of the US, any development at all, mineral development, new housing (especially condominiums it seems), highly developed resort facilities, shore based industry, expanded port facilities, and jetties and breakwaters, are all seen as encroachments on the current status of the coastal region. In many cases within the US, this has led to a confrontation of interests which is often resolved in the courts, at least temporarily, in the form of an injunction against continuation of the project, until studies can be made and the claims and concerns of other concerned ocean users resolved, often in the context of the judicial system. This very real risk to the investment and plans of the developer is often a very effective deterrent to project initiation, especially where the risks are high (mineral development, expanded ports, new industry).

As a result, a new approach is being sought, wherein the US coastal States and their local governments are now entering into the development of comprehensive planning for the well thought out and integrated use of coastal ocean assets, since under State and Federal jurisdiction, they do belong to all. Along the Pacific coast, the bordering States are now all engaged in such planning efforts. These activities were pioneered by the Gorda Ridge Task Force, formed in 1985 at the request of the concerned States at the behest of the US Department of the Interior, and the Oregon Governors Special Task Force for the creation of an integrated Ocean Resources Management

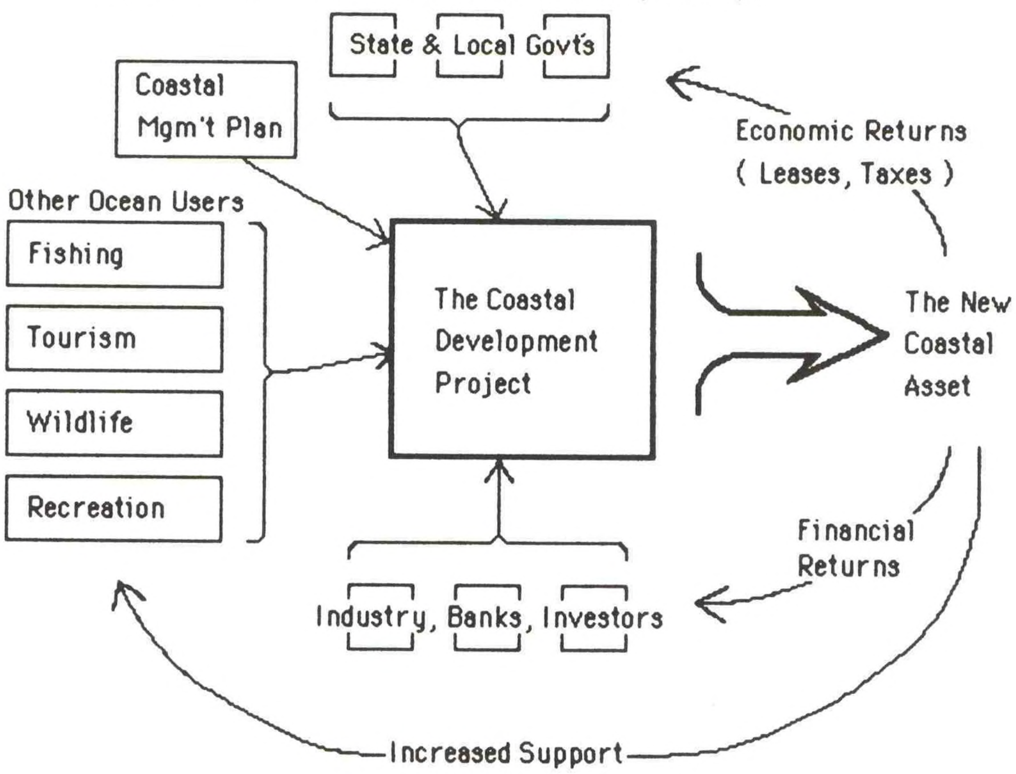
Plan, which was established in 1987 by Governor Goldschmidt. Although in many cases these planning efforts have been established as a means of protection against untoward development, in the case of the more recent efforts, including the Oregon project, have been established with the intent of developing an environment for the intelligent use of these coastal assets to realize their maximum benefit for all coastal ocean user interests through a balancing of risk, investment, and economic value.

This approach has been derived from the concept of a partnership between the State, local, and (where appropriate) Federal governments, the private sector development or industrial interests, and the ocean user communities (which include tourists, those with environmental interests, fishing interests, and retirees living along the coast but not a part of the coastal working community). The concept, which has been encouraged under the policies of the current US administration and the US Department of Commerce[4], is suggested in Figure 2.

As suggested by this figure, under the aegis of a comprehensive coastal management plan, and the interested support of industry, investors, and the banking community, a coastal development project is formulated, with the overall State and local government social and economic development objectives (recognized in the management plan) in view. The other ocean users are coupled into the project through such means as advisory councils, informal planning sessions, and when appropriate as actual participants in the project itself. It is important that delegates of these other ocean users will have participated in the writing of the management plan itself.

This team then works together to develop and execute the coastal development project. If the private sector provides the funding, the project must necessarily be designed to provide an adequate return on investment to justify the risk undertaken by the private sector investors. Joint funding, or sometimes sole funding, may also be provided by the Sate, local, and Federal governments. Wherever it is possible, it is highly desirable to involve the State and local intellectual assets in the form of

Figure 2: The Public-Private Partnership Concept



participating colleges and universities. These can be sources of needed technical support and also provide a highly trustworthy source of balanced risk/benefit analysis, which will be an important element in assuring the other ocean users that their interests will not be unduly injured, or put at risk, through the new coastal assets which is the objective of the development project. The special studies of impact on wildlife, the flora and Fauna of the affected region, can often be most convincingly done by these academic institutions, and by such State agencies as the fish and wildlife service, the environmental protection and land conservation agencies, and interested technical and environmental research organizations.

The "bottom line" point of the partnership approach to coastal project development is that of recognizing the complex nature of the ownership of coastal assets, and the need to provide an effective means of incorporating the perceived interests and needs of this ownership as an integral part of the developmental project. The principal benefit of this approach is to assure the maximum likelihood of success in the context of the varied interests of those perceiving that they hold a stake in the outcome of the project. In a very real sense, from the private sector standpoint, this approach is needed to assure the existence of a cooperative environment in which the investment in the new asset is to be made.

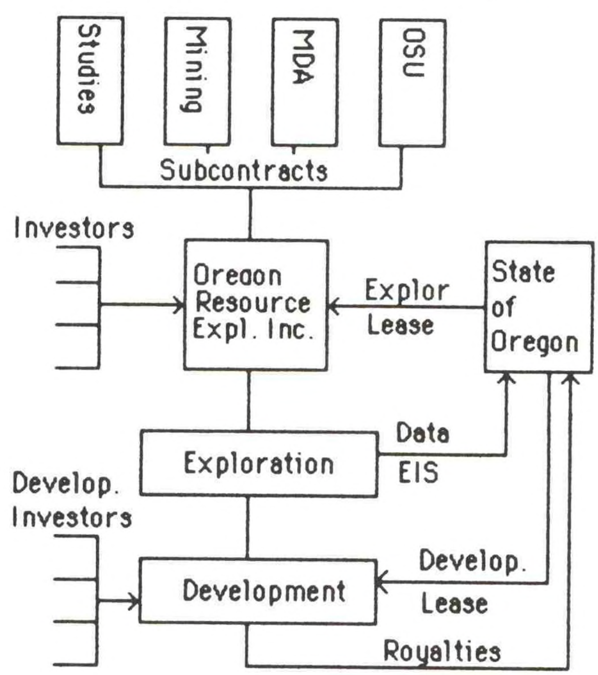
The Oregon Black Sand Placer Project as an Example Partnership

Development of placers along the Pacific coast of the US has so far been limited to gold and platinum group metal (PGM) placers, primarily in Alaska. Coastal placer tracts in the Nome area, for example, are currently being worked by chain bucket dredges, with some economic success. The presence of gold in the black sands associated with the northernmost California coast, and the southern third of the Oregon coast has been known for a long time. Gold Beach, Oregon got its name from the early gold placer operations in the late 1800's there. These sands also contain important amounts of chromite and ilmenite (titanium). During World War II, the deposits on land (beach placers now above sea level due to local uplifting) were mined successfully for chromite. This mining continued until the early 1950's when the US subsidized purchases for the upkeep of the strategic stockpile were terminated. The limited extent of the land deposit, and the lower price of chromite ore on the world market did not support continuation.

These potential assets have been the subject of extensive surface (halo) exploration by the Oregon State University (OSU) School of Oceanography over the past 25 years. A body of knowledge has been built up which now permits the definition of a detailed plan to explore and fully characterize the deposits in such as way as to allow a determination of the economic feasibility of their development. The general disposition of these deposits as derived from research to date is shown in Figure 4, the result of OSU work over the past several years[5].

Working with the State of Oregon over the past six years, the writer and his associates have been developing a plan (Figure 3) for the cooperative establishment of a project to fully explore and characterize these deposits.

Figure 3: Oregon Black Sands Development



Referring to Figure 3, a joint venture has been established, named Oregon Resource Development, Inc. in this example, to serve as an Oregon corporation in which to receive the private sector investment. This joint venture subcontracts with various organizations in order to carry out its work, initially exploration and associated studies. Among these subcontracts is one with OSU, to perform major exploration activities needed to characterize the deposits as potential mine sites. The joint venture operates under a cooperative exploration lease, which, under a new Oregon law, provides for a right of preference in converting the exploration lease to a developmental lease, to the leasee. In return, as a partner, the State receives data from the exploration upon which to base its development decision. The exploration project also yields data relevant to the preparation of an environmental impact statement (EIS) in support of the proposed development.

Upon the determination that an economic deposit is, in fact, in place, to which, under the terms of the exploration lease the joint venture and its owners have rights of preference for development (akin to staking a mining claim), and upon the further determination that the plans and techniques for such development will not have an undue impact upon other coastal ocean users, the State is empowered to grant a development license to the joint venture. In turn, the joint venture, under the terms of the development lease, can proceed with the development itself, sublicense the development to a mining operator, or sell the development lease, as a means of achieving an early return for its exploration investors. Upon commencement of the actual mining operation, the State receives royalties (as well as taxes) upon its operations. Assistance to the programs of other ocean users affected by or partners with the project, can also be derived from the mining returns. All of these factors, of course, have to be considered in determining the overall economic feasibility of opening and operating the mine, once a suitable deposit has been located and characterized. This is the principal objective of the exploration program.

At this time, the joint venture has been established, the appropriate authorities have been established by Oregon, its comprehensive coastal resources management plan is under development by a special Governor's task force, with a schedule for completion which provides that it will be in place in time to be used as a reference in any development decision arising from the black sands exploration results. So far, the process has been working well, and excellent open relationships have been established between the project and other concerned ocean user groups. The writer and his associates believe that this approach will be an increasingly important one for all major coastal development projects, of which the Oregon black sands exploration and development is but one example.

References:

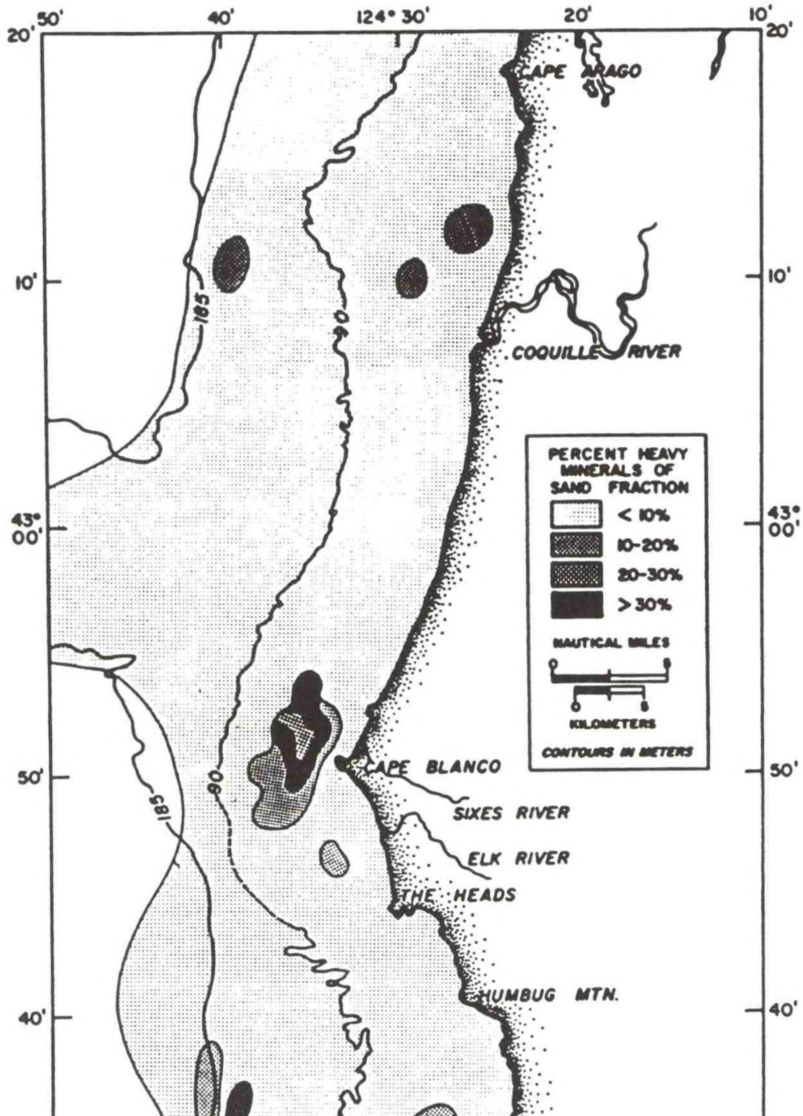
1. J. Wenzel, "Ocean Mining Industries", Marine Development Associates, Saratoga CA, March 15, 1988

2. J. D. Nyhart, "A Pioneer Deep Ocean Mining Venture", Massachusetts Institute of Technology Sea Grant Program Report MITSG 83-14, June 1983

3. "Mining Development Scenario for Cobalt-Rich Crusts in the Exclusive Economic Zones of the Hawaiian Archipelago and Johnston Island" Dept. of Planning and Economic Development, State of Hawaii and US Dept of The Interior, Mineral Management Service, January 1987

4. C. McLain, "A Strategy for the Creation of Public-Private Partnerships for Candidate NOAA Projects" System Planning Corp. Report No.1083, May 1985

5. LaVern D. Kulm, "Potential Heavy Mineral and Metal Placers on the Southern Oregon Continental Shelf", College of Oceanography, Oregon State University, paper for publication in Marine Mining, 10 Feb. 1988



CAPE ARAGO
COQUILLE RIVER
PERCENT HEAVY MINERALS OF SAND FRACTION
< 10%
10-20%
20-30%
> 30%
NAUTICAL MILES
KILOMETERS
CONTOURS IN METERS
CAPE BLANCO
SIXES RIVER
ELK RIVER
THE HEADS
HUMBUG MTN.
ROGUE RIVER
CAPE SEBASTIAN
CROOK POINT
185
90
124° 30'
43° 00'
42° 10'
50'
40'
30'
20'
10'

Figure 4.

Advances in Marine Geophysical Exploration for Sub-Bottom Resources - The MULTIPULSE® System

by Carl H. Savit

Introduction

In exploration of water-covered areas for hydrocarbon resources deep beneath the bottom and prior to drilling the commonly used method is reflection seismology. In reflection seismology, the practice has been to tow a device that periodically emits a loud sound, usually by the sudden release of compressed air, a few meters beneath the surface of the water and to listen for echoes from deep beneath the bottom by means of hundreds of sensitive instruments deployed for several thousand meters behind the towing vessel. The sounds are recorded on digital tape on the ship. On shore the tapes are converted by powerful computers to the equivalent of cross sections of the earth to a depth of 10 km or more.

On land, the equivalent process is, in most cases, carried out by transmitting continuous sound waves into the earth instead of an impulsive sound. At sea however, there have been constraints that have made the use of continuous sounds impractical.

To make a continuous underwater sound, attempts were made to vibrate one or more submerged surfaces in response to a control signal. In such an operation there is an inherent limitation on the radiated acoustic power that can be transmitted into the water per unit area of radiating surface. That limitation is set by the inability of the water to maintain contact with the radiating surface if that surface is withdrawn too rapidly, the phenomenon of cavitation. To equal the acoustic output of the customary compressed-air sources with conventional continuous, sinusoidal sources, the area of the radiating surfaces would have had to be inordinately large. In this paper, we shall present a continuous marine sound source that overcomes a good part of the cavitation limitation while being particularly efficient at converting input power to radiated acoustic power.

Nature of the Signal

In the land case and in previous attempts to emit continuous signals at sea, the signals have been swept-frequency sinusoids, that is, sine waves whose frequency varies smoothly over about 3 to 4 octaves. In the case of the MULTIPULSE® acoustic source, however, the signal is a carefully designed sequence of square waves whose power spectrum is nearly identical to that of a swept frequency sinusoid. The phase spectra are, of course, radically different.

In conventional, continuous, acoustic signals, the average amplitudes of the signals above and below the neutral values are equal. In MULTIPULSE signals, however, the positive amplitudes are twice the negative ones. The required zero mean for the signal is achieved by allowing the negative values to persist twice as long as the positive ones.

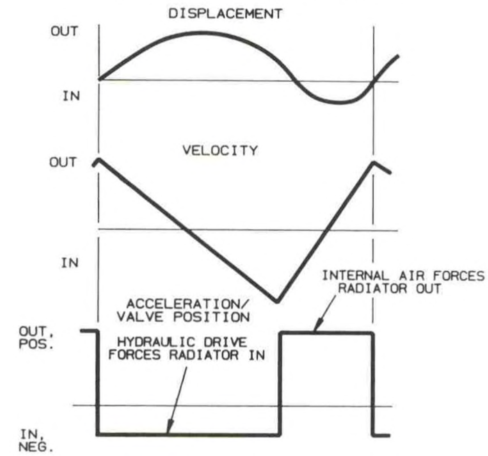


Fig. 1 Hydraulic pressure input to the MULTIPULSE unit is proportional to the acceleration of the radiating surfaces and to the radiated acoustic pressure. We adopt the convention that an acceleration into the ambient water is positive even though the corresponding hydraulic pressure is the lower of the working pressures of the system. The horizontal axis represents time.

Translated into the mechanics of the source, this means that the radiating surfaces push against the water twice as hard and half as long as they pull back from the water. This one factor alone produces a two-to-one advantage over symmetrical signals, in radiated acoustic power per unit area, before the cavitation limit is reached.

A further two-to-one advantage stems from the use of square waves rather than sine waves. This advantage is realized because the integral of the square of a sine wave is one-half that of the square wave with the same amplitude and zero-crossings. The net result is that, because of the form of the signal itself, for a given area of radiating surface, the MULTIPULSE source emits four times the acoustic power that could be expected from the older sources.

Mechanical Implementation

The fundamental unit of the present version of the MULTIPULSE source consists of a pair of opposed radiating plates 66 cm in diameter. Two such units in a parallel arrangement constitute a module. Each unit is

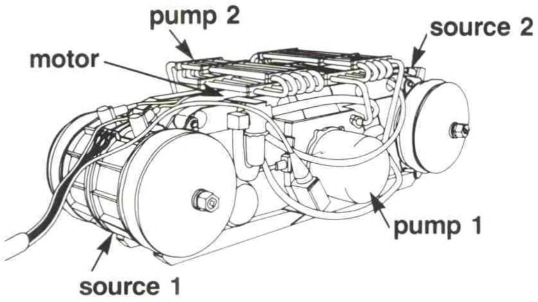


Fig. 2 Schematic of the MULTIPULSE module.

driven by a hydraulic pump and has its own individual digital valve, heat exchangers, and reservoirs. Total hydraulic fluid in each circuit is about 58.6 l. Motive power to the pumps is provided by an electric motor which receives its power through an armored umbilical from the ship. Each module is approximately 1 m high by 1.3 m wide by 3 m long and weighs 2300 kg.

Because the emitted signal is a square wave, the hydraulic control system driving the radiating plates is particularly simple, consisting of a microprocessor-controlled on-off valve to switch between high and low pressure valves. The primary requirement of the valving system is that the hydraulic pressure responds to the computer-generated square-wave program by actuating the valves within a fraction of a millisecond of the programmed times. Typically, the MULTIPULSE source is programmed to emit a series of pulses over a ten-second interval. The amplitude spectrum of that pulse-series almost perfectly sweeps continuously and uniformly over three octaves, usually from 12.5 to 100 Hz or the reverse. Other spectra and durations may be specified subject to the physical limitations of the hardware and the computer capacity.

Figure 4 is a schematic cross section of the MULTIPULSE unit. The opposed radiating surfaces are forced outward into the water by internal air pressure. Actually, to maintain a non-reactive atmosphere, nitrogen is generally employed in place of air. In this positive stroke, then, the hydraulic valves are in the "off" position and the lower hydraulic pressure is transmitted to the pistons. When the valves are in the "on" or high pressure position, the radiating surfaces are retracted, thus compressing the internal air and storing energy for the outward stroke. Judicious use of accumulators enables the system to expend little more work than is radiated in acoustic power. By contrast, sinusoidal sources dissipate most of their energy in heat because the kinetic energy of

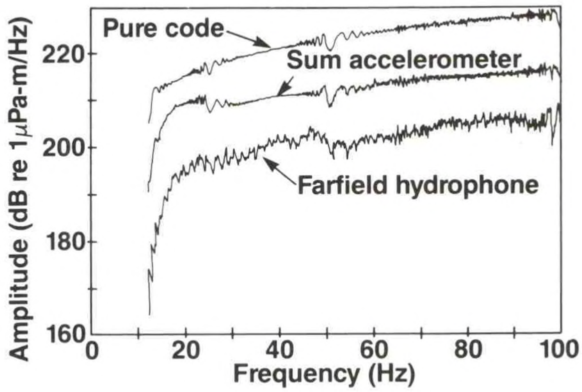


Fig. 3 Spectrum of a typical MULTIPULSE, 10-second signal as determined by the control system (top), by the sum of outputs of accelerometers on the individual units, (middle), and by a hydrophone in the water at some distance from the source (bottom).

the radiator is controlled each half cycle by hydraulic throttling and does not feed back into the system.

Operation of the unit is possible at any reasonable depth since the hydraulic system "sees" only the pressure differential between external ambient and the internal air. A simple adjustment of that internal pressure suffices to maintain the constant differential at any water depth.

Compliance is furnished by "boots" between the radiators and the stationary body of the unit. A boot consists of a rubber, toroidal body similar to an automobile or truck tire (without the tread).

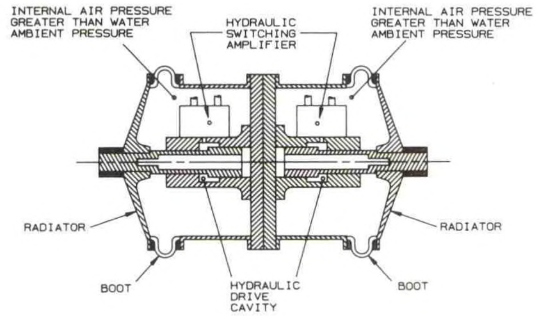


Fig. 4 Schematic cross-section of a MULTIPULSE unit. The pistons are shown in an intermediate position. In normal operation the pistons do not encounter the excursion limits at either end.

Monitoring and Control Electronics

Figure 5 illustrates the interconnections among the various subsystems, and emphasizes the central role played by the control electronics. Figure 6 displays the elements of the monitoring and control subsystem which include the code generator, the controller/synchronizer, a set of analog oscilloscopes, a SlowLog device, and the QC computer.

Parameters of the desired source output spectrum are entered by the operator and used by the code generator to select a calculated series of ideal radiator transition times. A table of such times is transferred into the controller memory. On/off signals to each digital valve for each radiator and for all modules are issued by the controller. Pressure and accelerometer sensors provide data for microprocessor feedback control of each valve in order to synchronize all radiator plates to the required signature.

Recording, analyzing, and displaying spectral and cross-correlation data from the source sensors is handled by the QC computer. Those sensors include the individual accelerometers, the sum-accelerometer from each module, and a nearfield phone mounted on each source unit.

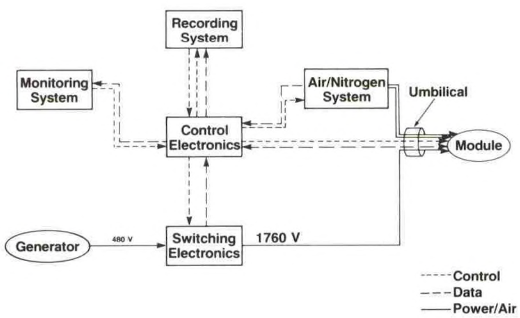


Fig. 5 Schematic diagram of MULTIPULSE control system.

Deployment

In operation, the module is suspended by chains to the desired depth, usually 7 to 10 m, from a float frame or sled and towed by the armored umbilicus at the desired distance aft of the ship. Normally an umbilicus 300 m in length is furnished for each module.

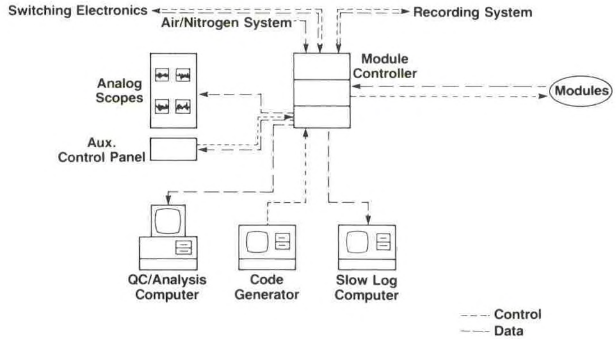


Fig. 6 Schematic of monitoring and control electronics.

Module Handling Gear

The module deployment and retrieval system is a pair (port and starboard) of overhead cranes each consisting of a traveling beam and an attached sled which can move fore and aft with respect to the beam. On the sled are mounted two winches which support the module/float on two lifting wires. When the module and float are lifted from the deck, they are "two-blocked" against the sled by mechanical stops. The beam and sled are driven aft until the sled and module/float are clear of the stern of the ship. After which, the unit is lowered into the water until the weight of the module is supported by chains connected to the float. The lift lines are then disconnected from the winch lines, attached to the umbilical, and the umbilical is run out from its reel until the module is in the correct position aft of the ship.

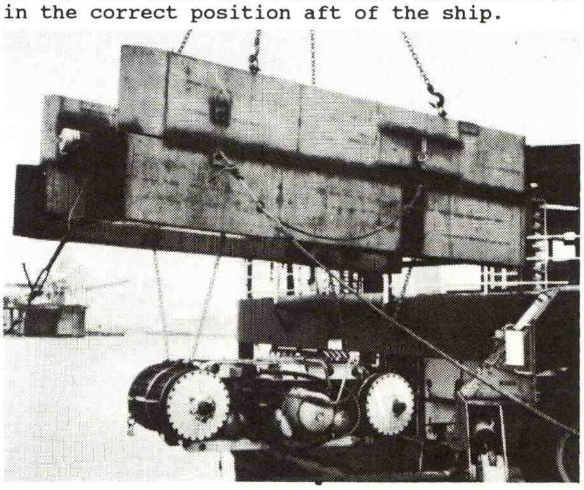


Fig. 7 Photograph of a module and its float frame (sled) suspended from the traveling beam.

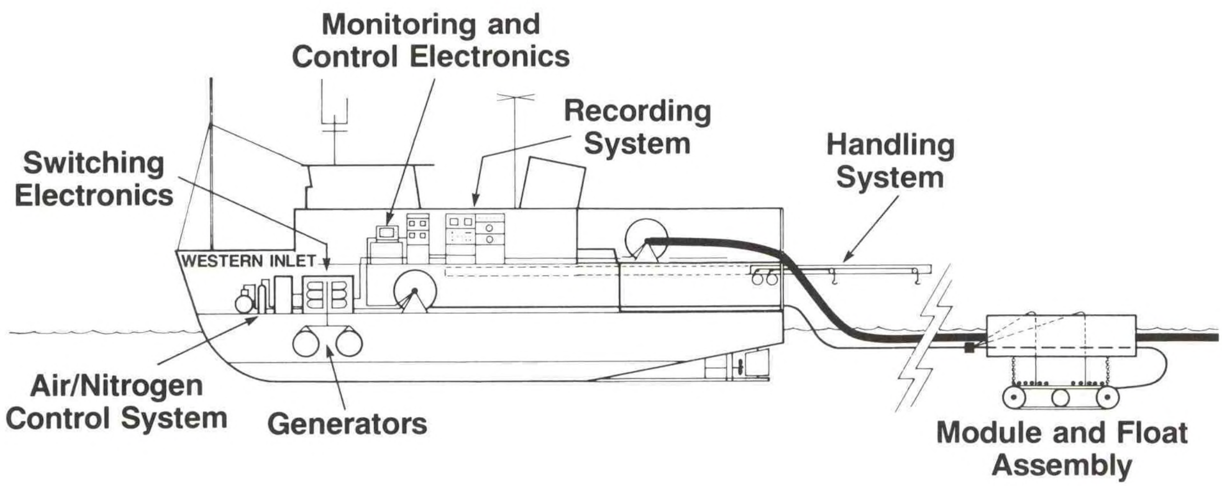


Fig. 8 MULTIPULSE system with towing vessel. Towing vessels are usually more than 70 m in length and are highly maneuverable.

Figure 8 illustrates schematically the entire MULTIPULSE system with its ship and subsystems. In normal operations, 4 modules are deployed, two from each side of the ship. Except for the Recording System no part of the signal-receiving system is shown.

Acknowledgements

MULTIPULSE technology is a joint development of Western Geophysical Company and Hydroacoustics, Inc. MULTIPULSE is a trademark of Hydroacoustics, Inc.

The Activities of "MARINO-FORUM 21" the research and development organization for new technology in fishery in Japan.

HIDEO OKATAKE
MARINO-FORUM 21

As it is well known, the surrounding conditions for Japanese fishery are recently facing a grave situation by international setting of 200 S.M. exculusive economic zone.

In this severe situation, in order to plan wealthy progress of Japanese fishery and stable supply of fishery products for the nation, it is considered as a pressing need and very important issue to increase the productivity in Japanese 200 S.M. zone and to secure rich fishing grounds and abundant resources.

For this purpose, it is an urgent matter to promote so-called "culture fihsery" such as development of coastal fishing grounds, promotion of fish farming, etc.

In this connection, an incorporation "MARINO-FORUM 21" (Y.UCHIMURA,Chairman) was formed as a research and development organization involving fishery organizations, private enteprises, prefectures, etc., to contribute to the development of Japanese fishery through the promotion of joint technical development involving beyond-barrier co-operations among government and private industry as well as among industries.

1.Establishment: October, 1985

Incorporated in June, 1986, under the jurisdiction of the Ministry of Agriculture, Forestry and Fisheries.

2.Purpose and Undertaking

Purpose : The organization aims at summation of technical development capabilities of private circles and desire and efforts of prefectures in fishery development, and carrying out new technology developments concerning fishing ground development and culture fishing centered at fish farming in Japanese 200 S.M. waters, to contribute to the development of fishery and stable supply of marine product.

Undertaking : To attain the above mentioned purpose the following undertaking are to be carried out;

1) New technology developments concerning fishing ground development and culture fishing centered at fish farming

2) Studies and researches to promote fishery development through fish farming

3) Information collecting and supply regarding above two items

4) Other necessary undertaking to attain the purpose of the organization

3.Members

March, 1988 organization member status

No.1	: Private enterprises and persons	133
No.2	: Prefectures, fisheries, universities, etc.	75
No.3	: Other besides above	9
	Total	217

4.Research Groups and Their Activities

Following research groups are engaged in studies,developments and field experiments.

(1) Artificial floating reef

Theme-1: Field experiments to test the mooring strength and durability

The most important problem of the existing artificial floating reefs is to improve their mooring strength and durability.
To above purpose, three artificial floating reefs have beeen tested in three different locations,at Miyazaki offshore,Kyushu ① in Fig 1, Wakayama offshore,near Osaka ②, Tokyo offshore③,since March, 1987.

Theme-2: Study on structural design for floating body and mooring system

The drafts of the structural design guidance for floating body and mooring system were prepared based on above experiments and published documents.

Theme-3: Field experiments to evaluate the fish gathering system and develop data transmission system

As next step, three artifical floating reefs have been tested in three different locations at Kochi offshore,Shikoku④in Fig 1 Tokushima offhore, Shikoku ⑤, Haboro offshore, Hokkaido ⑥ since March,1988, to evaluate the fish gathering system and develop monitor and data transmission sytstem for fish gathering, wind direction and speed, water current direction and speed,water temperature,wave height, etc.

(2) Large scale sand beach area development

Theme-1: Development of civil engineering method to control water flow and sand drift suitable for sand beach area

To improve settlement and survival of shell fish larva for preparing propagation sites of shell fishes in the open sea beach, model tank tests were carried out to develop civil engineering method to control water stream and sand drift.
New constructions were developed from model tank tests and the field test is planning this year.

Theme-2: Study on features of large scale sand beach area

The studies for production of sea weed bed in sand beach area were carried out and the field test is planning this year.

(3) Fish-seeding production system

Theme-1: Basic study on culturing bio-feeds

To mass produce seeding, based on studies for culturing rotifers as a bio-feed and production mechanism of rotifers, continuous rotifers culture test plant was installed at Okayama, near Kobe ⑦ in Fig 1, in December, 1987.

Theme-2: Culture technology for parent fish

Some methods for acceleration of ripening of parent fish by means of enriched artificial diets were studied.

Theme-3: Energy saving system for fish seeding production

Energy consumptions for seeding production, especially for those of abalone in northern Japan were researched and some experiments on effective energy saving system were carried out .

(4) Formulated feed

Theme-1: Clarification of nutrition requirements of larvae of important sea fishes and development of artificial micro diets.

Various types of artificial micro diets for red sea-bream, halibut, herring, yellow tail, striped jack, kuruma prawn, blue crab, etc. were tested.
The developed micro diets gave good possiblity in fish growth and survival especially in case of yellow tail, kuruma pawn and blue crab.

(5) Marine ranching

Marine ranching system is said to be of highly-developed system integrated by the technologies for breeding, keeping, cultivating and catching on the fishery resources.

Theme-1: Development of standard system to fish accoustic conditioning

In Japan, a technology of fish-seeding is getting advanced, and not little fishes producted are released all around every year.
On above, the most important point is how we can control the fishes to improve the rate of recapture after they have grown in the open sea.
The development of fish accoustic conditioning system is considered one of the way to achieve above point.
Hence we installed two standard systems at Oita, kyushu ⑧, ⑨ in Fig 1, last year and will continue to reserch the effects this year .
This system is planned to be adopted the public works of Coastal Fishing Ground Improvement and Development,which to be carried out in each prefecture under the governmental subsidies.

Theme-2: Increase of marine productivity by added nutrition

Field experiments at Otaru, Hokkaido ⑩ in Fig 1, and Tosa-shimizu, Shikoku ⑪, last year have been carried out in order to study how we can increase the productivity in oligotrophic sea.
At Otaru, fishmeal as a fertilizer for tangle and other sea weeds in the sea enclosed by silt-protector was added.
At Tosa-shimizu, large number of artificial reefs were installed around the way out of nutritious treated wastewater in order to promote seaweed growing.
Investigation and report to follow.

Theme-3: Development of offshore station for fish-seeding production and intermediate rearing

To above purpose, offshore station which has an integrated function for information and communication was designed.

(6) Fishing facilities development

Theme-1: Development of popular type fishing facilities

Studies on present situation evaluation of fishing facilities were made.
Typical sample fishing facilities such as wave-breaker, artificial fish reef, propagation reef, sea water stream control facilities, fish culture facilities,etc. were studied in aspects of function, construction and material.

Theme-2: Study on new material

Use of solidified coal ash made from coal ash, cement, plaster, etc. was studied and tested in order to utilize coal ashes from power generation plants, for making large scale sea bottom bank to generate up welling stream raising growth of plankton to promote fish propagation and improve fishing ground.
Use of solidified coal ash will be adoped the public works of Coastal Fishing Ground Improvement and Development.

(7) Fish culture system

Theme-1: Development of reforming fish-culture system for inside-bay

To reform from a serious build up of pollusion in the traditional, sheltered fish culture areas, ban of T.B.T.O. use is creating urgent needs for development of anti-fouling agent and method for fish cage netting.
To above purpose, a submersible fish cage was installed at Uwajima, Shikoku ⑫ in Fig 1, in November, 1987.

Theme-2: Development of fish culture system for offshore

For the expansion of fish culture system from inside-bay to exposed sea, offshore fish culture system is under development at Otobe, Hokkaido ⑬, at Hachinohe, northern Honshu ⑭ since November, 1987.
This system includes offshore station with fish feeds container and remotely operated feeds supply system allowing unmannd operation in bad weather and monitoring and remote watch and control system, and sea worthy offshore fish cages around the offshore station.

(8) "MARINOVATION" (Marine-Innovation) technology (Fig 2)

For the purpose of promoting activation of the fisheries and regional society including fishing villages and settlement of persons, a concept of "Marinovation" is framed by Fisheries Agency, in order to comprehensively develop and improve Japan's coastal and offshore water areas mainly around the fisheries.
"MARINO-FORUM 21" have settled 20 working groups, and as a case study, projects for investigating and examining the conditions for comprehensive development and improvement of the coastal and offshore areas are carried out at various sites.

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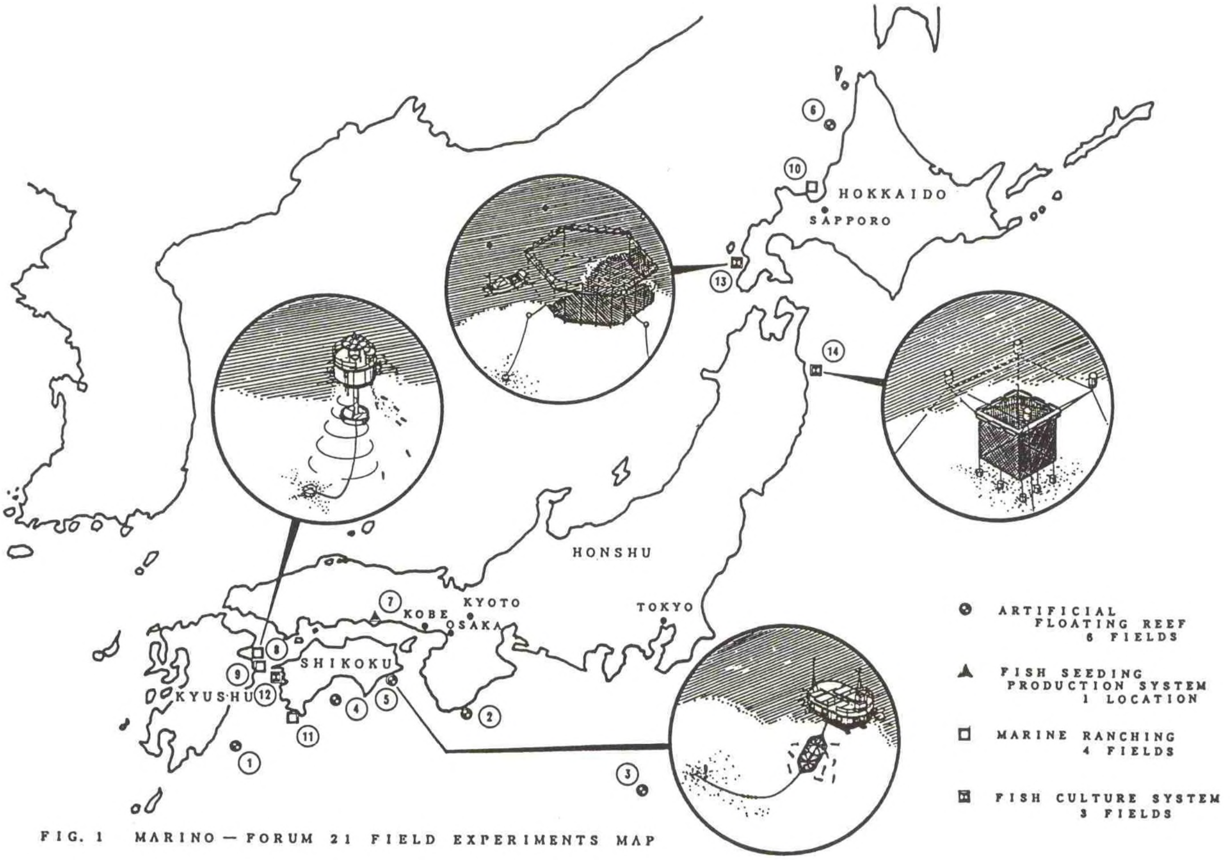


FIG. 1 MARINO — FORUM 21 FIELD EXPERIMENTS MAP

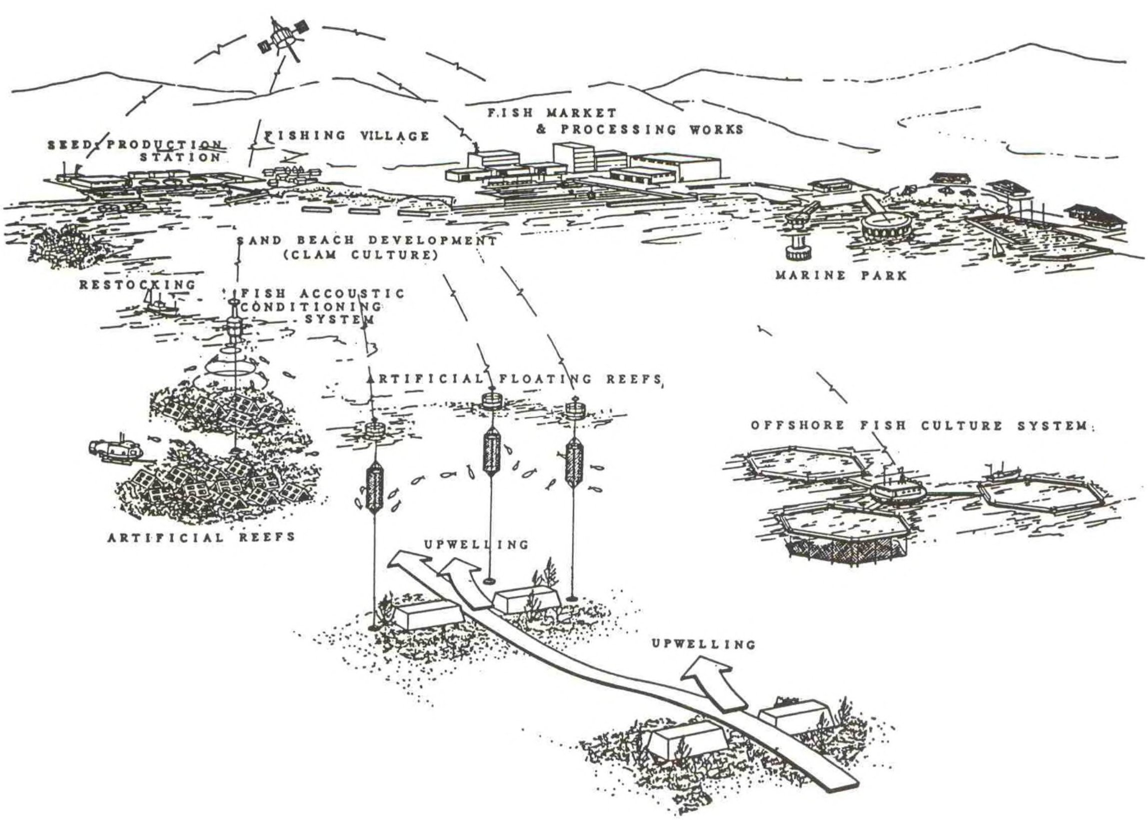


FIG. 2 MARINOVATION (MARINE INNOVATION) CONCEPT DWG

Uses of Deep Ocean Water as a Resource

John P. Craven
University of Hawaii

Abstract. The Natural Energy Laboratory of the State of Hawaii was established in 1974 as a corporation of the State of Hawaii. Its fundamental mission is to provide facilities that clients are encouraged to use to develop the natural energy resources of Hawaii (e.g., the sun, geothermal heat, and cold ocean water). The evolution of successful research and development projects has been such that we can now identify deep ocean water (DOW) as a generalized resource for many energy and energy-intensive applications. This paper will review in a qualitative sense the uses of DOW as a resource.

The qualities that make DOW a resource are its cold, its purity, and its nutrients. More specifically, the characteristics of the DOW are as follows:

Temperature	8.90 degrees C.
Alkalinity	2.35
NO3 + NO2 (micromolar)	38.97
PO4 (micromolar)	2.96
Si (micromolar)	74.59
NH4 (micromolar)	0.19
Dissolved Oxygen (mg/l)	1.21
Total Organic C (mg/l)	0.36

Except for a few diatoms, the water is free from living organic matter and is thus biologically pure.

Initially, the laboratory sought projects that used the cold in some form of ocean thermal energy conversion, but when the full characteristics of the DOW were appreciated, other projects that could use other qualities of the ocean water were sought. Initially, it was desireable to characterize the water in terms of its fundamental bioproductivity. To this end, the United States Sea Grant Program sponsored a study of the seaweed "nori." This is a seaweed well known in Japan in connection with, among other food uses, its use as an edible wrapper for sushi. The sushi proved to be an excellent retriever of nutrients, capturing up to 40 percent of the DOW nutrients in a single pass of water through the nori culture. Growth rates of 40 to 45 percent per day in biomass were observed. This phenomenal productivity inspired a host of exploratory projects. Most notable was the growth of macrocystis (California kelp) as a food for the mariculture of abalone. The Monterey Abalone Farm (now the Hawaiian Abalone Farm) has experienced success in a small pilot tank and in two pilot commercial production tanks. It is currently in commercial production in a four-acre artificial lake. An element of this successful production of marine products is the purity of the fluid. As a consequence, disease organisms are not present and could be flushed from the system should they be introduced at the surface. Also, there are no competitor organisms that would act as weeds as soon as the DOW was exposed to sunlight or other photons. On this basis, the Cyanotech Corporation investigated the production of various valuable algae. Among these are spirulina and dananiella (a source of beta-carotin). In this instance, the nutrients are of less, or even negligible, significance as compared with the purity and temperature control afforded by DOW.

The two-step mariculture system, in the form of the production of seaweed or algae as a food for a higher level organism, has been successfully employed in the production of oysters and Opihi, a Hawaiian shellfish delicacy. Experiments have also been conducted with the giant clam where the primary production organism is symbiotic with the clam such that there is apparently only one stage in the production process.

An appreciation of the economic efficiency inherent in this operation may be had as it is realized that DOW is deliverable to the mariculture site at an order of magnitude cost of approximately 10 cents per 1,000 gallons. Such water will be delivered with purity, at the optimum temperature for the particular organism, and with all or nearly all of the nutrients. Fresh water will be delivered to aquaculture sites (except in those rare localities where it occurs in natural abundance) at an order of magnitue cost of rom 25 cents to one dollar per 1,000 gallons. In general, this water will not be at the appropriate temperature and will require the addition of all the necessary nutrients. Trends in the cost of DOW are downward, whereas trends in the cost of freshwater as an aquaculture fluid are upward.

There are many other ways in which the cold properties of water make mariculture with DOW more economic. For example, the optimum temperature for growth of most seaweeds is less than the temperature at which they are found in nature. The economic costs of refrigerating surface waters prohibit optimum growth in regions where these marine organisms occur naturally.

Deep ocean water permits chilling the mariculture medium at extremely low cost. A more dramatic use of the cold attributes of DOW in agriculture is in the "waterless" production of cold weather spring crops. The prime example is the production of strawberries. In this process, small diameter plastic pipes are imbedded in highly porpous soil at the root level. Deep ocean water is passed through pipes making the ground cold, and consequently, forming condensate (i.e., dew). Studies have demonstrated conclusively that the growth rate and the quality of the strawberries is highly dependent on root temperature. Thus, a high-quality fruit can be obtained without the application of fresh water (except as it is drawn from the atmosphere in the form of dew). After the plants have fruited, they go dormant due to an increase in the flow rate of cold water. Thus, a number of crops can be obtained from one plant throughout the year and independent of the season. A number of spring crops and spring flowers have been successfully produced by this technique. The cold DOW employed in this process will suffer only a slight increase in temperature. It is immediately useful in other applications such that the economic cost of the water employed in this process is only that which is associated with the amotization of the irrigation system.

When large-scale power plants are developed there will be substantial quantities of cold water effluent. The opportunities for micro-climate control in selected valleys or coastal configurations are inherent in the production and distribution of these large masses of cold.

The cold aspects of the water have other standard commercial uses. Heat exchangers have been employed for cooling the process fluid in a standard chilled water air conditioning plant. Electricity costs for the use of such a plant drops dramatically since the refrigeration plant of the system will be in operation only during emergency, or perhaps, in overload conditions. Again, DOW, which is used for air conditioning, is available for use in mariculture or other resource applications.

Significant progress has also been made in the development of DOW as a cold fluid for ocean thermal energy conversion either in open cycle, closed cycle, mist lift, or in solare salt pond energy production. Initial concerns as to the economic viability of ocean thermal energy conversion are related to 1) the cost of protecting heat exchangers from biofouling; 2) the cost of heat exchangers; and 3) the cost and survivability of the cold water pipe. Initial experiments on heat exchangers with warm surface waters were conducted with many different types of mechanical, chemical, and physical techniques for preventing or removing biofouling. It soon became apparent that biofouling could be controlled effectively through a daily application of a miniscule amount of chlorine generated by electrolysis. The chlorine thus generated will not be detectable in the outfall and is, therefore, of no significance as a biocide or pollutant, except in the heat exchanger itself. More than five years of continuous testing with warm water demonstrated that heat exchangers could be operated without degredation of a heat exchange coefficient. These results suggest that very sophisticated wall configurations (flutes, fins, etc.) can be considered without concern for the loss of their effectiveness over time. Similar tests with cold water demonstrated that no treatment of any kind is required to prevent biofouling in cold water heat exchangers.

Although curtailed by a cut in funding, the tests conducted with OTEC 1 demonstrated that one can proceed with confidence in the design of a heat exchanger employing current theory and design practice. The presumption that titanium is the only effective material for heat exchangers may have been incorrect. Tests by Alcan Corporation on aluminum heat exchangers may have proven that aluminum might be appropriate as a heat exchange material. Results of the Alcan study are proprietary, but some of these results, reported by Alcan at Oceans '87 in Halifax, appeared encouraging. In the offing are new plastics that give promise of being low cost and of having excellent heat exchange properties.

Numerous techniques for deployment of the cold water pipe have now been tried and several failures have occurred. Analysis of these failures suggests that all were the result of elementary ocean engineering errors. Recent experience has demonstrated that the cost of deployment of cold water pipes, in a vertical configuration from a floating platform or in a horizontal position for a land based facility, will be less than the cost of installing a similar length of pipe on land. The use of buoyant pipe in an inverse catenary has been demonstrated a number of times, most recently and most notably at Ke-ahole point with a 40-inch diameter pipeline.

Experiments have also been conducted with various forms of OTEC generation. Experiments on flash evaporation have indicated that the dissolved gases in DOW do not leave solution in substantial quantities within the dwell cycle associated with lift to the surface and passage through the evaporator. Flash evaporation and flash condensation at low pressures and temperatures have been demonstrated and alternative techniques for developing efficiency are in progress. The efficacy of the mist-lift technique as an OTEC mechanism has also been demonstrated.

In conclusion, it may be said that the engineering parameters, which permit design of economically efficient and economically competitive energy, air conditioning, and aquaculute plants in the 300-500 kw range, have been established.

ADVANCED SHIP TECHNOLOGY DEVELOPMENT

A FEW PROPOSALS ON THE SHIP TECHNOLOGY FOR THE 21ST CENTURY

Dr. Noboru Hamada
President
Japan Marine Machinery Development Association

As President of the Japan Marine Machinery Development Association, it has been my job to investigate new ways and means of improving marine transportation systems. These include fuel saving methods, new concepts in ship design, and new types of ship machinery to support future ship designs. I would like to give a few proposals on the ship technology for the 21st century.

1. Ocean-going sail-assisted robot ship fleets

We are engaged in the research of ocean-going sail-assisted robot ship fleet as an expected sea transport system in the 21st century. (Fig. 1)

The concept envisages a fleet consisting of a mother ship manned by 20 to 30 crew and four to five remotely controllable robot barges. All of these ships are of the modern sail-assisted type. The fleet appears to be most suitable for carrying LNG and other materials that need secondary transport.

In the robot ship fleet, all controlling functions are integrated in the mother ship that also carries the crew of the fleet. The mother ship controls every robot barge by means of a radio system.

The advantages of the robot ship fleet may be outlined as follows:

(1) It would possibly reduce manning levels greatly compared with the present-day automated ships.

(2) In the event of any accident or damage, the mother ship will always be close to the robot barges to deal with the situation.

(3) The system is expected to put the crew's mind at ease.

(4) Initial construction costs could be significantly lowered as a result of reduced space of crew quarters and the number of life-saving equipment.

(5) The use of robot barges will reduce total construction costs for the fleet.

The robot barges will operate under the remote control system only when they are in high seas. When the robot barges approach closer to the coast, the crew will be transferred from the mother ship to operate them by helicopter and/or other means. Simulation experiments will be conducted in fiscal 1988.

2. High-speed Ocean-going Container Carrier

High-speed transportation of relatively light and small cargoes is primarily performed by airplanes and/or conventional container carriers. It is generally said that air-transportation takes less time but cost more, and on the other hand sea-transportation by conventional container carriers is vice versa. Based on this situation, development of a new transportation system by innovative ultra high-speed ocean-going container carriers, which will be able to realize moderate transportation time and cost, is strongly demanded now. Ultra high-speed ocean-going carriers will open a new frontier of sea-transportation and promote realization of an innovative high-speed transportation system.

Our project is to study the technical feasibility of construction of an innovative high-speed container carrier as one element of above-mentioned new transportation system.

This vessel is expected to be able to sail across the Pacific Ocean within about 100 hours, which means a speed of approximately 45 knots (about double the speed of a conventional container carrier), carrying about 240 8′ x 8′ x 10′ air-containers.

(1) Vessel shape

The vessel consists of a submerged main body, a navigation bridge and a single strut. This shape, which have been obtained from scale model tank tests, can remarkably reduce wave-making drag. The submerged main body contains cargo holds, a propulsion power system and fuel oil/ballast water tanks. The navigation bridge is located above the water surface. (Fig. 2, Photo 1)

(2) Fin control system

A fin control system is provided to control cruising water depth and stabilize vessel motion. A bridge height from surface is controlled according to wave height. (Fig. 3)

(3) Propulsion power system

Six sets of gas turbine engines, converted from aircraft usage, develop about 150,000 ps and drive 2 epicyclic gears which in turn drive 2 controllable pitch propellers. The gas turbine engine offers large savings of space, which is the most important factor in choosing it for this kind of vessel. The propulsion power plant is usually operated from the navigation bridge.

In the future, a superconductive electric propulsion system conbined with fuel cells, which is now in the process of development, is expected to be a good candidate as the propulsion system of this kind of ship.

(4) Cargo handling system

Cargo handling is performed by dockside container cranes through hatches of the main body only when the vessel is afloat in port in deballasted condition. Inside a cargo hold, an automatic container handling system, consisting of roller conveyors and an elevator, is fitted and operated from the navigation bridge. (Fig. 4)

(5) Conclusion

An ultra high-speed ocean-going ship is in the spotlight under JAMDA's 21st century project. In general, a submerged type and a SES type are suitable for this kind of ship. In this report, the semi-submerged type was selected from technically practical viewpoint and has been studied in more detail that ever before, which would contribute some help for realizing the innovative transportation system.

3. The Closed Circuit Diesel Engine for Submersibles

Submersibles and underwater robots used for research and development, however, depend on either batteries or power supplied via cable. They face difficulty from a limited range of action due to influence from the tide, short continuous operation time, or low power output. Moreover, operations using support ships are often interrupted by inclement weather at sea and a limiting annual operation ratio said to be below 30% in some areas.

The advent of development of a small self-propelled submarine as a fundamental solution for such circumstances is being anxiously awaited. Thus, attention was given to using the Closed Circuit Diesel Engine (CCDE) as the main engine of submersibles. Development started at Mitsui Engineering & Shipbuilding Co., Ltd. under the guidance of JAMDA.

The aim of the currently developed CCDE includes the application of this engine as the power source for underwater bases as well as for submersibles and underwater robots used in such submersibles development. Research and development for underwater power supply with a similar purpose is already under way in various western countries such as the U.S., England, France, and Italy, by using diesel engines and Stirling engines.

Ordinary diesel engines operate on the so-called open cycle in which the fuel is combusted by the air drawn in from the atmosphere and then the exhaust gas discharged into the atmosphere. With the CCDE, the exhaust gas from the diesel engine is cooled in order to concentrate and remove the vapor produced by combustion. The necessary amount of oxygen is then added and drawn back into the diesel engine to combust the fuel, thereby making it possible to operate underwater where air is not available.

However, since the exhaust gas is recycled within a closed system in CCDE, carbonic acid gas produced along with combustion of the fuel gradually increases the gas volume in the system whose surplus portion needs to be discharged outside of the system. The method of this gas disposal determines the working fluid and is therefore one of the important aspects in CCDE development.

It is desired to reduce the consumption of fuel and oxygen as much as possible to operate for a long time under the sea. Using the carbonic acid gas produced by combustion as the working fluid, however, lowers the thermal efficiency due to the low adiabatic index of carbonic acid gas. This increases the work required for discharging the gas outside the system, thereby increasing the fuel consumption considerably. In addition, various measures including remodeling of the engine will be necessary because it also lowers the ignition performance.

On the other hand, there is an example of trying to prevent the lowering of performance by absorbing and removing the carbonic acid gas with potassium hydroxide solution and avoid a reduction in performance by using nitrogen as the working fluid. Potassium hydroxide solution, though, is not only expensive but also must be carried in a large quantity because it cannot be recycled once it absorbs carbonic acid gas. Also, considering its weight, it is not suitable as a mobile underwater power source. Thus the exhaust gas processing method determines the composition of working fluid, and that working fluid has a large influence on the performance of CCDE.

Other important technical tasks of CCDE used under extreme conditions as underwater include supply and mixture of oxygen, utilization of waste heat, system control, and vibration and sound proofing.

(1) CCDE Development

The diesel engine used as the base for this development was the Mitsui-KHD BAM816 engine (water-cooled 4-cycle with turbocharger). The target specifications of this development are: 320 PS shaft output; 1800 RPM engine rotation speed; fuel consumption rate 220 g/PS-h; continuous operation time 200 hours; operable maximum water depth 450 meters; using gas oil for fuel and liquid oxygen for oxidant. Compared to the CCDEs developed by other countries, this engine has more than ten times the continuous operation time and output, as well as specifications with significantly improved performance in general. (Fig. 5)

(2) CCDE Development Characteristics

In exhaust gas processing, a method which selectively separates and removes the carbonic acid gas by using a recyclable alkanolamine solution was adopted based on the results of various studies. As a result, it became possible to maintain the air supplied to the engine in the same composition as atmospheric air without carrying a large quantity of absorbed liquid such as the above-mentioned potassium hydroxide. Characteristics and reliability equivalent to those in the ordinary atmospheric operation were also secured. Furthermore, since optional working fluid can be selected due to the adoption of carbonic acid gas separation and removal method, dramatic improvement in the characteristics of CCDE can be expected by using inert gases with high insulation index, such as argon, in some cases.

In terms of waste heat utilization, a matter of particular importance for power equipment used under extreme conditions such as CCDE is effective use of thermal energy contained in waste heat and improvement of overall thermal efficiency. As our CCDE has a small engine and collected heat use for power is difficult, heat from many sources such as the exhaust gas, lubricant and cooling water, are utilized for removing carbonic acid gas. This process prevents deterioration of engine performance caused by carbonic acid gas in the working fluid.

As for response of the oxygen supply and mixture system which governs the static and dynamic characteristics of CCDE, sufficient performance was obtained by detecting the concentration of oxygen in the engine air-supply and exhaust by a high-speed response, directly inserted, zirconia oxygen sensor and use of a microprocessor to maintain the preset proper concentration according to load, number of rotations and volume of fuel flow. To maintain the optimum condition according to respective conditions, carbonic acid gas separating device and other supplementary devices are also controlled by microprocessors. The microprocessors in turn, are controlled by operation control and computer monitor which manage the entire system including the main engine and peripheral equipment. In 1988, we will test the CCDE for endurance.

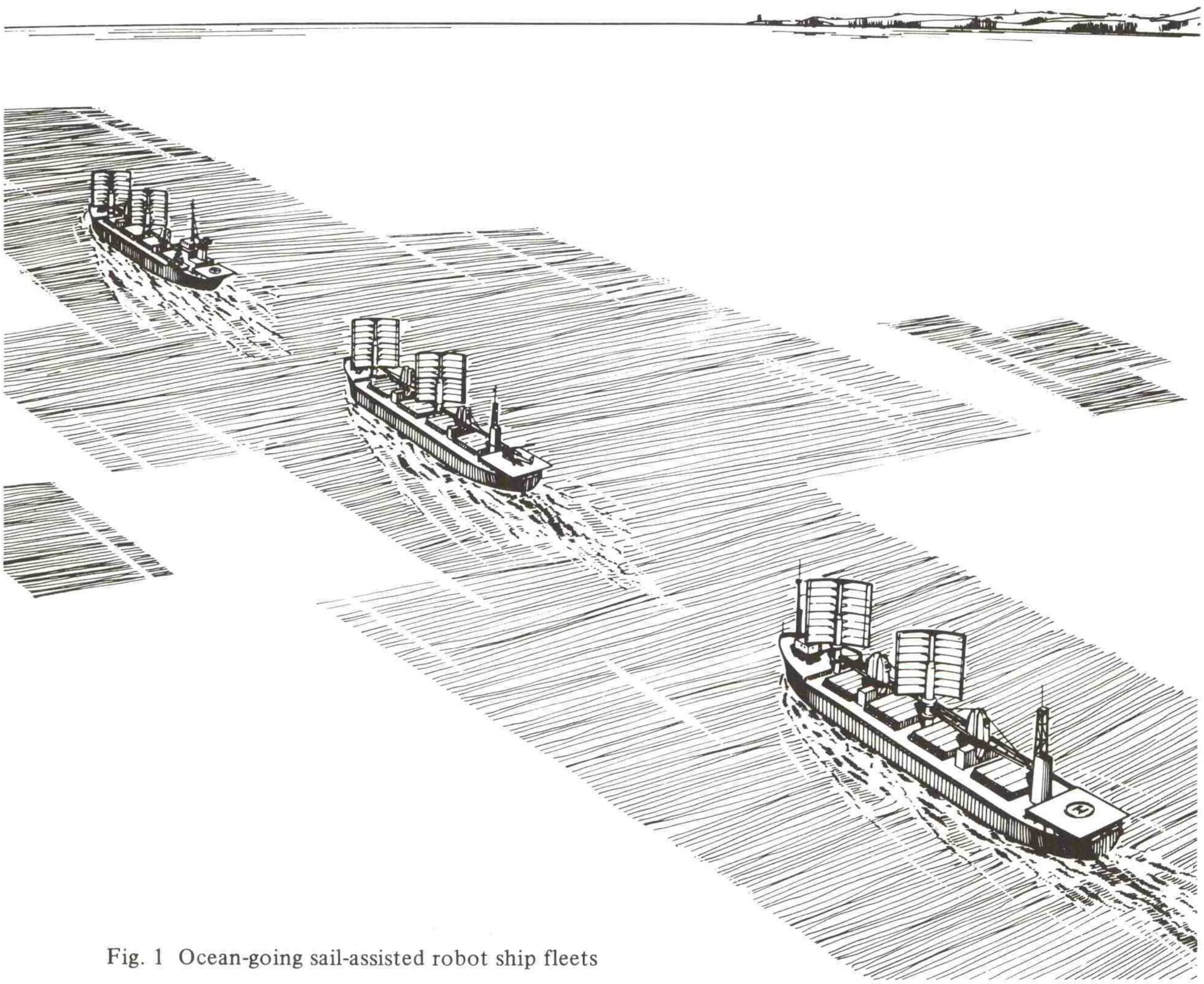
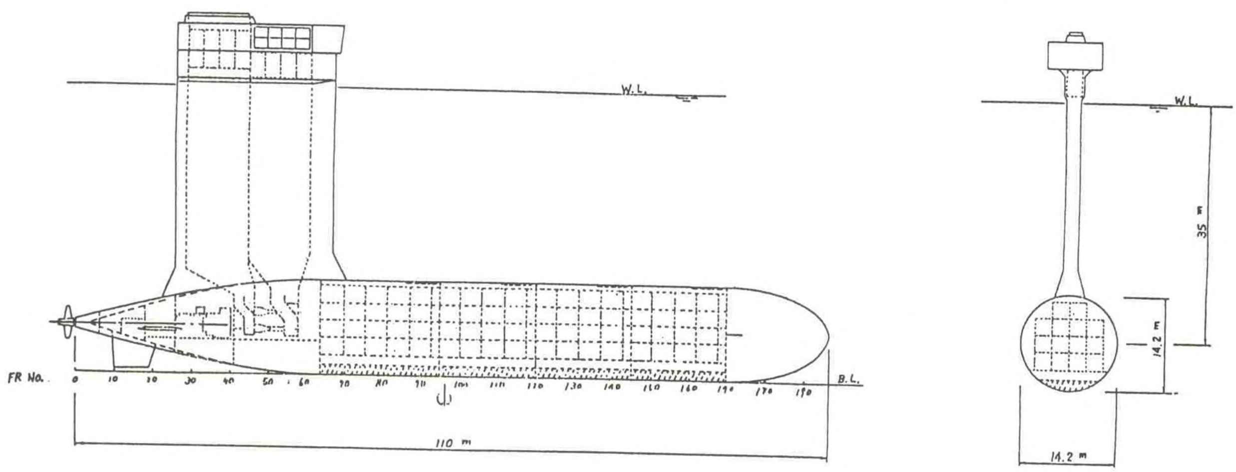


Fig. 1 Ocean-going sail-assisted robot ship fleets



Principal Particulars	
Overall length	112.5 m
Main body	L 110 m x D 14.2 m
Water depth	35 m (main body center line)
Displacement	15,000t
Cargo	1,000t (Air-container 8′ x 8′ x 10′, 238)
Main engine	Aero-derivated gas turbine Abt. 25,000 PS x 6 sets
Speed	Max. abt. 45 knots

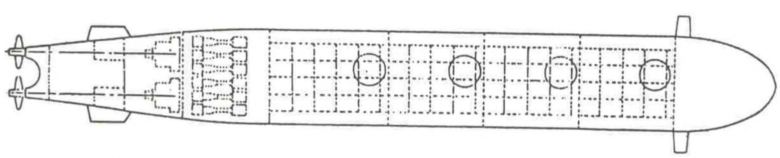


Fig. 2 General Arrangement

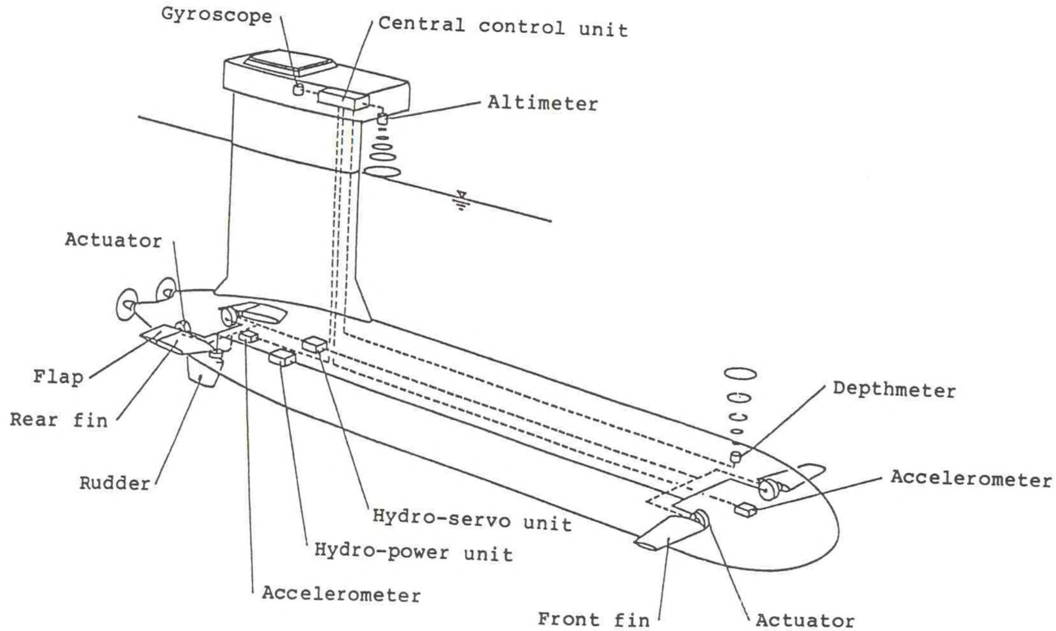


Fig. 3 Fin control system

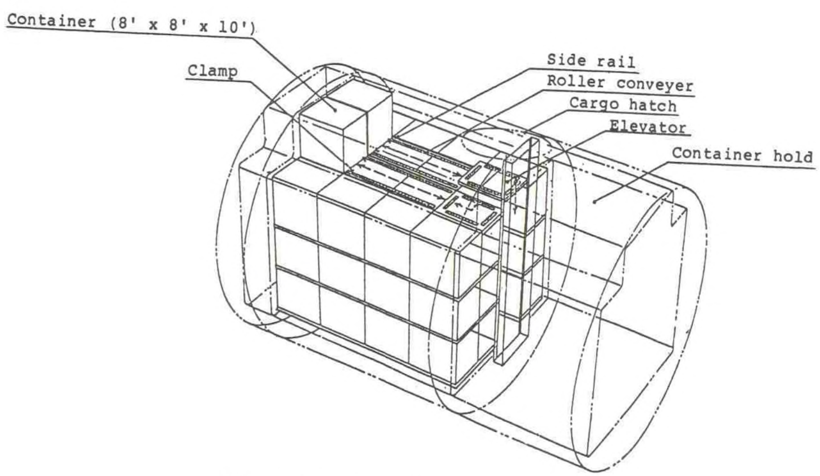


Fig. 4 Cargo-handling system

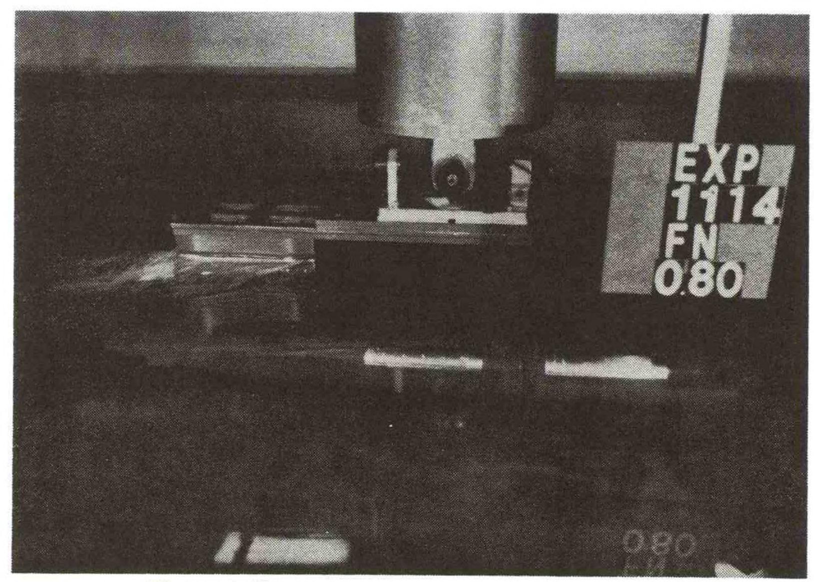


Photo 1 Tank test of 1.7 m scale model

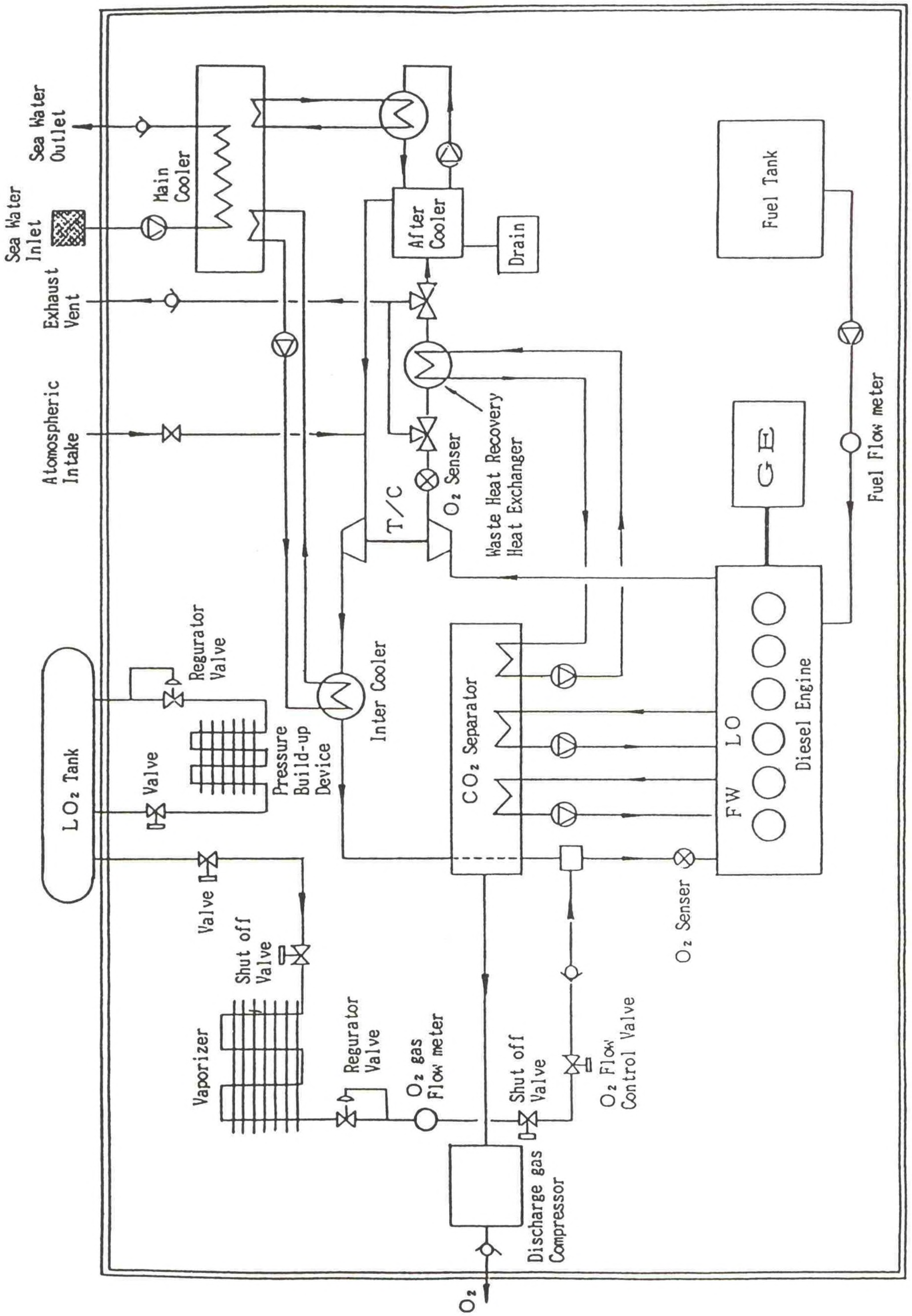

Sea Water Outlet
Sea Water Inlet
Exhaust Vent
Atomospheric Intake
Main Cooler
After Cooler
Drain
Fuel Tank
Waste Heat Recovery Heat Exchanger
O_2 Senser
T/C
G E
Fuel Flow meter
L O_2 Tank
Regurator Valve
Valve
Pressure Build-up Device
Inter Cooler
C O_2 Separator
FW
LO
Diesel Engine
Pressure Hull
Valve
Shut off Valve
Vaporizer
Regurator Valve
O_2 gas Flow meter
Shut off Valve
O_2 Flow Control Valve
O_2 Senser
Discharge gas Compressor
O_2

Fig. 5 CCDE

The Highly Advanced Automatic Ship Operating System

Hiromichi Sasaki

Technology Division
Maritime Technology and Safety Bureau
Ministry of Transport

The Council for Transport Technology made a proposal for the No.13 Inquiry "Development of Shipbuilding Technology to Be Promoted in Future to Cope with Recent Structural Changes in the Industry and Progress of Highly Advnced Key Technology" on August 20, 1982.

This report points out that R & D of the technology of "Highly Reliable and Intelligent Ships" should be promoted.

In accordance with it, Maritime Technology and Safety Bureau, Ministry of Transport established the Committee for the promotion of R & D on "Highly Reliable and Intelligent Ships" in order to deliberate the detailed plan and evaluate the progress and outcome of the R & D.

The R & D consists of "The highly advanced automatic ship operating sytem" studied by The Shipbuilding Reserch Association of Japan and "High Reliability Plant" studied by The Technological Research Association of Highly Reliable Marine Propulsion Plant.

These R & D are sponsored by The Japan Shipbuilding Industry Foundation (Chairman : Ryouichi Sasakawa).

In addition to them, from the view point of safety and reliability, Ship Research Institute, Ministry of Transport carries out the study.

These projects started in 1983FY to carry out basic research and development is to last until 1988FY. The total budget of the projects during the period of time is appraised at 15 billion yen.

Outline of the R & D is as follows:

① Automatic oputimum ship operating system

In present ocean navigation, a captain decides a route , evaluating the condition of the ship and cargo by his own experiences, he thinks optimum, considering a recommended route calculated in land, taking into account wave conditions obserbed by the captain within its immediate vicinity and the weather and sea conditions relayed from coastal stations.

On the other hand, in automatic optimum ship operating system, "the sea and weather conditions monitoring and evaluating system "automatically measures wave data and modifies the predicted data transmitted from coastal stations refering to the measured data.

Then, based on that information about the weather and sea conditions, "the ship conditions monitoring and evaluating system" calculate the safety zone of the course and allowable safety speed of the ship in any place, by calculatig its own conditions such as motion, acceleration and hull stress and evaluating the possible damage of cargo.

For example in this system, "the optimum route planning system" calculates the ship performance (the ship speed,etc.) under the effects of wind and waves, and plans the most economical route within the safe range of the course and speed, and control steering to keep track of the planned route not to cause economic loss by unnecessary deviation.

In addition, this system calculates the optimum trim and draught of the ship, then "the posture controling sytem" controls the ship posture.

Further, "the collision-avoidance ystem" or "the anti-stranding system" automatically avoid dangers combined with optimum route planning system. Development of such a series of systems make it possible to automatically operate ships in safety and economy.

② Automatic port entering-leaving system

Now in harbor maneuvers, almost all ship operating works consisist of crew's judgements depending on their experiences and mannual works. These works on bridge include the works of fixing ship's position, keeping watch, steering, operation of machinery and equipment and the works of judgement such as route planning.

In order to automate those works, as to the calculation for fixing ships position, development of technology to automatically deal with the information from satellite or radar and decide the ships position is being promoted.

As to the ship automatic operation,the research about the manoeuvr-ability is being carried out in order to keep the planned route with accuracy superior to mannual navigation .

It is not easy work to navigate ships in safety, keeping the regular schedule through a crowded waterway.

In order to ensure not only the safety of ships by observing rules and predicting the behavior of other ships but also the safety of areas around them and keep the planned route with high accuracy, R & D is being promoted to establish the system which can judge the optimal operation by computer.

In order to synthetically demonstrate and evaluate the results of the R & D, synthetic navigation simulation in a crowded water area is scheduled in 1988FY in Ship Research Institute.

Besides them, in automatic entering-leaving port operating system, the R & D of the following system is being carried out.

- "the automatic berthing system" to precisely compute the relative position of the berth and the ship and control tugboats
- "the automatic mooring system" to handle the mooring lines or control the length and tightening of them and the ship's position
- "the automatic anchoring system" to lower and raise anchor or prevent it to from dragging
- "the automatic loading-unloading system for dry cargo"
- "the automatic loading-unloading system for liquid cargo"

③ Highly reliable marine propulsion plant

In order to improve the reliability of diesel engine, it is necessary to realize the folloing items.

- mitigation of thermal stress around combustion chamber
- improvement of strength in high temperature components
- improvement of wear resistance in moving components

So as to realize these items, the R & D on the application of new materials such as new alloy metals and ceramics and the R & D on the various new mechanism of engine are being carried out . As to the establishment of high efficiency, the R & D on the combustion control of fuel oil to achieve perfect combustion and to optimize combustion in all range of load is being promoted.

Further, the R & D on highly reliable turbo charger, highly efficient fuel oil purifier and highly reliable stern tube sealing device were carried out.

In addition, the R & D on "the failure prediction and diagnostic system" was carried out in order to correctly predict the location and the time of occurrence of failure by monitoring and evaluating the operating condition of the shipboard machinery and equipment.

A Use of Graphics Workstations in Marine Container Terminals.

William C. Webster

The University of California, Berkeley

Introduction

A recent study completed by the Marine Board of the National Research Council reviewed the state of productivity in U.S. marine container terminals[1]. The issues involved were extremely complex since they cross cut labor issues, including the effects of work rules and of automation, technology issues, such as information systems and advanced container cranes, and organizational issues, including measurement of productivity and the physical arrangement of the container yard. This report reached several conclusions, some of which apply solely to terminal operations in the U.S., but most of which are equally applicable to international terminal situations as well.

One finding of the report was that productivity in a marine container terminal is not limited by the lack of technology. (The major finding was that labor-management issues are the most important). Some components of a container yard use the latest technology as exemplified by the modern container cranes used in the most advanced terminals. In other areas there may be an appearance of the use of modern technology, but careful examination reveals a subtle use of "old-fashioned" approaches.

The use of information in a container terminal is a typical example. Many years ago, most terminals introduced computer systems into their operations and developed programs which kept track of the various aspects of the operation. Through the years these programs have been upgraded to run on each of the several new generations of computers introduced in the last 10 years. In most cases, however, the "invisible" part, the underlying programming philosophy and design, has not undergone a change to reflect the new technology. That is, the principal benefit realized from the new computer technology has been to run the existing programs faster, and to have somewhat less cumbersome methods of data entry and transfer. Increased computational speed and development of terminals which are more ergonomic are, however, only one part of the computer revolution.

This paper focuses on a different aspect of the new technology, graphics workstations. A workstation is different from a computer terminal in that it has substantial computational capability and facilities of its own. A graphics workstation is one which can display highly detailed and complex (often colored) pictures as well as the normal alpha-numeric characters. Powerful graphics workstation systems have been available for many years, but they are just now becoming relatively inexpensive. As a result, there are a host of potential applications for which it is now feasible to apply this technology.

This paper describes a unique application of graphic workstations to the operation of American President Lines container terminal in Kaohsiung, the Republic of China. The application was developed by Ship Research Incorporated and installed in March 1988. Although the experience with it has been limited so far, every indication is that it is very successful. It is the opinion of the author that graphics workstation technology will lead to a new revolution in the way other large and complex facilities will be operated in the future.

Container Terminal Operation

In order to describe this application, it is necessary to first describe the layout and operation of a marine container terminal. A marine

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1 Improving Productivity in U. S. Marine Container Terminals, National Academy Press, Washington, D.C., 1986.

terminal contains four essential parts: the dock, the cranes, the yard and the gate.

The container dock is where an incoming container ship ties up so that it can be worked by the container cranes. Usually both loading and discharge operations occur. In a typical port only part of the cargo on board is discharged from the ship and only a comparable amount of cargo is loaded. In order not to accumulate containers at a given port, the number of containers dropped off must match the number loaded, averaged over time.

The essence of modern container shipping is that this loading/discharge operation must take place in the least amount of time so that the ship can depart to the next port. On-time scheduling has become extremely important because many goods are now transported in a partially assembled state and are part of a just-in-time inventory for the final assembly plant. As a result, most marine container terminals have very sophisticated, high speed container cranes which are capable of moving as many as 50 containers per hour. This capacity is rarely approached even in container terminals which are regarded are very efficient. Container cranes usually represent the most significant capital expenditure in the yard (excepting, of course, the cost of the land).

The container yard is a storage area in which the containers just discharged from the ship and the containers waiting to be loaded to the ship are stored. The size of the container yard dictates how the containers are stored. If the container yard has a considerable area for its throughput, then the containers are frequently stored one level high on a wheeled chassis. This is the arrangement which the containers are the most accessible. In areas where land prices are very high and the area of the container yard is small compared to the throughput, then containers are grounded (removed from the chassis) and stacked. If the containers are stacked three or even four containers high, then a large penalty accrues in the availability of an individual containers. Trade offs between these two extremes are usually required, since both space in a port and efficiency of retrieval of a container are important in the shipping operation.

The container yard is usually segregated into many different areas. There will be separate space for containers which are ready to be loaded, space for containers discharged from the ship, space for relay containers (those discharged from one ship to be reloaded to another), containers which require special handling, etc. A busy container terminal like Kaohsiung will see several ships in one week and often each of these areas will be further subdivided by the individual ship.

The gate is the interface between the container yard and the hinterland. All containers which originate in the country of the port must pass in through the gate; all those containers which originate in a foreign country and are destined for the country of the port must also pass out through the gate. As a result, the gate controls the flow into and out of the terminal and, if not run efficiently, can be a bottleneck which limits the flow of containers to the ship.

Information Needs

Most modern container terminals make extensive use of computer equipment and it is not hard to see why. There are many needs for data and often the same data is needed in many different contexts. When a container enters a terminal through the gate, the gate operator must assure that the container: was expected (that is, that the shipper arranged for its delivery to the dock), that it has an appropriate bill of lading, that it has adequate customs documentation for shipment to a foreign country, etc. In addition, the size and weight of the container must be verified and recorded, as well as any special characteristic of the container and cargo, such as refrigerated cargo, dangerous or hazardous (D&H) cargo, oversized containers, etc.

After the container enters the yard, it is usually placed in a particular waiting location which is designated by appropriate coordinates. For a chassis operation, it may be simply the number of the parking spot. Many times the trucker, not the yard personnel, are responsible for parking the container in a chassis operation. As a result, the veracity of the container parking spot can be in doubt. For containers stored in a stack it is necessary to give more complete coordinates. These containers are usually stacked by the yard personnel using specialized equipment, and as a result, the information is somewhat more reliable.

Finally, when the container is placed on board the ship, its location is specified by another set of three coordinates (usually the row, the cell and the vertical location in the stack). Unlike the container yard coordinates, the ship coordinates reflect the complicated three-dimensional geometry of the ship. Below deck, many more containers can be stored (both athwartships and vertically) in a hold amidships than in one far forward or far aft. Unlike a warehouse on ground, a ship is not on a rigid foundation but is floating. If, as a result of loading, the ship develops a list of only a few degrees then it may be difficult or even impossible for loading to continue. Further, imprudent loading can cause the ship to develop unacceptable bending stresses. The attitude or structural loading of the ship can be controlled by careful selection of the container loading sequence (i.e., which container is loaded where and when) and by the use of ballasting.

Thus, the container yard represents a one type of "warehouse" and a ship another. To load a ship it is necessary for a container to come through the gate and be stored (temporarily) in the container yard "warehouse" and then relocated to the ship "warehouse". Unloading involves a reverse of this process. Throughout this process, records must be kept of each container and its current location for billing, for inquiries concerning container status, for generation of specific instructions to the stevedores and crane operators for placement of the containers on board during loading, and for determination of the attitude and structural loading of the ship.

In traditional shipping line systems, the informational needs required for each of these requirements have been met by different computer environments. Data bases containing the container information required for the business aspects (billing, client inquiries, legal documentation, etc.) have been separate from programs of a more technical nature required to compute the naval architectural aspects of ship attitude and structural loading. Each of these programming systems usually generates alpha-numeric information which can either be printed out on paper or, more recently, displayed on computer terminals. However, in most systems this information can be viewed only one type at a time. For instance, when reading (or viewing) the database for the containers in the yard, it may not be possible to view simultaneously the database for the containers on the ship, unless one has two or more computer terminals available. In any case, translation of these data to either a physical or mental three-dimensional layout of the two "warehouses" (ship and yard) requires additional interpretation.

Programs for sequencing of the container loading operation have existed for simple route situations, but have not been in wide use for liner trades where a ship may stop in several ports in its route. The diversity of these programs and their separate informational bases has led to multiple entries of the same data (together with the possible ambiguities arising from mistakes) and to the obvious inefficiency resulting therefrom.

Container Ship Loading

With the bookkeeping support from the various computer systems, development of an adequate load/discharge sequence takes considerable manual labor with current computer support. The first step in the process is a load plan for the ship. This is developed from the load configuration of the ship on arrival at the port, taking account of the containers which must be discharged and those which must be loaded (including those which have to be discharged and reloaded in order to remove all of the cargo for the current port), and taking into account special loading requirements (including refrigerated containers, D&H containers, etc.) and naval architectural aspects of the ship (including attitude and stability requirements during loading and at completion of loading, hull stresses and trim requirements, etc.) Development of the loading plan often requires several trials to meet all of these requirements with reasonable efficiency.

With a loading plan in hand, a container sequencing plan can be developed which specifies the order in which containers are discharged and loaded on the ship. This plan is complicated by the fact that most modern container facilities use two to four cranes operating simultaneously in order to expedite the operation. Once again, trial and error is an essential feature in developing an efficient sequence. This demand is so severe that the sequencing officer using conventional information (lists of the containers in the yard and on board the ship, maps of the yard and drawings of the ship) must struggle just to focus on feasibility, let alone efficiency.

The TACTICS Solution

The system installed in Kaohsiung has been named the TACTICS project by APL. It involves replacing several different computer-based programs into one graphics operating environment using Apple Macintosh II color graphics workstations. These computers use a 32 bit architecture based on a Motorola 68020 CPU and a 68881 coprocessor. The individual computers on the network are connected using Appletalk, a relatively low speed local area network (LAN).

The distributed network has computers in the planning area (located near the gate), in the dock area (near where the loading and discharge operation occurs) and another, the file server, is centrally located. Each computer is capable of performing load planning or real-time operations, and each can access the needed data bases. The central file server stores data files which include the inventories of each of the "warehouses" in the system: the container yard, the ship or ships at the dock and those expected in the near future.

The workstation displays each of these inventories graphically, using color coding. Each aspect is displayed in a different window and, with the Macintosh system, it is possible to have numerous windows displayed simultaneously. Approximately 50 different windows are displayable by the workstation and include:

A profile of the ship and cross-section views of each hold showing the location of each container.

A "bird's eye" view of the container yard and cross-section views of each of the stacks showing the location of each container.

A "bird's eye" view of the tankage aboard the ship with separate views of the fuel oil, ballast and auxiliary tanks.

A screen which displays all of the characteristics of any given selected container including container number, size, weight, cargo, etc.

Screens which contains the state of the ship including the attitude, the bending moment and shear, the metacentric height, etc.

Figure 1 shows several of these windows used in the movement of containers. A vital feature of these windows are that they are hierarchical and are related to one another by a logical tree structure. Finer detail of any aspect can be instantly displayed. For instance, one of these windows is a profile of the ship. It shows each of the individual holds in the correct location. Placing the cursor on an individual hold and pressing the mouse button twice ("double clicking") causes another window to open up showing a cross-section view of the ship at that location and the containers in that hold (if any). A typical display of a cross-section of a ship hold resulting from "double clicking" is also shown in this figure.

Figure 1 also presents a window showing the layout of the various container stowage rows of Kaohsiung. "Double clicking" on any row causes a new window to be opened showing the contents of that row. A typical view of a transtainer stack (TT stack) resulting from this action is also shown. Further "double clicking" of an individual container yields all of the detailed identification of the container, as shown.

Since color is an essential feature of the graphics, it is difficult to represent its use in a black and white publication such as this. In order to facilitate the planners tasks, considerable care was taken in choosing color schemes as shorthand information and for container identification. This meant, for instance, that the presentations for loading and discharge had to be made distinct from one another. Also, the basic color of containers for a given destination are the same. Stripes or markers in the corners give further visual clues about the container type, cargo, etc.

The TACTICS system allows the operator to choose how much of the container terminal operation he wishes to see - all or only part - and allows him to see it in a form which is both familiar and intuitive. Scheduling the operation involves the operator selecting a container from one "warehouse" and "dragging" it (using the mouse) to the appropriate place in the other "warehouse", in the order he believes is a good one. The sequence can be played back and/or modified until the operator is convinced that it is a good one and that final loading is also good for the ship. Since the computer remembers each of these operations, it can produce on demand a detailed set of written instructions for each component of the container yard crew to execute the sequence.

Because of the need for the operator to have many windows open at one time for him so that he can "see" the whole operation, large screen monitors (19" diagonal) were used. This screen size allows, for instance, all of the windows displayed in Figure 1 to be seen without too much overlap.

The TACTICS scheme has several benefits. First, by freeing the sequence officer from the task of interpreting the location of each container from a long printed list, we have simplified a difficult visualization process. Second, by keeping track of the analog movements of the containers entered into the computer, the need to retype the container number and the coordinates of its movements into a computer is eliminated. Third, by allowing the sequencing officer to make several tries at a good loading sequence, he can come up with better sequences. Finally, in the Macintosh system, all of the display information is kept in a different resource file from the application's algorithm and thus changes in the display language (including pictograph languages, such as Japanese or Chinese) are easily accommodated without risk of corrupting the basic operation of the program.

The computational requirements for this operation (handling the databases, doing the ship computations, etc.) are reasonably intensive and it is important for the person generating the sequence to operate in real time. Having a powerful workstation relieves the container yard's mainframe computer from the burden of trying to keep up with these demands and to perform its other functions (gate entries, billings, etc.). The Macintosh II has the speed and capacity of minicomputers of only a few years ago.

Summary

The above discussion describes, albeit briefly, the considerations which led to the use of a graphics workstation for this marine application. The ability to have all of the information in front of a sequencing officer in a form which is easily seen and grasped has greatly improved the efficiency of APL's operation in this port. It is our opinion the graphics workstations, by unburdening the sequencing officer from the tedious tasks can help him apply his invaluable experience to the efficiency question and thus provide a superior operation. Use of the distributed processing in the workstation frees the main computer from the high transactional and computational load which is needed in graphics processing and, in addition, provides redundancy to eliminate a dependence on the main frame being "up".

Use of this sophisticated new technology requires an integrated software and hardware system, which is, however, much more difficult to bring into operation than normal business software. Our experience is that programming of this type takes an effort at least three or four times greater than traditional programming which produces batch, alpha-numeric data. However, the cost of this effort can be easily justified in terms of the immediate savings resulting from the improved efficiency.

The Kaohsiung project is a pilot and plans are now being made to introduce it at several other APL terminals. It is our belief that there exist many other contexts in which this approach will yield similar benefits and, as these benefits become known, we expect the graphics applications to grow explosively.

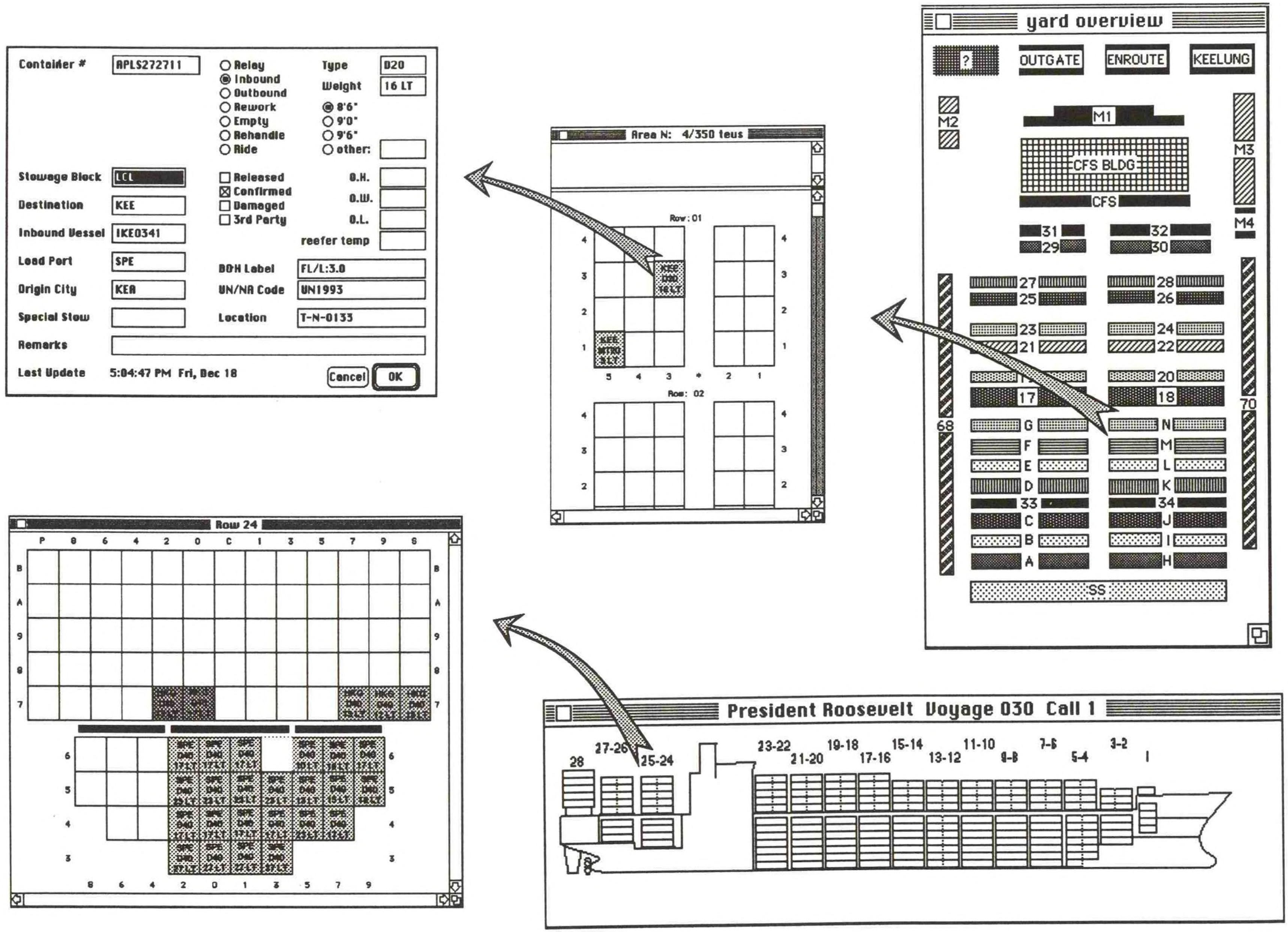

Figure 1. Some Windows Available in the TACTICS Workstation System

THE DEVELOPMENT OF HIGH STRENGTH KEVLAR LINES
FOR USE IN THE OFFSHORE INDUSTRY

RICHARD M. SHAMP

ENGINEERING SERVICE ASSOCIATES, INC.

This paper discusses the myriad of uses of Kevlar especially in the offshore industry.

In 1972 Dupont introduced a new family of fibers composed of aromatic polyamides, or aramid fibers, under the trade name of "Kevlar". These fibers have proven to have outstanding physical characteristics and are being introduced in some form in almost every industry. Some of its physical characteristics are as follows:

1. Its strength to weight ratio is very high. On a lb for lb basis Kevlar is 5 times as strong as steel and 10 times as strong as aluminum, yet its lighter than fiberglass.

2. It has an extremely high specific tensile strength 525,000 psi and the lowest specific gravity 1.44 of any continuous fiber commercially available.

3. The minimum break strength of a 1¾" Kevlar line is 300,000 lbs. 4" diameter Kevlar line has been tested to break at 1,060,000 lbs.

4. It modulus of elasticity is 9 million psi.

5. It has a very high resistance to fatigue and corrosion. In certain constructions 1¼" lines have been tested in over sheave tests for 250,000 plus cycles.

6. Kevlar has a small negative coefficient of expansion.

7. The fibers are inherently flame resistant. They don't melt and have a wide continuous use and temperature range from -320°F (-196°C) to 400°F (240°C)

8. Impact resistance is excellent.

With these physical characteristics engineers have designed products such as tires, sporting goods, sail cloth, to replace asbestos in clutch and brake shoes, auto and truck bodies, boat hulls, aircraft interiors, racing car exteriors, bullet proof clothing, work gloves, protective helmets, cables for use in the space shuttle and submarines, all types of high strength lightweight frames for many industries.

RISER TENSIONER LINES

In the offshore oil industry one of the first applications of Kevlar was in its use as riser tensioner lines. Western Oceanic reported that on the basis of tests they ran, they planned to replace all the steel riser tensioner lines aboard the Alaskan Star with Kevlar. Santa Fe Drilling Co. has used Kevlar side by side with steel in riser tensioners lines aboard two rigs operating in the North Sea - the "Santa Fe 135 and 140". The Kevlar lines aboard the 135 have surpassed 10 million ton cycles and plans call for them to go to 35 million before replacement. While the durability of Kevlar lines is impressive there are other advantages to be gained in the handling side. The Santa Fe engineer stated it took 4 men 2½ hours to install terminations on a steel tensioner line before the platform left the shipyard while it took one worker 20 minutes to terminate a similar Kevlar line. A reel of Kevlar tensioner line is about 1/5th the weight of a reel of steel line. This makes a difference of over 50,000 lbs of payload. There are numerous other examples of Kevlar riser tensioner lines being used advantageously aboard oil rigs.

MOORING AND ANCHORING

In water Kevlar lines have only 1/20th the weight of comparable strength steel lines and 1/80th the weight of an equivalent strength chain. A mobile rig or floating production platform designed for a Kevlar mooring system requires less displacement and has more payload capacity. Conoco has recently inserted a section of 1 million lb break strength into a mooring line of a semi-submersible operating in the Gulf of Mexico. Using the same line, tests have also been run recently by Petrobas offshore Brazil. The results of these moorings and the survivability of these lines will go a long way in convincing the oil industry to replace the heavier wire lines and chain with the much lighter, more flexible Kevlar lines. The US Navy, for 3 years, has been testing million pound break strength line made up of 4 250,000 pound strength lines. They are hoping to prove a 20 year life with little degradation in the strength or fatigue life of the line.

PENDANT LINES

Pendant lines made of lightweight Kevlar are far easier to handle than steel wire lines and require much smaller buoys. Lines have been made to anchor oceanographic instruments to water depths 20,000 ft over long periods of time. Electrical circuitry and power cable have been incorporated into many of these lines.

DEEP WATER PLATFORMS

Designs have been made using Kevlar lines to moor a floating production system in deep water. Studies have indicated that a 2,300 ft section of Kevlar rope extending at a 45^{o} angle beneath a storage production terminal, to a 2,625 ft bottom chain would yield optimum mooring system geometry. This type of a system would give smaller static loads and greatly reduce peak dynamic loads. It would control excursion and simplify installation. Combos of Kevlar line, chain and steel wire ropes offer a variety of solutions to difficult mooring problems, expecially in deep water.

FLEXIBLE RISERS

Another application for the lightweight high strength Kevlar fiber is in its use in the construction of flexible riser pipes. Instead of steel being used as reinforcement, Kevlar is used. Calculations indicate that the weight of the Kevlar reinforced flexible pipe could be 25 - 50% that of comparable steel reinforced pipe and the Kevlar pipe would be more flexible.

Other applications for Kevlar include its use as lifelines aboard ships and platforms, dockside mooring lines that exhibit less snapback than traditional nylon and dacron lines, and lines to be used for salvage operations that exhibit very low torque and long life over sheave characteristics.

The potential applications of Kevlar in its many forms is ever expanding. The developments are only limited by the imagination from the engineers utilizing this relatively new fiber.

DESIGN STUDY OF MODERN COASTAL/OCEAN-GOING VESSELS

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Prof. Hisaaki MAEDA — The University of Tokyo
Mr. Hiroshi OKADA — The Maritime Safety Agency *
Mr. Takaichi SOMEYA — The Maritime Safety Agency
Dr. Masahiro YAMAGUCHI — Ship Research Institute

ABSTRACT

The design study is made of two types of vessels for transportation among islands and various activities of the Maritime Safety Agency. One of them is high speed craft and the other is Small Water-plane Area Twin Hull (SWATH). The study plan and the results are presented.

INTRODUCTION

Most of the ship owners have had the intention to replace passenger boats to those with higher speed and better seaworthiness than before, which can serve among islands. The Maritime Safety Agency, which is surely expected to play roles of the enforcement of the law, marine environmental protection, and search and rescue, needs ships and crafts of modern types with higher speed and better seaworthiness.

Development of offshore resources and marine products has been increasing the ocean space to be investigated and utilized. The International Convention on Maritime Search and Rescue, 1979 has widened the Agency's patrolling area. Comparatively small vessels will then be required to build with wide deck area and stability among waves, and researchers can work for oceanographic investigations and a helicopter can take off and land on the deck.

Overall performance of small boats would vary with speed and seaworthiness, and stability of small vessels would be poor even with wide deck area. Therefore, it is necessary to evaluate the performance of various types of ships and crafts. The design study was performed by the committee of Japan Foundation for Shipbuilding Advancement (the Chairman of Foundation is Mr. Ryoichi Sasakawa). This paper presents the study plan and the results of the committee work.

STUDY PLAN

This study was performed in 1985 and 1986 by the committee of Japan Foundation for Shipbuilding Advancement under the chairmanship of Prof. S.Motora.

The design study planned by the committee is shown as follows;

1. Requirements of ships and crafts
2. Configuration of hull form
3. Preliminary design
4. Model test on performance including cavitation test
5. Full scale measurement of wave and swell around the coastal waters of Japan
6. Full scale measurement of vertical accelerations on the high speed crafts
7. Wave load and structure
8. Estimation of performance.

* At the study and the Maritime Credit Corporation at the present

REQUIREMENTS

The two types of vessels were studied with thw above situation in view. The requirements for the two types are shown in Table 1. The high speed type was requested to have speed of about 40 knots in still water and over 30 knots in sea state 4. The wide deck area type was required to be wide and stable enough for the take-off and landing of a helicopter on the deck.

CONFIGURATION OF HULL FORM

A: Type of High Speed Boats
- 1 Monohull
  - a Hard Chine
  - b Round Bottom
  - c Hybrid (Fore Body; Round Bottom, Aft Body; Hard Chine)
  - d Hard Chine with Semi-Submerged Bow
- 2 Hydrofoil
- 3 Surface Effect Ship

B: Type of Wide Deck Area Vessels
- 1 Small Water-plane Area Twin Hull
- 2 Ship with Anti-Pitching Fin

PRELIMINARY DESIGN

The two types of vessels were preliminarily designed to meet the requirements. One of the general arrangements is shown, for example, in Fig.1. For the vessels of wide deck area type, two SWATHs were designed. Larger one could carry a helicopter, and smaller could not carry any helicopter but could supply fuel oil to helicopters, which had landed on the deck.

The required power of boats was estimated by means of conventional design procedure and the performance in waves was preliminarily estimated by means of theoretical calculation.

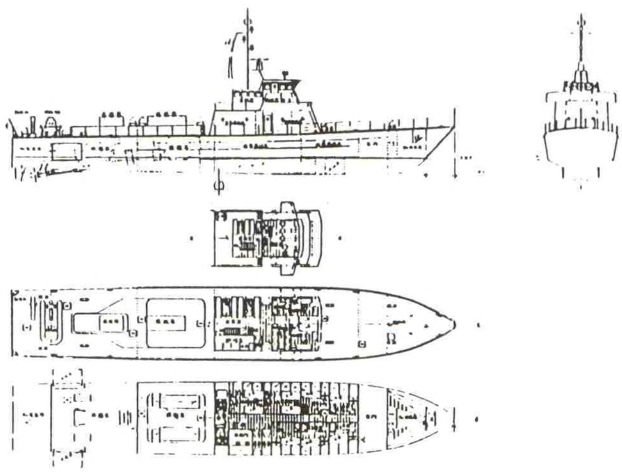


Fig.1 GENERAL ARRANGEMENT OF CRAFTS WITH HIGH SPEED (HYBRID)

TABLE 1.A REQUIREMENTS OF CRAFTS WITH HIGH SPEED

1	SPEED:	ABOUT 20 KNOTS IN STILL WATER
2	RANGE:	OVER 3000 NAUTICAL MILES
3	NAVIGATION AREA:	OCEAN-GOING AREA
4	CAPACITY:	TAKE-OFF AND LANDING OF A HELICOPTER
5	MEMBER OF CREW:	34
6	OPERATION DURATION:	25 DAYS

TABLE 1.B REQUIREMENTS OF VESSELS WITH WIDE DECK AREA

1	SPEED :	ABOUT 40 KNOTS IN STILL WATER OVER 30 KNOTS IN SEA STATE 4
2	RANGE:	OVER 600 NAUTICAL MILES
3	NAVIGATION AREA:	GREATER COASTING AREA
4	MEMBER OF CREW:	16
5	OPERATION DURATION:	5 DAYS

MODEL TEST ON PERFORMANCE

The resistance test and self propulsion test were performed in the towing tank at the Ship Research Institute on four ship models, three of which had mono-hull with hard chine and hybrid, and with semi-submerged bow. The other was SWATH. Ship motion in regular waves were measured in the tank to get the response function of ship motion. (Fig.2 and 3)

Cavitaion test to clarify the effects of cavitation on performance was conducted in cavitation tunnels at the Shipbuilding Research Centre of Japan and the Ship Research Institute on the model propellers with crescent sections. The cavitation effect on performance were clearly recognized by the test, but the results were slightly different from those found in the references [1].

FULL SCALE MEASUREMENT OF WAVE AND SWELL

The Maritime Safety Agency was going to develop onboard monitoring equipments, named Ship Motion Analyzing Computer System, which could record simultaneously ship motion responses in waves, encounter waves and the reason of change of ship's course and/or speed [2]. The vertical accelerations of ship motion were recorded in three different zones of coastal waters of Japan on the large patrol ships of 1000 GT. The wave spectra were estimated through the recorded accelerations. The obtained wave spectra was found to be classified as International Ship Structures Congress (ISSC) spectra.

FULL SCALE MEASUREMENT OF VERTICAL ACCELERATION

In order to survey the muscular endurance, the vertical accelerations were measured and some comments of the crew were also

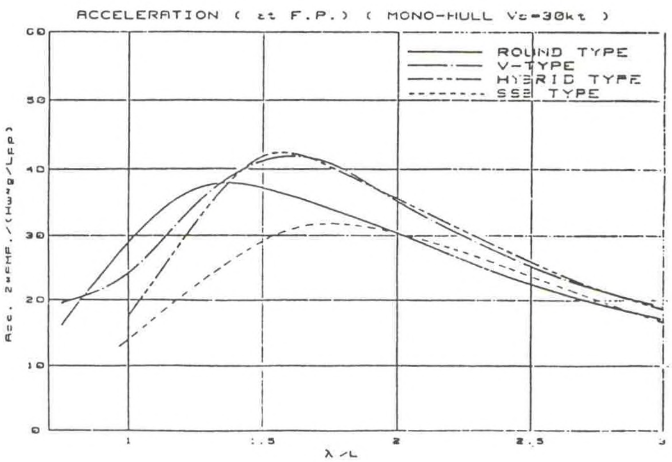


Fig.2 RESPONSE FUNCTION OF VERTICAL ACCELERRATION AT F.P. IN REGULAR WAVE (HIGH SPEED TYPE)

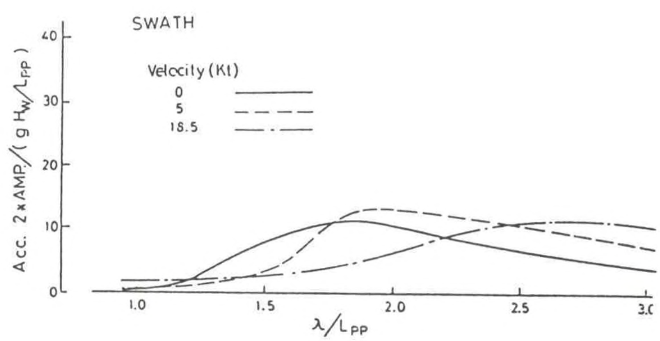


Fig.3 RESPONSE FUNCTION OF VERTICAL ACCELERRATION AT F.P. IN REGULAR WAVE (WIDE DECK AREA TYPE)

recorded of two high speed crafts of 28.5m Lpp in the two different zones of coastal waters. The vertical accelerations often showed about 0.25g at normal navigation and about 0.5g without slowdown in an emergency. It was found that the crew could endure vertical accelerations higher than 0.75g in a short time. It was descided that high speed crafts should be designed within the vertical accelerations of 0.5g in waves when the performance of high speed boats was evaluated.

WAVE LOAD AND STRUCTURE

The ship structures of two type of vessels were designed with taking wave loads into account. Wave load for high speed type was estimated by two methods, one of which was the Temporary Standard for Light Structure Craft in Japan [3] and the other was a new proposal for design load [4]. It was found that there were some differences between the results of the two methods.

ESTIMATION OF PERFORMANCE

Performances of high speed type and wide deck area type were estimated through the results of model test, full scale measurement etc. The estimated speed of high speed type was slightly lower than the requirements. The wide deck area type satisfied the speed requirements.

The vertical accelerations were estimated by wave spectra of full scale measurement and the response functions of ship motion in regular wave in the towing tank. The results supplied the requirements. The wide deck area type was found to have enough deck area and stability for take-off and landing of helicopters.

CONCLUSION

Preliminarily designed high speed boats with mono-hull were found to satisfy the most of the requirements. The cavitation effect on performance was clearly recognized by the model test.

The type of wide deck area vessels, which was SWATH, was found to satisfy the requirements, too.

ACKNOWLEDGEMENTS

The authors would like to extend their appreciation to the members of the committee who contributed their ideas and comments. Special appreciation goes to Mr. Kihara, Mitsubishi Heavy Industries,Ltd. Mr. Shinoda, Hitachi Zosen Co. and Mr.Ozawa, Mitsui Engineering & Shipbuilding Co.,Ltd. for their efforts to establish this study..

REFERENCES

[1] Newton,R.N. and Rader,H.P., "Performance Data of Propellers of High-Speed Craft," RINA, Vol.103, No.2, 1961.

[2] Someya,T. and others,"An Experimental Study on Ship Handling in Waves," Journal of The Soc. of Naval Arch. of Japan, Vol.161, June 1987.

[3] The Temporary Standards of Light Structure Vessels, The Circular Notice of Ship Bureau, Ministry of Transport, 1972.

[4] Kaneko,Y. and others,"A proposal for design load on structural hull girder and bottom structure of large high-speed craft," Trans. of The West-Japan Soc. of Naval Arch., No.72, Aug. 1986.

RESEARCH AND DEVELOPMENT OF SUPERCONDUCTING ELECTRO-MAGNETIC PROPULSION SHIPS

by Seizo Motora

Japan Foundation for Shipbuilding Advancement

1. Introduction

The concept of electro-magnetic propulsion was proposed by W. A. Rice [1] in 1961 as a similar idea of electro-magnetic pump used for liquid metal. The principle is based on Fleming's left hand rule which is one of the basic rules of electro-magnetism. When a magnetic field is generated in sea water by a magnet placed inboard, and electric current is generated in sea water so as to be perpendicular to the magnetic flux, the sea water is pushed away by electro-magnetic force (Lorentz force), and the reaction acts on the magnet resulting in propelling of the ship (see Fig. 1).

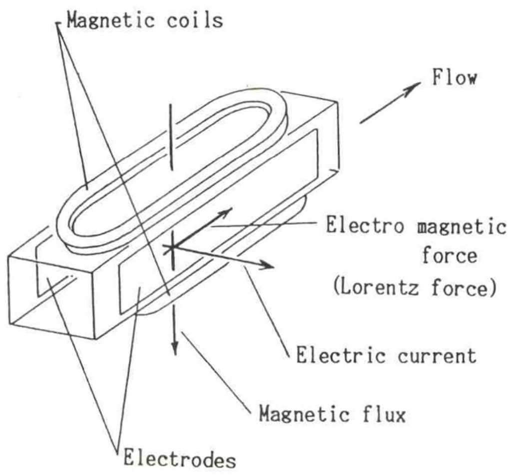


Fig 1

The propulsive efficency of electro-magnetic propulsion ships is roughly expressed by formula (1).

$$\eta \propto \frac{U \cdot B \cdot b}{E} \qquad \cdots\cdots(1)$$

where

η is propulsive efficiency
U is speed of sea water (ship speed)
B is magnetic flux density
b is distance between electrodes
E is electric potential difference between electrodes.

To improve propulsive efficiency, the following means can be taken;

1) to increase speed of sea water(ship speed)
2) to increase intensity of magnetic field
3) to decrease potential difference

Since the potential difference cannot be decreased unless the electric conductivity of sea water is improved, either to increase the intensity of magnetic field or to increase ship speed are the possible means to improve propulsive efficiency.

Therefore, it can be said that utilization of super conducting magnet is the only economically feasible solution to realize electro-magnetic propulsion ships, and that electro-magnetic propulsion is suitable for high speed ships.

Theoretical as well as experimental research works on superconducting electro-magnetic propulsion have been done by Saji et al.[2], Doragh[3], Way[4], Way et al.[5], etc., attracting public attention.

Based on the experience of Saji et al. Japan Foundation for Shipbuilding Advancement set up, in 1985, a committee chaired by Mr. Yohei Sasakawa to promote an extensive research and development project aiming to construct a prototype experimental ship of about 150 tons which is capable of carrying all necessary apparatus on board and run itself with electro-magnetic force. Total budget of the project is about $ 40 Millions, being subsidied by The Japan Shipbuilding Industry Foundation (Chairman : Ryoichi Sasakawa).

2. Choice of type of propelling system

There are two different systems in electro-magnetic propulsion; one is external magnetic field system in which electro-magnetic force is generated in sea water at peripherical space of ship's body (Fig.2(a)) and the other is internal magnetic field system where the electro-magnetic force is generated in sea water within a longitudinal duct inboard (Fig.2(b)).

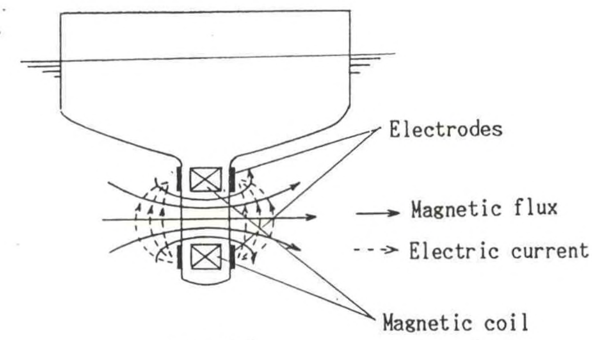


Fig 2(a)

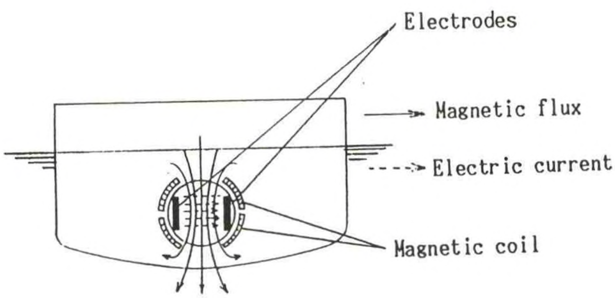


Fig 2(b)

The former may be advantageous in view of efficiency but may be disadvantageous in view of leakage of magnetic flux into outer space. The latter may be disadvantageous in view of efficiency due to frictional loss of the duct, but is advantageous in view of environmental protection because magnetic field as well as electric current are almost confined inside the duct.

Considering these merits and demerits, the committee dicided to adopt the internel magnetic field system for the first experimental ship.

3. Development of prototype dipole superconducitng coil

A prototype dipole coil was designed and constructed which enables to generate magnetic field of 2T perpendicular to the longitudinal axis of a water duct (see Fig.3).

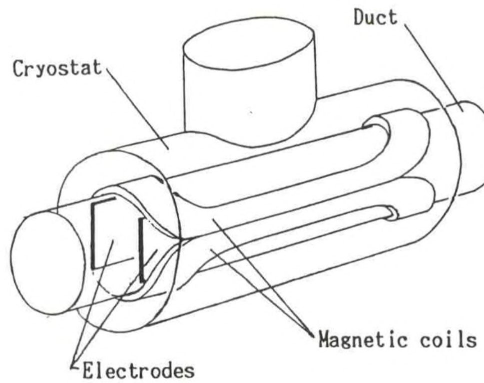


Fig 3

The principal items are as shown in Table 1.

Table 1
Principal items of the R & D dipole coil.

Inside diameter of duct:	0.210m
Length of electrode	1.00m
Super conductor	NbTi alloy
Copper ratio of superconductor	1.4
Number of turn of a coil	107
Operating current	4,000A
Magnetic flux density at center of the duct	2T
Max electric current in sea water	2,000A
Corresponding Lorentz force	400N

Constructed superconducting coils are contained in a cryostat filled by liquid helium, and magnetic field of 2T at center of the duct was attained at designed operating current. It was also confirmed that the magnetic field is almost uniform and unidirectional inside the duct.

An electric current perpendicular to the magnetic field was generated through electrodes provided both sides of the duct and pressure increment due to Lorentz force is measured varying salt water speed as well as electric current. Position of manometers to measure pressure distribution along the duct are as shown in Fig.4.

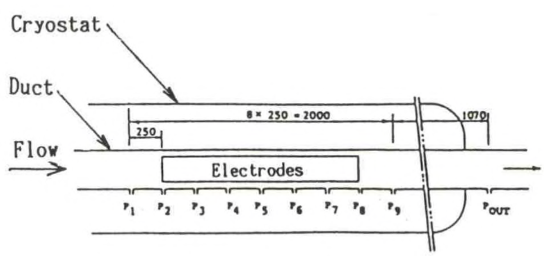


Fig 4 Position of manomenters

An example of measured pressure inside the duct for different electric current is shown in Fig.5.

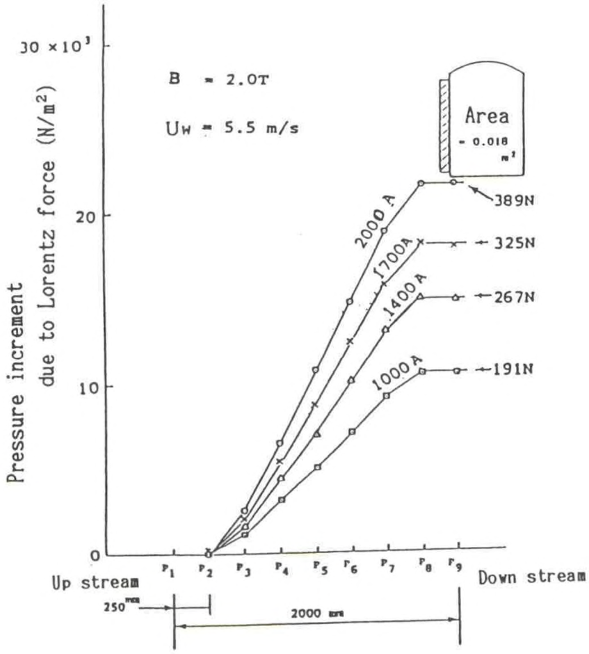


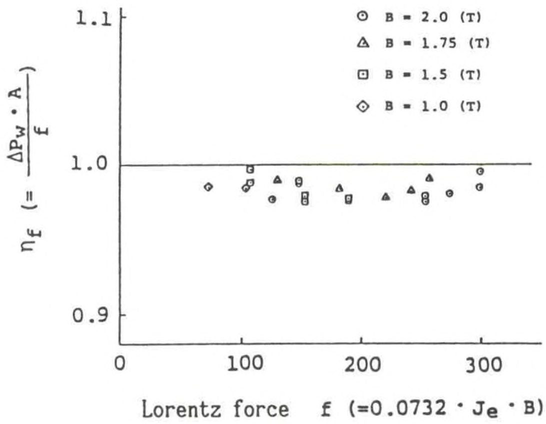
Fig 5 An example of pressure increment due to Lorentz force

It was recognized from the result that:

1) Pressure inerement due to electro-magnetic force is almost linear except at both ends (P_2~P_3, and P_7~P_8) where the magnetic field is not uniform due to end effect of the coil.

2) Attained Lorentz force for total length of the duct is very close to the theoretical value. The difference between theoretical and attained Lorentz force is supposed to be mainly due to frictional loss of the duct(see Fig.6).

3) attained efficiency (ratio of attained momentum change of water to the energy input in form of electric power) was about 1%.



f : Theoretical Lorentz force per 1m length of duct(N)

ΔP_W : Pressure increment per 1m (N/m²)

A : Sectional area of duct

Fig 6 Ratio between measured pressure increment to the theoretical value

This poor efficiency is mainly caused by Joule loss due to poor conductivity of sea water. Neverthless, there is some hope to improve efficiency.

It was stated in Chapter 1 that the propulsive efficiency is approximately given by formula (1).

$$\eta \propto \frac{U \cdot B \cdot b}{E} \qquad \cdots\cdots(1)$$

On the other hand Lorentz force F is given by formula(2)

$$F = JsB \cdot b = \sigma ld(E \cdot B - U \cdot B^2 \cdot b) \quad \cdots(2)$$

where

Js is total electric current

σ is conductivity of sea water

Since, at present, the first term of the formula(2) which represents Joule loss due to electric current is much greater than the second term which represents the work done by Lorentz force.

$$E \gg U \cdot B \cdot b \qquad \cdots\cdots(3)$$

Therefore, approximately

$$F \propto E \cdot B \text{ , } E \propto F/B \qquad \cdots\cdots(4)$$

If Lorentz force F is kept conotant,

$$E \propto 1/B \qquad \cdots\cdots(5)$$

Substituting (5) into (1), we get;

$$\eta \propto U \cdot B^2 \text{ (Constant with dimension)} \quad \cdots\cdots(6)$$

This means that the efficiency is proportional to the square of the intensity of magnetic field, and proportional to the flow speed which is proportional to the ship speed.

If B becomes fourtimes the present case which means 8T, and flow speed is twice the present case which means 11m/sec, η may become of an order of 30%. Therefore, realization of powerfull magnet is the key to realize economically feasible electro-magnetic propulsion ships.

4. Practical design of propulsion system for the proto-type experimental ship

Based on the results of measurements on the prototype dipol coil, a practical design of propulsion system for the experimental ship was conducted as the following conditions:

1) The propulsion system consists of twin propelling units.
2) Each propelling unit consists of six dipole coils forming a ring so that leakage of magnetic flux outside the unit is very small(see Fig.7(a)(b)). Therefere, magnetic shield can be eliminated except few vital spaces such as control room.

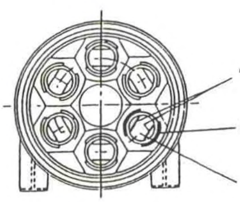


Fig 7(a)

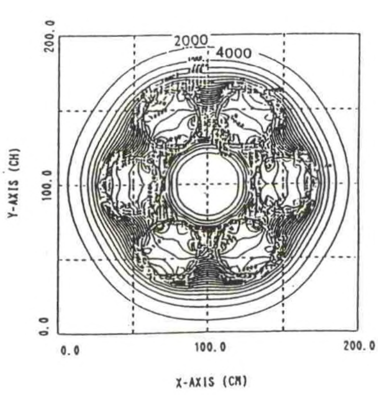


Fig 7(b)

3) Lorentz force for each unit is 8,000N , and designed total thrust is 8,000N where the efficiency of converting Lorentz force into thrust is estimated to be 0.5.

Principal items of the propelling unit is as shown in Table 2.

Table 2
Principal items of the propelling system of the experimental ship

Type: twin propelling units, each consists of 6 dipole coils.	
Inside diameter of the duct	0.260m
Magnetic flux density at center of ducts	4T
Max. electric current density inside ducts	$4{,}000A/m^2$
Length of electrodes	2.50m
Lorentz force:	about 8,000N × 2
Thrust:	about 4,000N × 2
Capacity of main generator	3,800kw
Total weight of the system	about 100ton

5. Design of the experimental ship

(1)Principal dimensions

Principal demensions of the experimental ship are as shown in Table 3.

Table 3
Principal items of the experimental ship.

Displacement:	about	150ton
Length:	about	22m
Breadth:	about	10m
Thrust:	about	8,000N
Speed:	about	8kts

(2)Hull form

Since the dimension (diameter) of the cryostats is too large to be contained in a regular mono-hull maintaining proper stability in limited displacement, an unusal type of monohull is adopted (Fig.8).

Resistance of this hull is about the same as a catamaran of equivalent size. But by this design length of ducts can be shorten than a catamaran resulting in improving of attained thrust.

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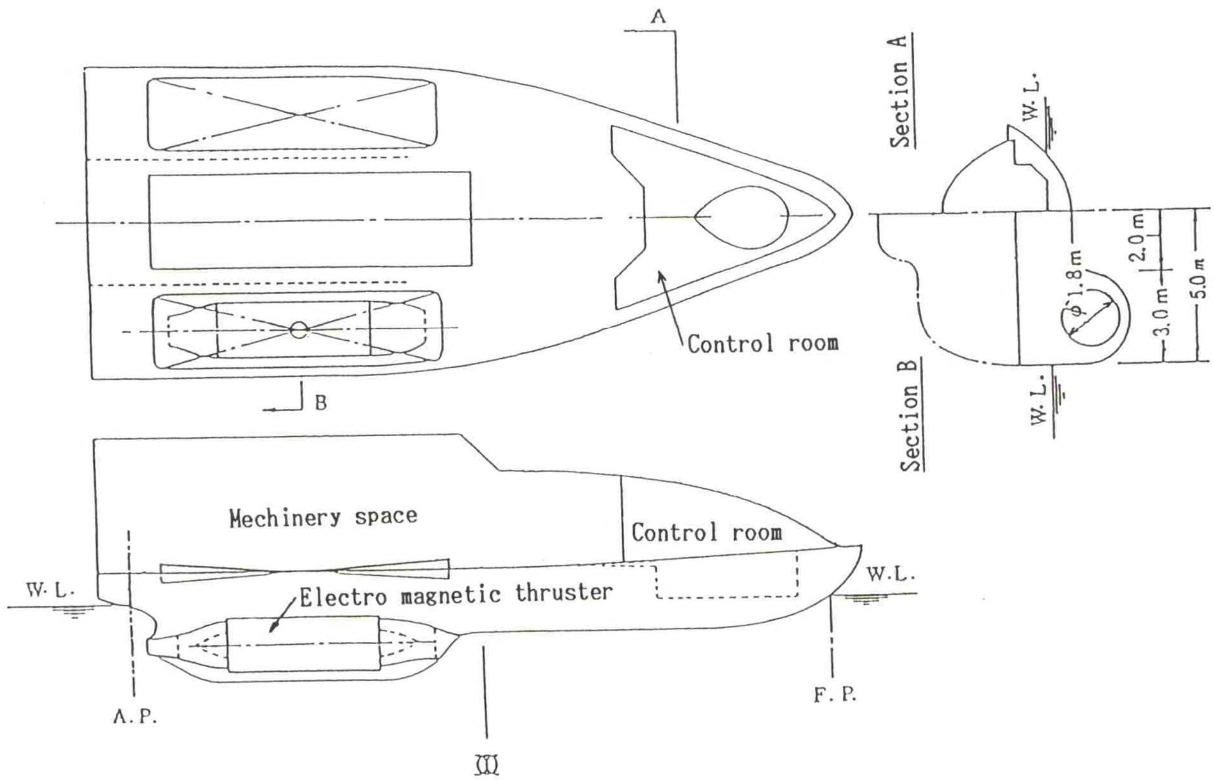

Fig.8 Rough arrangement of the experiment ship

As for the schedule of construction of the experimental ship, the propelling units as well as main engine (gas turbine), generators, helium refrigilator, etc. will be constructed in 1988, and detailed design of the ship also will be completed in 1988.

Construction of the hull and fitting of propelling system will be done in 1989 ending up at the end of 1989 followed by preliminary testing of the system. Sea trial to evalute the characteristics of the experimental ship is scheduled in 1990.

Reference

1) W. A. Rice : US Patent 2997013 (August 22, 1961)
2) Y. Saji, M. Kitano and A. Iwata : Basic Study of a Superconducting Electromagnetic thrust Device for Propulsion in Seawater, Advanced Cryogenic Engineering, Vol.23 (1967), pp. 159~169
3) L. R. A. Doragh : Magnetohydrodynamic ship Propulsion Using Superconducting Magnets, SNAME Annual Meeting, New York, November (1963)
4) S. Way : Electromagnetic Propulsion for Cargo Submarines, Journal of Hydronautics, Vol.2, No.2(1968) pp.49-57
5) S.Way and C. Davlin : Prospects for the Electromagntic Submarine, Paper 67-432, AIAA 3rd Propulsion Joint Specialist Conference(1967)

SUPERCONDUCTING ELECTRIC DRIVE FOR SHIP PROPULSION

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ABSTRACT

The U.S. Navy has been developing the technology base for advanced superconducting electric ship propulsion systems since the early 1970's. The David Taylor Research Center (DTRC) has provided the technical leadership of this program through the development of critical technologies, proof of principle 300KW drive system development, and the direction of 2250 KW model drive system development and testing. Preliminary designs of full scale 40,000 hp/shaft machinery systems have been developed and assessments of the impact of such machinery on ship design and performance completed. The recent discovery of high critical temperature superconductors has led to an increased interest in superconducting electric drive. This paper reviews the progress made in superconducting machinery technology, the potential benefits to be gained in its applications to ship propulsion and a perspective on the future of this technology.

BACKGROUND

Application of electric drives for large ship propulsion in the U.S. Navy originated with an experimental installation on the 4.1 MW per shaft collier JUPITER (AC-3) in 1913. This turbo-electric ac drive employed wound rotor induction motors. The experiment was successful and the collier JUPITER was converted to the Navy's first aircraft carrier, LANGLEY CV-1) in 1922. The electric propulsion machinery remained in operation until the LANGLEY was sunk in 1942[1].

The early success with turbo-electric ac drives led to major shipbuilding efforts in electric propulsion and over 50 vessels were constructed with these drive systems during the interim between World Wars I and II. These included five battleships (BB-43, 44, 45, 46 and 48) with 21 MW shaft output and two aircraft carriers (CF 2 and 3) with 135 MW output[2].

Application of dc electric drives in the Navy includes the use of many diesel electric submarines. Over 160 escort vessels were built during World War II with turbo-electric or diesel electric drives ranging from about 4.5 to 9 MW. Approximately 500 small surface ships have been equipped with dc electric propulsion systems in the 225 kW to 15 MW range[2].

The early Navy experience with ac and dc electric drives clearly showed their advantages as compared to contemporary turbine gear drives. The number of turbo-electric propelled ships was increased by the lack of gear cutting capacity during ship building of the World War II era. However, by the 1940's double-reduction-gear ship drive systems had become competitive in the United States and any further large scale surface ship application of electric drives in the Navy was inhibited by the higher weight and increased space requirements and comparatively lower overall transmission efficiency associated with conventional electric machinery.

ADVANCED ELECTRIC DRIVE FEATURES

Technology advances of the 1960-1980 period have provided the opportunity to dramatically increase the attractiveness of electric machinery for Navy ship propulsion. Among these technology advances was the devlopment of stabilized superconductors. Certain materials, for example, niobium-titanium, will support very high electric currents (over 60,000 A/cm^2) without resistance losses when their temperature is reduced below a critical level, typically in the liquid helium range (4.2°K). Using these superconductors in field windings of electric motors and generators, it is possible to produce very intense magnetic fields with relatively small quantities of materials and very low power requirements to maintain the superconductive state. Application of superconductive field windings, along with direct water or oil cooled armature conductors and high current density brush systems, provides very compact, lightweight electric drive machinery. The reduced weight and volume of advanced motors and generators provides an opportunity for realization of the ship design and operational flexibility advantages which are inherent to electric drive systems without the penalties of conventional electric machinery as indicated in figure 1.

SHIP FLEXIBILITY

TURBINE/GENERATOR INDEPENDENT OF MOTOR/PROPELLER — ALIGNMENT FREE ARRANGEMENT; REDUCED SHAFTING; REDUCED DUCTING; SMALL DIAMETER

OPERATING FLEXIBILITY

TURBINES SELECTABLE; CROSS CONNECTABLE; RAPID REVERSAL; RAPID ACCELERATION — NO GEARS; NO CLUTCHES; NO CRP; LOW NOISE

FUEL ECONOMY

CONTINUOUSLY VARIABLE REDUCTION RATION — MATCH PROPELLER/TURBINE OPERATION; MINIMIZE FUEL CONSUMPTION

POTENTIAL APPLICATIONS

DESTROYERS; SUBMARINES; SWATH SHIPS; HYDROFOILS; SURFACE EFFECT SHIPS

Fig. 1. Electric drive system advantages

One of the more important ship design flexibility advantages of an electric drive system results from the alignment-free machinery arrangement. Prime movers can be located remotely from the motor-propeller drive to occupy less critical spaces and to minimize ducting in the case of gas-turbine-powered ships. Smaller diameter superconductive motors will permit reductions in propeller shaft rake angle and location further astern in restricted hull spaces with consequent reductions in shafting runs.

The cross-connectability of electric drives permits individual selection of turbines on a multi-turbine ship during reduced ship speed operation. This will increase turbine availability by reducing the total operating time for each turbine during a ship mission.

Electric reversal capabilities eliminate the need for reversing gears or reversible pitch propellers. Rapid deceleration from high speeds is achievable with energy dissipation in electric resistors and without concern for turbine overspeed.

By cross-connecting turbine-generators and propulsion motors in multishaft installations, simple cycle turbines can be operated at more favorable fuel conditions. Infinitely variable speed reduction ratio dc electric drives permit optimization of turbine efficiency at various ship speeds. Through optimized turbine operation with a dc electric drive system, decreases in fuel consumption up to 25% may be achieved as compared to a non-cross-connected, twin-shaft turbine-gear propulsion system. Studies have indicated that application of advanced dc drive to destroyer type hulls could result in significant size and cost savings compared to a conventional geared driven ship of equivalent mission capability.[3,4]

The ship design and operational potential of electric drives are not limited to applications in twin-shaft, gas-turbine-powered, monohull, displacement ships such as cited in the above discussion. Small-water-plane area-twin-hull (SWATH) ships have similar propulsion power requirements to a twin-shaft, monohull ship but would most likely have a transmission path between the prime movers and propeller shafts involving a Z-configuration. Such a transmission path would be more effectively transversed with electric transmission lines than with a gear system. Compact, lightweight electric drives also appear beneficial for future high performance ships such as large hydrofoils and surface effect ships (SES's) which might have either long or difficult transmission paths and will require lightweight machinery.

SUPERCONDUCTING MACHINERY DEVELOPMENT

The original thrust of the U.S. Navy's advanced electric drive program was to exploit the technologies of superconductivity, advanced current collectors and advanced machine cooling to provide attractive drive machines for the future. Various machine concepts using one or more of these technologies were evaluated with respect to their attractiveness for marine propulsion. Although some concepts showed improvement over conventional approaches,[5,6] d.c. acyclic superconductive machines best satisfied performance requirements while taking maximum advantage of available technology. Such machines are capable of generating full torque at all speeds, have low helium refrigeration requirements since the superconductive field magnet sees no torque, have the inherent control flexibility of d.c. machines, and had the most attractive size, weight and efficiency characteristics of all machines considered.

The DTRC program proceeded in the early 1970's with the design, fabrication and testing of a 300 KW superconducting propulsion system. The motor design process, after many iterations, resulted in selection of a "shaped field" design[8] which was considered the best physical arrangement for large, low speed, acyclic motors. The machine arrangement that evolved is shown schematically in figure 2. The stationary superconducting solenoidal magnet and helium dewar are the innermost machine elements. These are surrounded by a hollow cylindrical rotor on which are mounted concentric copper cylinders. A similar set of stationary cylinders surrounds the rotor to complete the armature circuit, with current transfer between the rotor and stator cylinders accomplished through liquid metal current collectors. A ferromagnetic shield surrounds the stator, effectively confining the magnetic flux within the machine envelope. The resulting magnetic flux distribution is thus shaped to minimize magnetically induced collector losses, thus the name "shaped field machine. The 300 KW motor is shown in figure 3. The 300 KW generator design, figure 4, is similar to the motor in concept, but with the location of the field winding and armature circuit reversed in order to minimize the rotor tip speed. This change was necessary in a high speed machine design to limit structural stresses in the rotor and velocity-dependent losses in the current collectors.

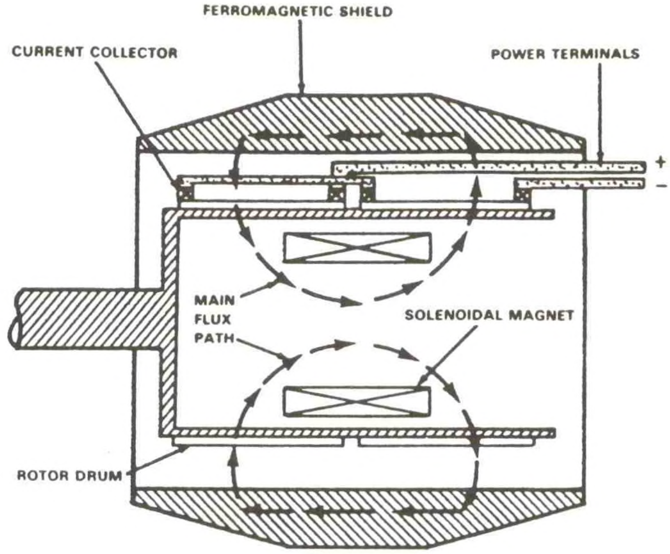

Fig. 2. Shaped Field Machine Concept

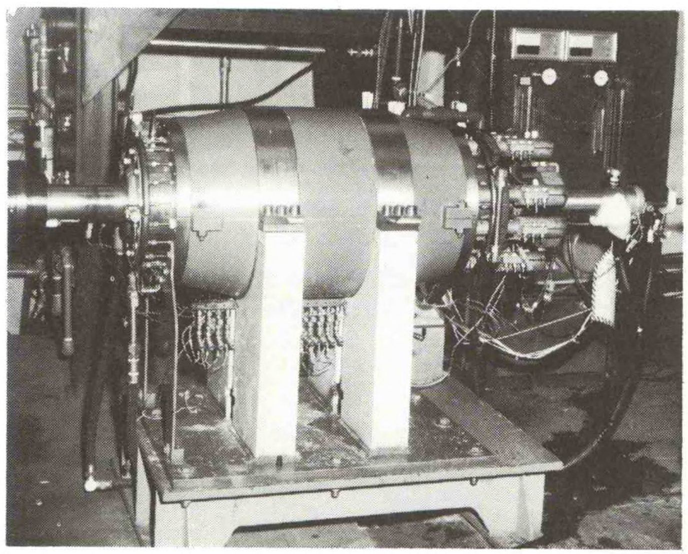

Fig. 3. 300 KW Superconducting Motor

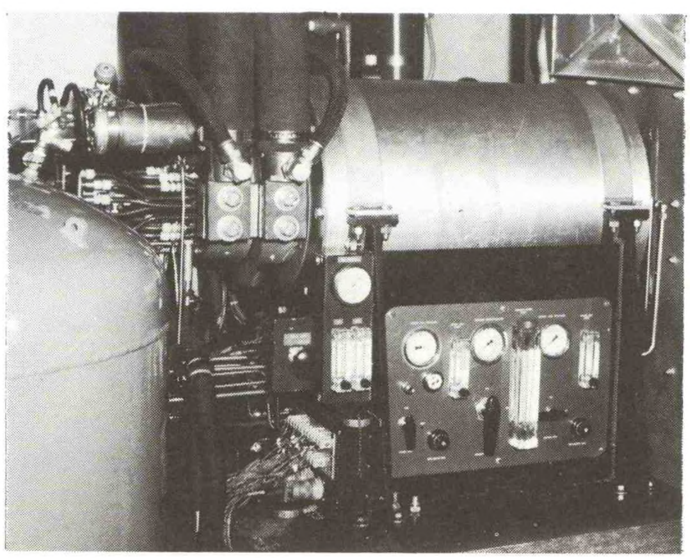

Fig. 4. 300 KW Superconducting Generator

Both machines are direct water cooled on the armature to remove ohmic and collector losses. The rotors are cooled by conduction to the stator, although in larger sizes, rotors would be cooled directly. Rotating face seals serve to confine an inert cover gas to the machine interiors to prevent oxidation of the sodium-potassium liquid metal in the current collectors.

The 300 KW effort was followed in the late 1970's and early 1980's by the design, fabrication and testing of 2.25 MW supercon ducting propulsion systems in cooperation with U.S. industry. These model machinery systems were based on full scale designs carried out by each participating contractor. The 2.25 MW machinery were specifically required to demonstrate to the maximum extent practical, the materials, design parameters, fabrication and assembly approaches required for full size 40,000 hp per shaft systems. The 2.25 MW superconducting motors developed were based on the shaped field concept described earlier. A 2.25 MW motor is shown in figure 5. The machine ratings are:

Speed - 1200 RPM
Voltage - 100 volts DC
Current - 22,500 Amperes

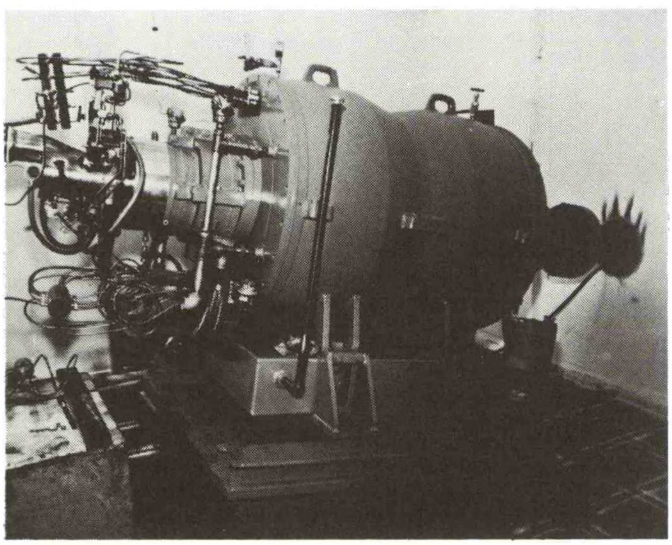

Fig. 5. 2.25 MW Superconducting Motor

Both 300 KW and 2.25 MW systems were successfully tested in the laboratory and aboard the Jupiter II testcraft shown underway in figure 6.

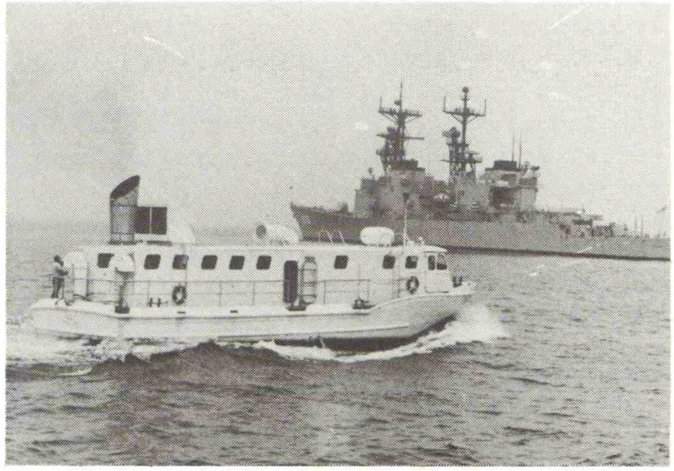

Fig. 6. Jupiter II Supercnducting Electric Drive Testcraft

CRITICAL TECHNOLOGIES

The superconductive electric propulsion program includes many critical technologies; foremost among these are: (1) superconductors and magnets, (2) Cryogenic refrigeration systems (3) high performance low loss liquid metal current collectors, (4) high current switchgear and transmission lines and (5) homopolar machine design and fabrication. Each of these has been vigorously pursued to establish an understanding of basic principles to develop mathematical models and scaling laws, and to verify feasibility in test devices and model machinery systems.

SUPERCONDUCTORS AND MAGNETS

The technology of superconductivity includes the basic application of superconductive materials to conductor configurations which can meet the system and opertional requirements of electric propulsion machinery. These conductor designs take into account the stability of the conductor to flux jumps and external disturbances causing temperature rise, and seek ways and means to improve these parametrs. Methods of reducing conductor weight by use of aluminum stabilizing material are being developed with added advantage of significant improvements in conductor stability. The effects of longitudinal strain on the critical current of superconductors was initiated by DTRC with the National Bureau of Standards in the mid 70's. This pioneering work on an extremely important property now influences all superconductive systems throughout the world especially where brittle superconducting compounds are used. The use of Nb_3S_n, as a superconductor has been investigated because of its higher transition temperature and critical field. Magnet fabrication techniques, using vacuum-pressure impregnation have been developed which allow stable and predictable performance of high current density machinery/field windings such as that shown in figure 7. Extensive work has been conducted and is continuing on superconducting magnet design, fabrication and performance improvement as well as modeling and scaling law development to assure our ability to construct full scale machinery which meets the operational and environmental requirements of Navy shipboard equipment.

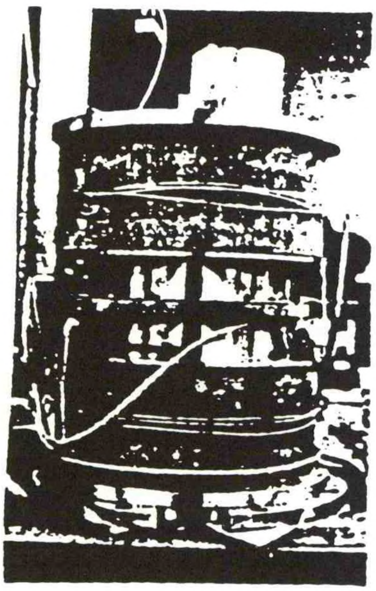

Fig. 7. Potted Magnet for 300 KW Generator

The new higher T_c materials (95K) are being considered for incorporation in propulsion motors and generators. An aggressive program will be required to develop these materials for Navy application developing processing techniques for these high T_c ceramic superconductors, undertaking the basic research related to their environmental stability, and to develop methods to fabricate the new materials into useful conductors with adequate critical current and field capabilities for magnet applications. All materials work is part of a team effort involving the machinery and materials communities at DTRC to provide for the transitioning of high T_c superconductors into electric propulsion systems applications when and if the materials are successfully developed.

CRYOGENIC SYSTEMS AND REFRIGERATION

The Navy pursued a vigorous program to develop a helium cryogenic refrigeration system to support the superconductive machinery development effort. This program focused on three main issues: (1) The development of compressor concepts to improve efficiency and reduce contamination in the gas stream; (2) Improved liquifier designs for increased reliability, shock and vibration tolerance, and performance; and (3) A suitable shipboard helium management system to minimize logistic problems and make the system self contained. The compressor developments resulted in the qualification of a screw compressor for shipboard helium service including shock test. Helium liquifiers in existence have three major drawbacks, efficiency, tolerance to shock and vibration and reliability. These are being improved on a component by component basis and significant progress is being made. A simple vibration model of the system is complete and vibration tests have been performed to verify this model. This work has provided an excellent guide for design changes to improve environmental performance and maximize efficiency. A total shipboard helium management system has been studied, designed and partially implemented in the laboratory. This system, if implemented, should be capable of acoomodating all operational situations for a complete superconductive propulsion system.

The technologies, components and design approaches developed for shipboard helium cryogenic systems hould be directly applicable to a shipboard nitrogen refrigeration system for cooling the new high T_c superconductors if they become available.

CURRENT COLLECTORS

Liquid metal current collectors have evolved as the only successful means of handling the high current densities essential to preserving the high power densities characteristic of homopolar machinery. This sliding electric contact, or current collector, must successfully operate in the very high current density, magnetic field and speed regimes of a homopolar machine. The additional requirements of low power losses and long life virtually eliminate traditional monolithic brushes, such as the metal graphites, from consideration. Liquid metals on the other hand, can provide all the proper operational charaacteristics as well as minimizing losses and maximizing life time. State of the art, continuous duty liquid metal current collectors have successfully operated in the extreme environment of 26 mega amps/m2, 100 m/sec tip velocites in 5 tesla magnetic fields. These numbers are very encouraging, being well above anticipated requirements for a full scale superconducting propulsion motor Implementation at full scale will entail considerable work to verify that the design approaches are valid at the increased diameters and tolerances, as well as shock and vibration conditions associated with full scale shipboard applications.

Research and development effort is presently underway addressing several of the key current collector issues. Fundamental research in hydrodynamic and magnetohydrodynamic flows and instabilities in current collectors is being carried out. Alternate geometries of the collector interface are being studied and of particular promise are metallic fiber brushes in combination with a liquid metal. A variety of liquid metals are being investigated with the idea of increasing simplicity of operation and reducing maintenance

SWITCHGEAR

The high currents, typically 100,000 amps, characteristic of large homopolar superconducting machines require highly efficient switchgear, not readily available, to allow control and machine reversal. A portion of the Navy program has therefore been devoted to the development of compact, lightweight switchgear consistent with the overall weight and size reductions obtained in the machines. 30,000 amp switches have been designed and constructed using Multilam[14] material in the contact regions. These switches are from 5 to 10 times smaller and lighter than equivalent commercially available switches. In addition, a unique 30,000 amp coaxial "multilam" reversing switch has been designed and fabricated at DTRC. The use of liquid cooled coaxial transmission lines in conjunction with such switches results in lightweight, compact electrical transmission systems which have the additional advantage of very low stray magnetic fields. The scale up and testing of these components is a necessary next step to verify the feasibility of full scale systems.

MACHINE DESIGN AND FABRICATION

The design of successful homopolar superconducting motors for ship propulsion requires very careful attention to the details of the materials and processes for construction. All machine designs require the interconnection of large liquid cooled conductors separated by electrical insulation in the machine armatures. Differential thermal expansion, electrical insulation, adhesives and coatings compatible with liquid metals, liquid coolant and gas seals, bearings which operate in high magnetic fields and highly stressed electrical structures are a few of the problems that required successful solutions during 300 KW and 2.25 Mw machine development. While success was achieved at this level, significant additional effort development to assure long term reliability, ease of manufacture, and affordability is now required. DTRC experience has been that many of the problems encountered in the model machine development and testing were in the area of leaks, material failures and complexity of fabrication, rather than in the "high tech" areas described above.

CONCLUSIONS

Superconductive electric propulsion systems extend the benefits achieveable with conventional electric drive rather dramatically while eliminating the drawbacks. As a result of the substantial improvement in power density, superconductive electric propulsion makes possible attractive direct electric drive propulsion systems for conventional and advanced ship concepts such as SWATH and SES. The result is ship performance improvements, reduced ship construction and opeating costs, and the opportunity to significantly increase pay load.

High power density superconductive electric propulsion systems have the following attributes:

- Smaller size
- Lower weight
- Simple control
- High machinery efficiency
- Low noise (eliminates need for gear; no magnetic or electrical variations in machine)
- Direct contrarotating capability

The essential technologies have been addressed at reduced scale (3000 hp) and now require development to the full scale levels of current, size, stress, etc.

Machinery designs incorporating recently discovered materials exhibiting superconductivity at temperatures above 90 Kelvin may revolutionize the electrical industry and could simplify existing superconducting machinery system designs. High T_c (critical temperature) superconducting materials can be applied directly to the advanced DC propulsion machinery concepts developed to date. Some increase in power density will be expected, but major changes in geometry or machine arrangements are unlikely. The major benefits accruing from the application of High T_c materials in shipboard superconducting electric propulsion machinery are:

- Reduced refrigeration power and complexity
- Simplification of machine thermal design
- Improved logistics - eliminates helium supply requirements; nitrogen can be extracted from ambient atmosphere
- Improved reliability

The machinery system and critical component technology developments required to realize full-scale superconducting machinery for ship propulsion are described above. To realize a full-scale electric propulsion machinery system employing High T_c materials will require a simultaneous intensive materials research and development program effort to obtain practical superconductors and magnet systems.

REFERENCES

1. Johnson, E.J., "The First American Floating Aerodome: USS LANGLEY (CV-1)," NAVSEA Journal, July 1977.

2. Janes' Fighting Ships 1944-45, New York, The Macmillan Company, 1946.

3. Stewart, A.J., Springer, J.H., and Doyle, T.J., "Effectiveness of Superconductive Electric Drives," Naval Engineers Journal, April 1979.

4. Rains, D.A., Van Landingham, D.J., and Doyle, T.J., "Padded Destroyer Propulsion," Naval Engineers Journal, April 1979.

5. Greene, D.L., "Analysis of Marine Propulsion System Incorporating Superconducting Electrical Machinery," MIT thesis, Ph.D., 1970.

6. Appleton, A.D., "Status of Superconducting Machines at IRD, Spring 1972," Proceedings of the 1972 Applied Superconductivity Conference, IEEE, New York, May 1972.

DEVELOPMENT OF A MARINE SUPERCONDUCTING MOTOR AND HIGH SPEED SHIP

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1. Introduction

The first proposals to power ships with superconducting electric motors and generators date back some years,and research and development have been underway chiefly in the U.S.and Britain. In the U.S. an electric motor on the superconducting electric propulsion system was completed in 1980 for use in naval vessels,and has been successfully tested at sea in an experimental boat.

In Japan,in 1979 Sumitomo Heavy Industries, Ltd. joined the Japan Marine Machinery Development Association,with the support of the Japan Shipbuilding Industry Foundation,in developing a superconducting electric propulsion system.

The development work has so far focussed on the superconducting motor. In 1982 a 50 PS homopolar D.C.motor was built for laboratory test purposes and has given satisfactory results. Work is now in progress to scale up the laboratory test motor to 650 PS.

In this article,we give a brief outline of the system and then describe the superconducting electric motor which is its main component,and high speed ship concept.

2. The System and Its Features

The superconducting electric propulsion system is no different in principle from conventional electric propulsion systems.

Although the conventional systems have many points in their favour,such as good manoeuvrability and a high degree of freedom in the machinery layout,they also have drawbacks that have restricted them to special purpose vessels which leave cost effectiveness out of consideration. These drawbachs include their heavy weight and large space occupancy,and their low efficiency.

These problems can be solved,however,and the maximum benefit gained from electric propulsion if the motor and generator are converted to a superconducting system. In comparison with conventional systems,this offers the following features:

1) Light weight
   For a generator of 20,000 HP or over, 1/5 to 1/8 conventional weight.
   For an electric motor,1/3 to 1/4.
2) Small size
   By volume,the genarator is 1/10 to 1/15 and the motor 1/13 to 1/15 convensional size.
3) Good efficiency
   An improvement of 6 to 8 percent is expected in the DC—DC type,and approximately 3 percent in the AC—AC type.

A comparison the diameter,langth and weight of the two systems was reported by Edward F.McCannll et.al.[SNAME AnnualMeet.Nov. '73].

Next,we take a look at the vessel in which the new system can be applied.

With their lighter weight and smaller size,the superconducting generator and motor have increased potential for use in many types of vessel. They show particular promise for the new special vessels in which there is limited enginespace or a long distmnce over which the power must be relayed.

The new system is believed to have particular advantages in the following types of vessel:

1) Vessels with a small space to house the engine,or a complex power transmisson mechanism
2) Vessels which require a large propulsive output
3) Vessels in which a more compact engine room (due to greater freedom of machinery layout)- would allow greater cargo space
4) Vseesls requiring high manocuvrability
5) Vessels which travel on partial loads of the maximum output for much of the time.

More specifically,some of the most promising areas of practical application are :

1) Special vessels such as hydrofoils, semisubmerged catamarans,surface effect vessels,etc.
2) Large displacement type vessels which require large output plus high manoeuvrability,such as large icebreakers,icebreaking LNG carriers, and icebreaking oil tankers.

One proposal to make effective use of the motor's light weight and small size is to house it in a pod mounted beneath the hull. The research on this proposal will be watched with great interest.

As shown in Fig.1,the complete system consists of a propulsive generator and motor with superconductor field winding,and a helium refrigerating subsystem.

To control motor speed,the Ward—Leonard system is used. As this involves varying the generator voltage by means of the field current,the field winding of the generator must be able to provide an excitation speed of 1 T/s or more. Since this means that superconducting wire materials needed for high−speed excitation,the motor and the generator must be treated differently in designing for superconductivity.

The helium refrigerating subsystem cools the superconducting field winding to the temperature of liquid helium (4K) and keeps it there in order to maintain a stable superconductive state.It comprises a cooling subsystem and a recovery and refining subsystem for evaporated helium gas. The cooling subsystem consists of a helium refrigerator which can alternately manufacture liquid helium and refrigerate at that temperature ; a helium gas compressor ; a liquid helium storage tank ; and a liquified helium condenser. The recovery and refining subsystem consists of a recovery gas bag, recovery gas compressor, recovery gas cylinder, gas refiner,etc.

The helium refrigerator equipment is the one component that is unique to this system,and even in a 20,000 HP unit it requires only 20 to 30 kW power.

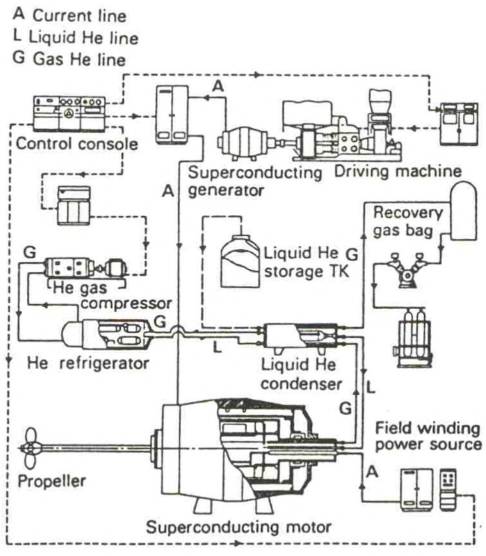

Fig.1 Schematic diagram of superconducting electric propulsion system

3. Outline of the Superconducting Electric Motor for Ships

There are several types of superconducting electric motor : the A.C. synchronous,the D.C.multipolar,and the D.C. homopolar. None of these has conclusive advantages over the others for use in ships,as each has its own disadvantages and technical problems as well. Thus the vessel's operation and sysem as a whole must be taken into account in choosing the motor type. Here, we take a closer look at the D.C. homopolar motor.

Homopolar motors were given preference over multipolar at an early stage of superconducting motor developmet for the following reasons :

1) Since the multipolar motor's armature current varies over time, A.C. loss occurs in the field winding under the superconducting state with resulting loss of efficiency.
2) Superconducting field winding can genarate a high magnetic field, but the electromagnetic force is correspondingly large. Also,when a multipolar motor is used the whole torque reaction is applied to the superconductor,which thus requires strong mechanical support.
3) As a result of 1) and 2), the multipolar motor has a greater A.C. loss in the superconductor coil and a greater heat leak through the supporting material. The refrigeraator load is therefore greater at the temperature level of liquid helium.

In operating a homopolar motor,a large current supply and large current feeding brushes are necessary. The first problem is solved by using a homopolar generator;ie.in designing for superconductivity,ideally both the motor and the generator should be homopolar. That leaves feeding and collection of the large current as the most important problem,but a current density of 105 A/cm² and a voltage drop of 90 mV can beachieved by using brushes made up of several hundred thousand metal−coated carbon fibres.

Superconducting homopolar motors can have a variety of structures. The type discussed here has the armature on the outside of the superconducting field coil.

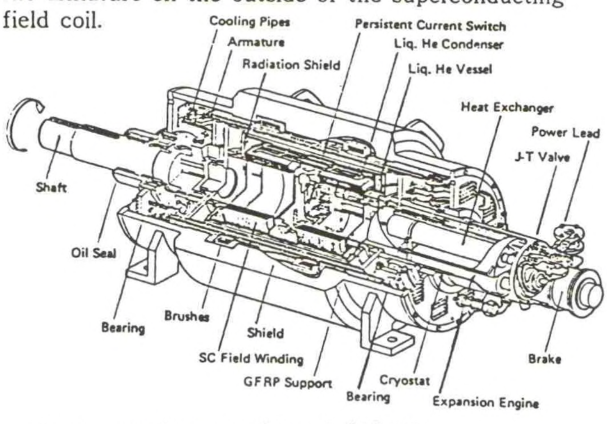

Fig.2 Bird's-eye view of 650 PS superconducting D.C. homopolar motor

FIg.2 shows the structure of an outer−drum D.C.homopolar motor.

The motor works on the principle that a radial magnetic flux is obtained between the superconducting air—core coil and the magnetic shield yoke around it,and when this radial magnetic flux links with the axial current in the cylindrical armature it gives rise to rotational force. This structure has the following advantages :
1) it enables design of small ,lightweight motor ;
2) at least 70 percent of the magnetic flux produced in the coil can be used as rotational torque, i.e. it has a high efficiency of utilising magnetic flux ; 3) it can readily be scales up for large output. On the other hand,its comlexity is a disadvantage.

As shown in Fig. 2, the superconducting homopolar motor can be broadly divided into the stator(superconducting field winding,cryostat,stator bracket,magnetic shield yoke,current collector,stator drum, power terminal, etc.), and the rotor (armature drums, armature bracket, and shaft).

The superconducting field winding is a solenoid-type air—core coil which can obtain a central field of 5 to 6T. After excitation it operates in the persistent current mode:thus it is equipped with a detachable power lead and persistent current swith.

GFRP is used to provide the cryostat (which holds the superconducting field winding at 4.2K) with a strong enough support against the ship's pitching and rolling,and the liquid helium vessel which contains the winding is a welded and gastight construction with a mechanism allowing release of evaporatedgas even when the ship is inclined.

The stator bracket supports the rotor via bearrings and the cryostat,and is itself mounted on the magnetic shield yoke.

The magnetic shield yoke has two purposes : to hold external stray flux to 200 gauss or below ; and to rectify the flux generated in the winding for effective linkage with the armature.

The current collector,installed between the rotating armature and the stationary stator drum,-feeds the armature. Metal—coated carbon fibre brushes are used ; Fig.3 shows one made for trial use. The brushes are located on the circumference at both ends of the drum.

The main components of the rotor are the armature drums. Located outside the superconducting field winding, these are divided into two drums with their currents flowing in opposite directions. The ends of the drums, where the field is weaker, are in contact with the collecting mechanism. The two drums are insulated from each other and mounted on a torque tube. Each drum is segmented along its cylindrical axis to increase the armature voltage, and the segments are connected electrically in series.

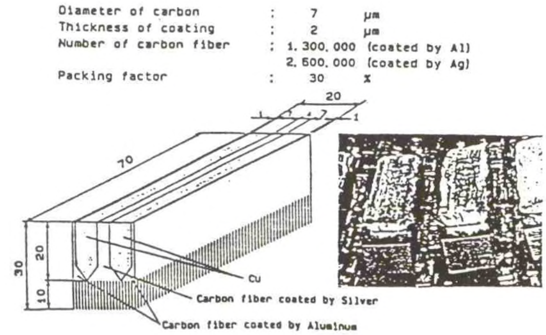

Fig.3 Metal-coated carbon fibre brush

4. The Present State of Development Work

The main components of the super conducting electric motor——the super conducting field winding,cryostat, persistent current switch,armature, current collector,etc.——have been under development since 1980. In 1982 the 50 PS homopolar DC motor was built as a laboratory machine,and it has since undergone a range of tests with satisfactory results.

Based on this work,development of a large—output(650 PS) trial motor shown in Fig.4 began in 1984,and now under testing. Their basic specification are listed in Table 1.

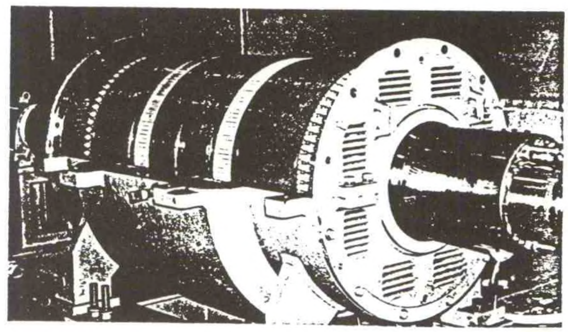

Fig.4 650 PS superconducting motor

The 650 PS motor has the following characteristics:

1) The field winding is of the split solenoid type to increase flux utilisation.
2) The superconducting field winding operates in the persistent current mode. After excitation,-

the excitation source is removed.

3) The condensation heat exchanger and refrigerating system are built into the motor for a more compact coil cooling system.
The refrigerator is a small,lightweight CLODE−cycle model using a laminated metal head exchanger developed by Sumitomo Heavy Industries, Ltd.
4) The armature uses a forced water−cooling system.
5) The current collector is a metal−coated carbon fibre type developed by Sumitomo Heavy Industries, Ltd.

Table 1 Particulars of 650 PS superconducting D.C. motor

Type	: Outer drums superconducting homopolar D.C. motor
Output	: 650 PS at 420 r.p.m.
Armature Voltage & Current	: 220 V, 2300 A
Efficiency	: Approx. 90 %
Size	: 1000 mm dia x 2700 mm length
Weight	: Approx. 4.4 ton
Current collector	: Metal-coated carbon fibre brush
Armature	: One drum -- segmented type, water cooling
Field winding	: NbTi superconductor, split-solenoid type
Persistent current	: Thermal type
Refrigerator	: Two-stage expansion, CLODE-cycle type 1 W capacity at 4.2 K

5. Concept of High Speed Ship with S.C. Motor

It is well−known that,when the speed of ship becomes high and Froude's number exceeds 0.3, then the wave making resistance becomes large rapidly and reaches its peak called "Last Hump" approximately in the range of 0.4 to 0.5 Fig.5 shows general tendency of this resistance.

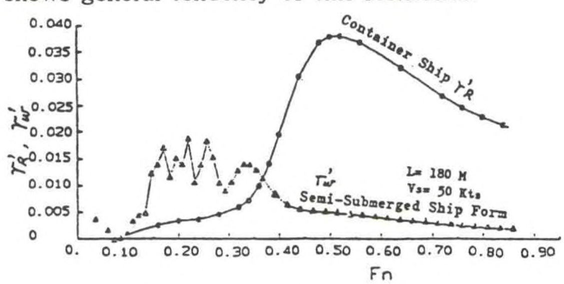

Fig.5 General tendency of wave making or residual resistance for displacement type ship

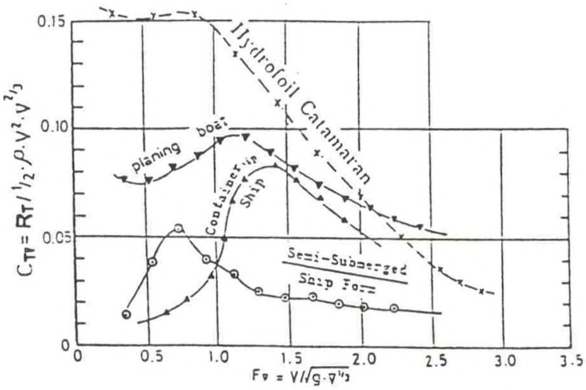

Fig.6 Total resistance coef't for various type of ship

For reduction of this wave making resistance,-various theoretical hull forms such as slender ship and semisubmerged ship form are being studied.

In addition,researches are being made on planing boat,hydrofoil catamaran,etc.as well as displacement type ship. Fig.6shows total resistance coef't for typical hull forms.

As shown in Fig.6, the increased speed of planing boat and hydrofoile catamaran,etc. results in the reduced displacement. Semisubmerged ship form shown in Fig.5 and 6 indicates possibility to satisfy the displacement and as well to minimize the wave making resistance. These theoretical hull forms need large horsepower and cannot be applied to the stern because of shaft arrangement in case of multiple shaft.

S.C. motor propulsion system is free from any restriction from shaft arrangement and therefore can apply theoretical hull form,both forward and afterward. Presently,this concept is being developed jointly by Yokohama National University,JAMDA and Sumitomo Heavy Industries, Ltd.

6. Conclusion

Development of a superconducting propulsion system for ships is only in the initial stages, and many problems remain to be solved. Experts in many fields will have to pool their knowledge;they will include electrical engineers,cryogenics experts, mechanical engineers,and naval architects who can enjoy greater freedom in ship design.

The fusion of shipbuilding and engine technology, with its long tradition,and the leading−edge superconducting technology will surely contribute much to shipbuilding and the shipping industry of the future.

OFFSHORE AND UNDERSEA TECHNOLOGY AND SYSTEMS

OFFSHORE TECHNOLOGY RESEARCH FOR THE TWENTY-FIRST CENTURY

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INTRODUCTION

In 1983, The National Science Foundation of the United States of America established the Engineering Research Center program. The purpose of the program was to stimulate research in areas of interest to American industry which would enhance their competitiveness while providing extensive participation in interdisciplinary research involving undergraduate and graduate education as an integral part of the Center's program. The establishment of the NSF Center Program demonstrated the United States' awareness of the existence of a world market for technologically based products and systems.

Texas A&M University has submitted proposals in each of the four years that this opportunity existed. The most recent proposal, submitted in 1987, was recommended for funding by a peer review group after study of the proposal, site visits, defenses and evaluation by an outside panel of experts as well as NSF management.

The Offshore Technology Research Center proposed in 1987 is a joint venture between the University of Texas at Austin and the Texas A&M University. This joint venture is the latest of a large number of research undertakings by the two universities. The primary goal of the Center is to discover, verify and provide the basic information needed to develop systems which permit economic ocean operations at great depths. Our focus on the deep ocean resources is based on strong evidence that there are one or more very large petroleum provinces in the United States Exclusive Economic Zone in the Gulf of Mexico. The challenge of these petroleum provinces is the water depth of, say, 2000 meters, and their location far from shore. The increasing level of lease bidding by American petroleum companies in the deep Gulf of Mexico presents clear evidence of the industry's interest. In addition, The U. S. Geologic Survey has announced promising seismic and geologic evidence has been developed that supports the conclusion that these petroleum provinces exist.

Our universities were encouraged to undertake research in this area in as much as offshore technology and ocean engineering are fundamentally multidisciplinary activities. We are convinced that the technology used to develop deep oil is also applicable to hard minerals, alternate energy, waste disposal and other ocean opportunities. Our increasing awareness of the international nature of the market is reinforced by the American companies' experiences in the North Sea, Brazil's competitive efforts, Korea's low-cost capability, and the United Kingdom's strong academic support of research in the area. Our approach is a classic technical research effort involving discovery and verification of basic information and its codification. The Center will educate students of all levels while gaining hands-on experience in multi-disciplinary, environmentally sound engineering research projects and provide the opportunity for the close association of industry and academic researchers in a high achievement environment. Industry support for the program is very broad and we expect it to increase as the program develops. American industry feels that offshore technology research offers a potential for needed long-range studies. The establishment of the Center at this time is particularly suitable, as optimism increases for corporate profitability and while corporate research programs are at there lowest ebb in several decades. The multidiscipline approach matches the industries' technology development practices, providing added confidence that it is, in fact, the correct approach. Such a close cooperative effort between the universities and industry oriented toward the ultimate solution of real problems will permit effective transfer of technology from industry to academia, and from the universities to the industry.

The Gulf of Mexico is an area of intense petroleum exploration and production. Existence of a major petroleum regime in this area is of particular importance as the proven domestic onshore reserves are clearly in decline, hence the area represents perhaps the last U. S. frontier for the addition of major reserves. In addition, the required infrastructure exists such as the seismic service companies, service fleets, rig builders, and an experienced but idle labor force is in place with Houston, Texas, serving as the center of the U. S. petroleum industry. However, the depth of water in the area to be developed represents a technical challenge of significant magnitude. We are convinced that more cost effective technologies must be developed if this deep petroleum is to be proven economic.

THE CENTER'S THRUST & PROGRAM

The thrust of the Offshore Center is to conduct fundamental engineering research in deep water technology with attendant education and technology transfer which can support in the first instance economical deep water offshore petroleum development. Our objectives are to foster innovative ideas and to reduce the empiricism and cost while maintaining the required high degree of reliability and safety. We are convinced that the extension of land and shallow water technology to the deeper areas

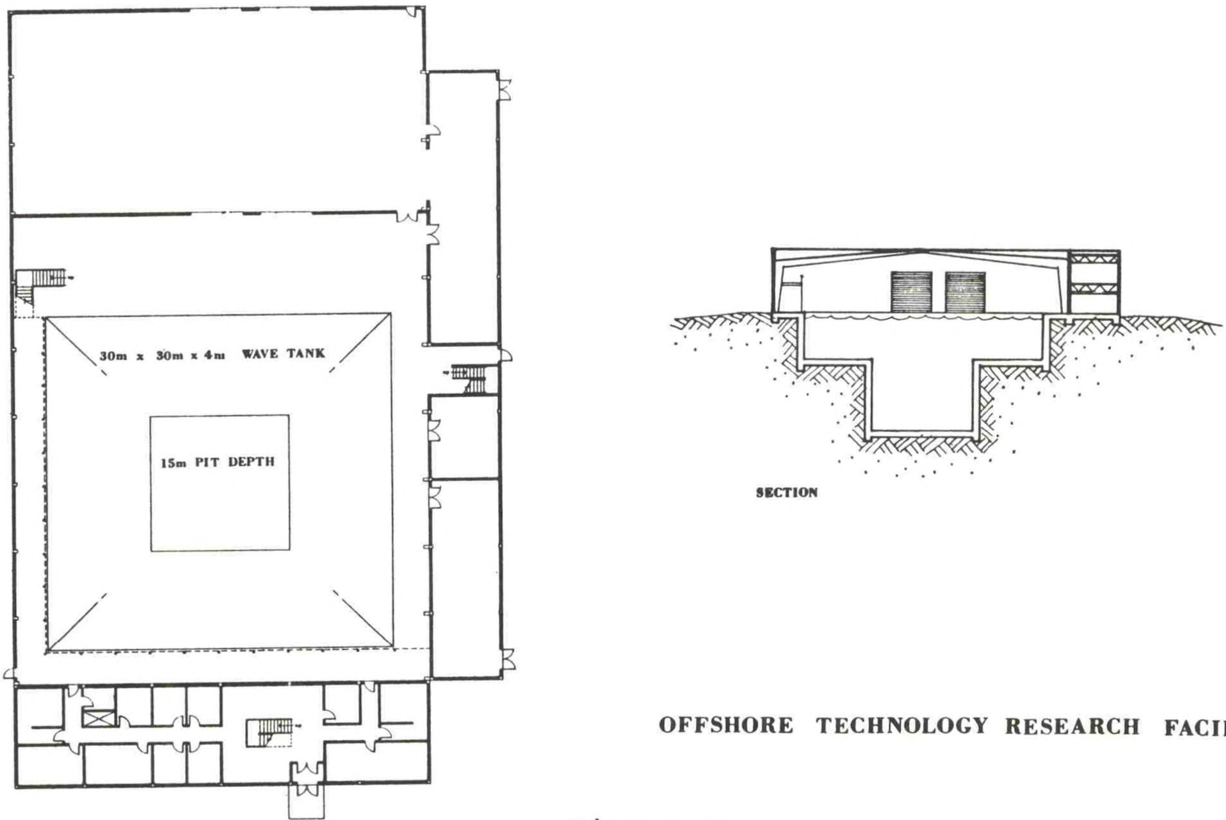
of the Ocean will raise costs to a point that deep petroleum reserves will be uneconomic unless the price of oil is extremely high.

After indepth discussions with the companies supporting our Offshore Center we agreed that three major areas should be approached in the early program. Our first area of interest is the design of mooring systems for floating platforms in the 2000-3000 meters deep ocean. We recognize that problems in hydro-dynamics such as fluid structure interaction, non linear loading, platform response and motions, and the combined action of waves, currents and mooring forces present real challenges. We believe the structure of the mooring system, its handling by auxiliary vessels and its attachment to the platform and the seabed are critical problems. In addition the development of low maintenance dependable materials for application to deep ocean mooring systems is essential.

Another area of major interest is the understanding of seabed properties at this depth. The presence of gas hydrates (the freezing of water and sediments in the presence of methane) is a major area of concern even in the semi-tropical Gulf of Mexico. The success of any deep mooring system as well as other interfaces between the seabed and systems or structures located thereon is expected to be critical to either surface or subsurface production system installation. The major difficulty of in-situ measurement exists in as much as the material rapidly decomposes and melts as it is raised to the surface unless pressurized and cooled. Basic knowledge of these materials can be developed only with the prior development of effective sensors, measuring devices, recording devices, and subsequent computer handling of the data.

A more urgent problem is the design of tendons for tension leg platforms. A compliant platform at the sea surface makes relatively large excursions from its center location. These systems are currently being developed for application in the 1000 meter depth, but to utilize this type of platform in 2000 meters ocean depth requires new knowledge and techniques. Again, we will be involved in research in the areas of hydrodynamics, structures and materials in order to succeed. Solutions to the problems identified in the research areas above are germane to the timely production of the areas currently under lease. This is a very high cost field of endeavor with the developers requiring production from the fields in the next three to five years.

The centerpiece of the offshore technology research program will be a new facility located at Texas A&M (Figure 1). A wave tank of approximately 30 meters by 30 meters with a depth of 4 meters will be built. In the center of the tank there will be a fifteen meter deep pit with an adjustable floor to provide the capability to test tension leg and other compliant platforms at various scaling factors. The tank will be equipped with



OFFSHORE TECHNOLOGY RESEARCH FACILITY

Figure 1

programable hydraulically driven wave makers on two sides and be spanned by a carriage capable of simulating motion in multi-directional waves. The purpose of the facility is to provide hands-on experience for our graduate students and to verify experimentally the computer models that are prepared to analyze these non-linear phenomena.

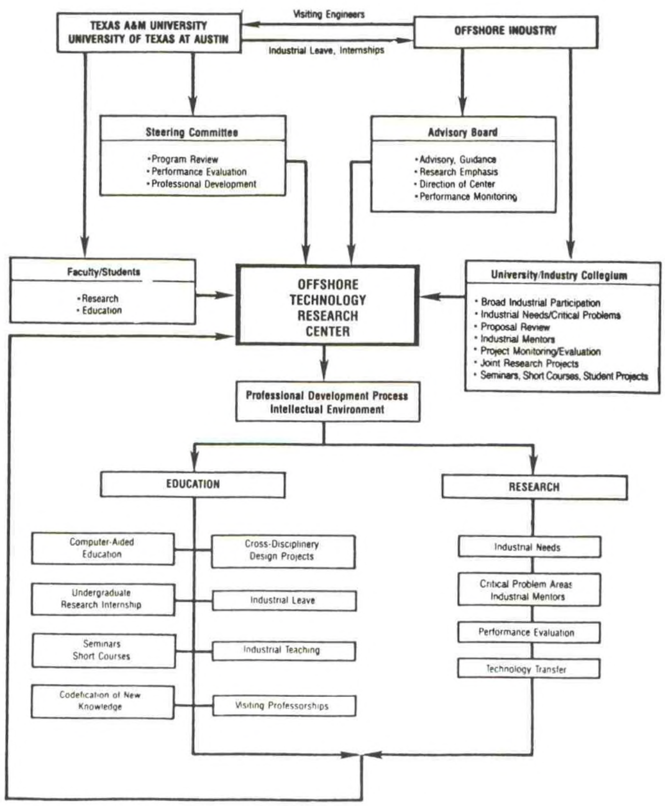
SUPPORT

The Center is very well supported by the sponsoring institutions, The National Science Foundation, The University of Texas, and Texas A&M as well as many major United States industrial companies with offshore interests.

The University of Texas has made available its Cray XMP 24 supercomputer for the solution of our complex nonlinear flow and structural design problems. In addition they will provide one million dollars in new equipment and make available the six million dollars of applicable existing laboratories at their campus. Their academic support includes providing two chairs, eight professorships, and four fellowships to attract and support outstanding faculty for the conduct of the program. Texas A&M is committed to provide the new offshore technology wave tank facility and building and to equip it with a water circulation system. In addition a chair, a named professorship and four new tenure track faculty positions will be provided. Monetary support for the development of academic curricula will also be provided by Texas A&M. The National Science Foundation's commitment is for $17.5 million dollars during the first five years with continued support based upon the success of the Center. Industry support includes major oil companies such as Exxon, Shell, Tenneco and Marathon, and corporations deeply involved in the offshore such as Brown and Root. Their current pledges amount to just under two million dollars for the initial five year period with at least twice that expected when we have completed our solicitation. The Center is interested in developing major support from Japanese corporations and institutions.

OPERATIONS

The Offshore Technology Research Center will be managed by a small staff of professionals where I will serve as the Director & Principal Investigator and Drs. Jack Lou of Texas A&M and Joseph Yura of The University of Texas will serve as associate directors. We will report to a steering committee which represents the two universities and be advised by an industry group called the Advisory Board. Major programs will include the educational coordination, the research program, and the offshore experimental facility operation. A flow chart (Figure 2) is included which clearly indicates the relationships and the industry participation both through advisory board and the University/Industry Collegium. We expect to involve both graduate and undergraduate students in all of our activities in order to fully meet both the educational and research objectives of the Center. We remain convinced that the technology developed through this effort will make a substantive contribution to the development of the offshore in the 21st century.



Essential Features and Workflow of the Offshore Technology Research Center

Figure 2

OCEAN ENGINEERING/NAVAL ARCHITECTURE NEEDS IN THE 21ST CENTURY
- MAINLY FROM THE STANDPOINT OF COLLEGE EDUCATION -

BY

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ABSTRACT

This paper discusses ocean engineering/naval architecture needs in the 21st century, mainly from the standpoint of college education. After a short introduction, the paper discusses (1) ocean-related engineering activities at present and future, (2) potential areas of future research and development, and (3) ocean engineering/naval architecture eduction.

INTRODUCTION

Since ancient times men have utilized surrounding oceans for various ways, as places for getting foods and other resources, means for transportation, battlefields, just to name a few. As scientific knowledge expands and technical know-how develops utilizations of oceans have expanded. For example, by around the 15th century it became possible to cross huge oceans by sailing ships resulting in discoveries of the new world. By the 19th century large steel ships propelled by screws powered by steam engines became available resulting in significant reduction in time and cost of ocean transportation. Large and powerful warships were developed.

Tremendous changes have occurred during the last 50 years. Days of huge oceans liners and battleships have been long gone. A large number of people fly over oceans in hours, not days, every day. Man-made satellites scan over oceans providing almost continuous information for various applications ranging from military surveillance, weather forecast, communication, and navigation assistance. Large portions of oil and gases that we use today come from under the sea bottom. We are making man-made islands for var-ious uses. It is certain that many new other activities will be made for using oceans.

As our utilizations of oceans increase, there will be more concerns about preserving natural environments. Many issues, some of which are contradictory and/or competing, will be debated on a local, regional, national, and international levels.

Political situations for managing and using oceans will become more complicated. Until recently, oceans beyond three miles off the coast belonged no nations. The new treaty of the law of the sea, drafted during the 1982 United Nations Law of the Sea Conference, has been signed by many nations. The main contents of the draft include establishment of 12-mile territorial zones, 200-mile exclusive economic zones, and equalization of profits obtained from deep sea developments. The world has entered a new regime of the law of the sea.

These scientific, technical, economical, social, and political changes will undoubtedly cause profound changes in all aspects related to oceans. And educational and research activities in universities are no exception. This short paper discusses ocean engineering/naval architecture needs in the 21st century mainly from the standpoint of education and research in universities, especially in departments related to ocean science and technology. Professor Judith Kildow and I organized an MIT Industrial Liaison Program Symposium entitled "Oceans in the 21st Century: Bringing Advanced Technology to the Ocean Industries, " in October 1987. At this symposium Professors Koichiro Yoshida and Tekeo Koyama of the Department of Naval Architecture of the University of Tokyo and I jointly presented a paper entitled "Present Status and Future Directions of Ocean Engineering Education and Research in Japan." I also gave a talk entitled "An Overview of Ocean Science and Engineering Research." Large portions of this paper come from the above-mentioned two articles.

OCEAN-RELATED ENGINNERING ACTIVITIES AT PRESENT AND FUTURE

Educational and research activities in universities should ultimately meet needs of the society. Therefore, it is worth studying ocean-related engineering activities at present and future. Engineering fields for practical uses of ocean may be classified into:

(1) Ocean-land interface engineering, including engineering activities for developing harbors, preserving shore lines, reclaiming foreshores, etc. Many of these activities have been traditionally included in civil engineering.

(2) Ocean transportation engineering, including shipbuilding and navigation engineering. Many of these activities have been traditionally included in naval architecture, and marine engineering.

(3) Fisheries and ocean biological resources engineering for developing food and medicines. Many of these activities have been traditionally included in fishery.

(4) Sea bottom mineral resources development engineering for obtaining oil, manganese modules and other mineral resources. In fact, engineering activities needed for exploration and production of offshore oil and natural gases have been the major driving forces for expanding traditional engineering activities into what is now regarded as ocean engineering.

(5) Engineering for ocean energy utilizations, including power generation by ocean currents, wave power, and ocean thermal energy conversion (OTEC).

(6) Seawater resources development engineering, including desalinization of sea water and extraction of uranium and other solvent materials.

(7) Ocean space utilization, for utilizing vast spaces above and in the sea as well as on and below the sea bottom for various purposes.

(8) Ocean military utilization engineering, including those activities performed by the navy and the air force. This engineering field is listed in the end, because this paper mainly discusses non-military uses of the oceans.

POTENTIAL AREAS OF FURTHER RESEARCH AND DEVELOPMENT

An important aspect of research and education in a university is to advance the state-of-the-art of science and technology. Presented below are examples of research subjects which the author thinks that good potentials exist for further research and development. The underwater acoustic technology consists of:

(1) Ultrasonic technologies including sensors for transmitting and receiving ultrasonic waves, controlling, and amplifying these waves

(2) Information processing technologies that include processing of a huge amount of signals and transforming them to information meaningful in both time and space. Further advancements of underwater acoustic technologies can be achieved through improvements of ultrasonic and information proces-sing technologies.

We believe that significant advancements can be achieved by combining underwater robotics and power technologies. As far as basic principles of automatic control are concerned, the fact that a robot is immersed in water does not create major problems. In fact, the speed and acceleration of an underwater object are rather low resulting in a relatively low load needed for controlling computers. However, problems exist in developing forces needed for mechanical control. Also there are problems for making the system immersible to water, especially in increased depths. These problems are more severe in controlling a remotely operable vehicle (ROV) for various works that require large powers compared to an ROV for observation. In either case, there are some problems with maneuverability, duration period, and safety. Further R & D efforts are needed (a) for improving element technologies and (b) for developing standards for selecting power adequate power systems.

Efforts also should be made for developing mechanical joints with improved reliabilities at larger depths. In order to accomplish this goal, we must improve our understanding on friction and wear of joints between instruments operating in deep sea.

Regarding design and fabrication of underwater structures that can withstand high pressures of deep sea, the following efforts are needed:

(1) Improve theories of buckling strengths of shell structures

(2) Develop new materials and fabrication technologies that will allow fabrication structures with increased buckling strengths

(3) Develop new structural design that will provide increased space underwater.

For structures needed for production of sea-bottom oil at increased depths, several types of compliant structures including tension leg platforms (TLP), guyed towers, and articulated towers have been developed and used. Further efforts should be made on:

(a) Development of a structure with less vibration by having soft connections between sources of vibration and the structure

(b) Development of a structure with an increased resistance against corrosion by having an increased ability of absorbing impact energy by locally reducing the rigidity of the structure.

Other structures with various specific characteristics may be developed through new structural design, materials and fabrication technologies.

More R & D efforts are needed for improving capabilities for minimizing and controlling corrosion through such technologies as coating, lining, painting, and cathodic protection. Through these efforts it should be possible to develop ocean structures and instruments that are more reliable and economical. Efforts that are needed include (a) new synthetic paints, (b) new surface finishing methods, and (c) new materials with improved corrosion resistance. Also needed are studies of fatigue crack growth of structural elements and joints exposed to corrosive environments. These studies will not only increase fatigue lives of ocean structures and instruments but also improve our knowledge of estimating their usefulness. Considering the enormous costs needed for installing ocean structures and instruments, these studies are essential.

So fat I have discussed further advancements of existing technologies. There are many opportunities of developing new practical applications as stated below.

It is now known that cobalt-rich crusts exist on sides of seamounts approximately 1,000 meters (3,300 feet) deep. Hydrothermal deposits containing metal sulfides also have been confirmed at ocean ridge regions 2,000 to 4,000 meters deep. Manganese nodules containing various metals exist on deep ocean bottoms. Efforts should be made to design and construct systems capable of performing surveys, test drillings, as well as actual recovery of these materials.

Although reclaiming foreshore has been done for many years, it becomes non-economical for over certain depths, say over 50 meters. In order to utilize space in these middle waters, new types of ocean structures that can be constructed at reasonable costs are needed. Critical problems that need to be solved include proper methods of supporting weight of a large floating structure and position it securely. Design and construction of large floating breakwaters capable of controlling and suppressing waves will enable development of large calm waters that can be used for various purposes.

In order to develop artificial fisheries, seaweed farms, and ocean ranches, we need various systems including man-made seabeds, artificial upwelling generating devices, and large net structures of which movements can be remotely controlled. With these and other new developments, the amount of fish catch in the world can be increased significantly.

OCEAN ENGINEERING/NAVAL ARCHITECTURE EDUCATION

I have been seriously concerned about the future of education ocean engineering and naval architecture. Today in the world, there are a few hundred universities that have departments of naval architecture and/or ocean engineering. In fact, college education on naval architecture started around 100 years ago when building of large ocean-going commercial and military ships, especially ocean liners and battleships, required the most advanced technologies at that time. The basic curriculum of naval architecture, which may be called principles of naval architecture, was developed. The curriculum on what is commonly called ocean engineering has been developed rather recently to meet mainly the needs of the offshore petroleum industry. However, the core curricula of naval architecture and ocean engineering that include hydrodynamics, structural analyses, thermodynamics, and design have remained virtually unchanged. A question here is:

"Should we teach more or less the same thing for the next fifty years?"

If the answer is no, the next question is:

"What changes should be made?"

In my opinion, many departments of naval architecture and/or engineering, especially in prestigious universities in advanced nations, have problems these days. Firstly, industries that have traditionally hired large portions of their graduates are struggling. The military shipbuilding is no longer as big as it used to be in many countries, except two superpowers. Centers of commercial shipbuilding that have moved from the United States to Western Europe and then to Japan are shifting to Korea, Taiwan, and perhaps to Mainland China in the not-so-distant future. The offshore oil industry that prospered in the 1970's and the early 1980's has suffered from low oil prices during the last few years. Secondly, technologies applied to marine industries today do not normally represent forefront of science and technology as they once did many years ago. This causes the decline of academic standings of departments of naval architecture and/or ocean engineering within universities to which they belong. I believe that we are already experiencing some symptoms as follows:

(1) Academic levels of students admitted to departments of naval architecture and/or ocean engineering have decreased over the years.

(2) Significant portions of students graduating from ocean-related departments seek employments in fields unrelated to the ocean.

(3) Some universities have abolished ocean-related departments or consolidated them with non-ocean-related departments.

However, if we think about the importance of the oceans for our lives and those of future generations, we must have strong academic programs covering subjects related to the oceans. In order for an academic program to be strong and truly useful, it must cover subjects that are needed to further advance forefronts of science and technology related to the oceans. One problem here is that because of the immense size and enormous complexity of the oceans, studies and education of ocean-related science and technology have been fragmented. For example, some people are mainly interested in fishing, while some others are concerned with ocean transportation. And some others are interested in studying ocean currents. As a result, various scientific and technical disciplines covering different aspects of ocean have been developed. They include fishery science, ocean civil engineering, naval architecture, navigation technology, and oceanography. As science and technology advance, there have been more and more narrow specializations.

I believe that we must seriously consider how to educate young people who will enter ocean-related professions. I fully recognize that I am addressing an extremely complex subject with no simple and clear-cut answer and that education is not among central subjects being discussed in this panel. I do believe, however, that the problem has become serious enough to warrant some attention in this panel. For any profession to to operate properly and maintain proper reputation in the society, it is essential to maintain flow of qualified young people into the profession.

At the end of this paper, I would like to briefly discuss just two subjects as follows:

(1) Ocean engineering/naval architecture curricula in future

(2) Development of texts for future curricula.

Ocean Engineering/Naval Architecture Curricula in Future

I believe that present curricula employed by many departments of ocean engineering and or naval architecture need considerable revisions. I recognize that a particular curriculum used by a certain school has been developed to meet its operating conditions including its history, regional and/or national needs, availabilty of faculty members, and relationships with other depaertments in the school. Nevertheless, present curricula used in many departments are basically what are commonly called ocean engineering, ocean civil engineering, offshore engineering, naval architecture, and marine engineering. Although there are some differences among these technical disciplines, the present curricula tend to cover subjects related to design, construction, operation, and maintenance of various structures that operate in the ocean. There is no doubt that future cullicula will cover these subjects; however, there exists a strong demand for expanding the curricul to cover the following fields:

(1) Political, economical, and management aspects of ocean-related activites. Ocean engineers in the future have to deal with political, economical, and managerial problems as well as technical ones.

(2) Advanced sciences and technologies as applied to ocean-related activities. It is important for students to learn the most advanced knowledge at anytime and how to apply it to ocean-related subjects.

(3) Fields that can be regarded as border regions between ocean engineering and ocean sciences. Up to now, most of naval architects and ocean engineers have dealt with ships and offshore structures operating in relatively shallow water. In the future, however, they must deal with systems operating much deeper waters. They will also have to deal with various systems quite different from conventional ships and offshore structures.

In order to accommodate these fields within the class schedule, curricula on traditional naval architecture and ocean engineering may have to shrink to some extent.

Development of Texts for Future Curricula

One problem that we will face if we decide to expand the curricula to include the above-mentioned fields is a shortage of qualified faculty members and adequate texts. Of course we can try to train young people and develop textbooks in a conventional manner. We should also try to use unconvetional methods for developing tests such as those mentioned below.

One possible method for developing texts covering new subjewcts will be to develop a series of video lectures. Unique advantages of video lectures are effective uses of visual and audio assistances.

Another possible method is to develop an encyclopedia covering all important subjects in all fields of science and engineering related to the oceans including naval architecture, marine engineering, fishery, navigation, oceanography, etc. The encyclopedia will be extremely useful if it is written by experts in many nations so that information generated in various parts of the world is included. Such an encyclopedia is not only useful for students but also for professional people working in the industries, government agencies, and other organizations. In fact, many companies are now trying to expand their activities from traditional fields such as shipbuilding and offshore engineering to broader fields related to the oceans. A critical problem is that there is no extensive book that can provide up-to-date information covering all subjects related to ocean science and engineering.

RESEARCH NEEDS IN OCEAN ENGINEERING

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Prior to a discussion of research needs in ocean engineering, it is important to impress upon the reader that the focus of this paper is on long range research leading to new and improved technology that contributes to the improved utilization of the ocean areas. Therefore, this paper addresses the perceived needs for new knowledge that can be applied in the future. As always, in dealing with the future, we must be prepared to make mid-course corrections, as time progresses and reassess the directions that the technology and the system needs dictate.

Ocean engineering began as the application of engineering principles and processes to the design and operation of ships. Subsequently, the discipline was applied to the development of large-scale harbors and terminals to accommodate larger ships with heavier cargoes. This in turn led to the design and building of structures to endure the ocean's attack and the building of structures in less-than-solid and floating platforms.

Ocean engineering now includes the development of highly sophisticated and "smart" subsea work systems.

The future challenge will be to develop and use these smart machines and technologies to serve as extensions of man to work in the marine environment.

The new engineering initiative at the National Science Foundation has been designed to compliment and augment the activities taking place in the ocean science reseach areas. As such this new initiative tends to be interdisciplinary and couples the engineering research needs with the ocean science programs. The objective of the ocean engineering intiative is to identify and advance engineering knowledge fundamental to future needs in the ocean environment, and to enhance the U.S. academic infrastructure so as to foster technological innovations related to the conservation, development, and use of ocean resources. Engineering solutions developed for other environments are often inappropriate, sometimes counterproductive, and occasionally catastrophic in the ocean environment. Mathematical models and design and synthesis methods are needed to better adapt man's tools to the ocean environment and its impact on structures, materials and facilities.

The development of low cost, safe and effective capabilities to provide ocean generation of food and fiber, energy production and distribution, non-traditional transportation, and the occupation of ocean space, require a substantially enhanced ability to design and synthesize solutions to engineering problems in the ocean environment. This in turn will mandate improved understanding of the ocean's physical, chemical, and biological properties.

Research Areas

The Ocean Engineering Initiative will support research in many generic areas. Some examples include:
(1) Autonomous Ocean-Based Systems;

A major need for development of ocean resources is the design of autonomous vehicles and other devices capable of operating efficiently over extended periods of time in an ocean environment. Design of such systems will require the development of sophisticated and reliable artificial intelligence capabilities.
(2) Materials in the Ocean Environment;

The design of safe, reliable, and economic engineering systems for operation in the ocean reliably in the marine environment for reasonable periods of time. There is increasing interest in the use of advanced materials, including composites, that promise corrosion resistance and favorable strength-to-weight ratios. Almost nothing is known about the long-term behavior of these materials in and around seawater. Specific research areas that have been identified as of high priority include: (a) The effects of fatigue cycles on strength retention in sea water,
(b) The combined effects of static stress and corrosion on strength retention, (c) Effects of biofouling on structural reliability,
(d) Stress corrosion and fatigue for buried elements, and (e) Effects of high pressure at moderately low temperatures on mechanical properties. (3) Sensing, Processing, and Communications of Ocean Data;

The design of multiple sensor systems, multiple-technology sensor systems, and the integretion of their outputs is essential to the effective characterization of ocean data. Most current ocean characterization systems have only a few sensors, and few take advantage of sensor systems making use of more than one sensor technology. Specific sensor technologies include quantitative use of backscattered/reflected acoustic systems, introduction of multiple frequency sonars, and design of electromagnetic techniques for detecting conductivity anomalies.
(4) Synthesis and Design of Large-Scale Ocean Structures for Reliability;

The design of complex, large structures and associated support facilities that will function consistently and reliably in the marine environment is central to many aspects of exploiting the ocean environment. Failures have occurred during the past decade due to designs which did not adequately reflect the effect of the ocean environment under extreme conditions. New approaches based on improved understanding of the various ocean phenomena are of particular interest.

NSF encourages development of research programs in the above areas in which research is conducted at, or in conjunction with, a Federal research laboratory (e.g., a Navy Department of National Oceanographic and Atmospheric Administration research facility), other universities, or private-sector laboratory when proper equipment or instrumentation is not available at the University.

The research activity also lends itself to cooperative efforts with on-going programs, and specifically with international collaboration. Since the cost of research in ocean engineering is very high, international cooperation is essential and will benefit all countries equally. An example of this cooperation is the "International Advanced Robotics Program (IARP)" that has been active since the Heads of State met at Versailles in 1982. The most recent activity planned by the IARP is the Second International Workshop on Subsea Robotics organized by Japan, France, and the United States. This workshop is scheduled for November 14-16, 1988 in Tokyo, Japan.

The intent of the workshop is to provide an informal forum for the benefit of the participants and to encourage international collaboration in the area of subsea robotics. The organizers invite papers which describe research projects in progress as well as completed works. Examples of the topics to be coverd by the workshop are:

- Subsea robotics projects in each country
- Manipulator for subsea work
- Locomotive mechanism and control systems
- Sensor and visual sensing technology
- Subsea communications
- Autonomous control
- Teleoperation
- Man-machine interface
- Artifical intelligence technology for subsea robots
- Power and energy systems
- Other subsea robotics topics

Recently, the National Science Foundation supported a meeting at the University of California at San Diego. This meeting was attended by a group of outstanding researchers and sought to develop a general agreement on research needs in ocean engineering. The following is a short summary of their findings and conclusions:

Research needs were identified against several criteria:

-Importance to ocean engineering
-Significant influence of the unique attributes of the ocean environment
-Appropriateness for NSF Ocean Engineering funding
-Potential linkages to other disciplines and to other funding sources
-Topics which are focused on problems of the deep ocean

During the workshop, there was a considerable body of discussion concerning priorities for research. In the final product, only those research needs judged by the participants to be critical were reported. No attempt was made to provide a list of research proposal topics. Rather, research needs were described in the broadest terms possible to allow for creative and unorthodox proposals.

Five research areas were identified as critical, some with subareas within them:

- o Dynamics of Structures
  - Free surface hydrodynamics and the response of structures
  - Long, flexible structures
- o Water Column Utilization
  - Living resources
  - Biotechnology
  - Non-living resources
  - Critical water column kinematics
- o Seabed Utilization
  - Modeling of dynamic deformations
  - Measurement of resources and engineering properties
- o Electromechanical Systems
  - Automation for improved assessment and work capabilities
  - Energy transmission and generation
- o Materials for Ocean Engineering Applications
  - In each of these critical areas, the problems are defined and the present state of the art is assessed.

The research needs under each subarea are identified and the linkages to other disciplines are discussed.

The Co-Convenors of this meeting were Professor Richard Seymour at the University of California, San Diego, and Professor William Webster at the University of California, Berkley.

Clearly, the above list indicates the vast and complicated task that is before us if we wish to more fully utilize the oceans of the world. Progress will be slow but let us never lose sight of the rewards and benefits for all of mankind.

JAPANESE 6,500M MANNED DEEP RESEARCH SUBMERSIBLE PROJECT(2ND REPORT)

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ABSTRACT

This is a second report of the 6500m deep manned submersible which JAMSTEC(Japan Marine Science and Technology Center)is now developing. Following to the first report which describes the design concept and main features of the submersible, this paper presents more detailed features of her subsystems with the highlights of applied advanced technologies.

The experience in construction and operation of "SHINKAI 2000" integrated with researchers'reguirements have been real advantages to fabricate, test and establish these subsystems.

This submersible named as "SHINKAI 6500" is to be completed in FY1989.

INTRODUCTION

The recent opinion research among scientists and researchers in Japan reveals that the necessity for ocean and deep sea research is stably increasing in the various scientific fields. Especially the development of a manned submersible which can penetrate to the depth 6000m class becomes an urgent issue in the fields of geology, oceanograpy and biology.

With the help of advanced survey systems such as deep sea camera, the medium depth submersible "SHINKAI 2000" has played an improtant role and has got valuable data in the recent deep sea activities. At the same time, the information and confidence obtained in the development and operation of the submersile are well utilized for the new one.

The JAMSTEC's goal for manned reseach submersible system for deep sea field is to establish the integrated research system with combination and collabolation with support ships and ROV system which can conduct advanced survey and rescue operation.

MISSIONS AND REQUIREMENTS

The world down to 6500m depth requires far more laborious travelling than those which surface or space world do.

The primary missions of the manned deep submersible are not only transportation to the bottom but close contact observation and flexible research just above the deep sea floor. To accomplish these objectives, the following functions are required as performance of well established systems.

:High speed mobility in elevation to make the research mission effective

:Low speed manouvability in observation to enable the close contact observation

:Effective Sensing,Monitoring and Measuring

The operational time schedule of the submersible is designed as;

Research and Observation	3 hours
Launch / Recovery	1 hours
Descent/Ascent Elevation	5 hours

The reliability consideration has been conducted by appling the means of Fault Tree Analysis (FTA) and Failure Mode and Effect Analysis (FMEA). Consequently emergency strategies for each subsystems are defined and realized to maintain self bouyancy and finally to release the rescure bouy.

SUBSYSTEMS AND SUPPORT TECHNOLOGY

1 Structure and Configulation

To reduce the travelling time between the surface and sea floor becomes a critical issue for deep sea research submersibles. And it is typically accomplished by two means; first by reduction of the weight of the submersible itself and secondly by the improvement of hydrodynamical resistsnce drag of the hull.

A material of titanum alloy (Ti-6Al-4V) is adapted for pressure hull and pressure vessels because it presents high strength-weight density ratio.And highly advanced technologies such as electron beam welding procrdure and three dimension machining process are also adapted while their validity is confirmed with a series of tests.

Structuring with pressure resistant vessels is minimized by introduction of oil immersed pressure compensated containers such for the main circuit of power transister inverters.

The wind tunnel test with scale model proved that a considerable improvement of the drag could be attained by the converted vertically slim body and by fairings especially in bow part and horizontally stabilizing fins.

Principally titanium frame works are assembled to support the pressure hull, pressure vessels and every equipments in its defined configulation These T-sections and built-up frames are assembled by Tig welding procedure in the dust free clean zone in the factory.

In order to lighten the body, FRP material is widely adapted to skin plates and ballat tanks. CFRP(Carbon Reinforced Plastics) is applied to the top and bottom plates of the ballast tanks where extra static strength are required.

In subsea to compensate the submersible's weight to the density of seawater, bouyant material is quite necessary and important. To accomplish light and pressure resistant bouyancy material (density of 0.54gr/cm^3 and collapse pressure of 1200kgf/cm^2), the unique structure of binary mixtured microbaloon and fabrication procedure of vaccum plastic immersion and heat hardening treatment have been developed. The production test with sampled pieces for every producing lot has been carried out and proved sufficient performance both in density snd strength.

2 Powering Systems

The electrical power system of this submersible is mainly composed by two groups of main batteries, a distribution pannel and power transister inverter/ control circuit inverter, and also emergency battery unit. The schematic diagram of the electric system is shown in Fig.1 which adapt the parallel wiring as widly as possible to insure the reliability.

The main batteries are composed of silver zinc cells with the property of high energy density to space and weight and of long serving life. Their capacity is 108V X 400Ah for each two groups and the life of two years long. To evaluate the life of the battery, the cyclic charge/discharge test with high currency (about 30A) has been performed since the early days of design and planning. The sufficient property of the battery cell is confirmed.

For the purpose of effective and accurate speed control of the AC induction motors equipped, the submersible adapts inverters with VVVF/PWM (Variable Voltage and Variable Frequency/ Pulse Width Modulation) control algorithms.

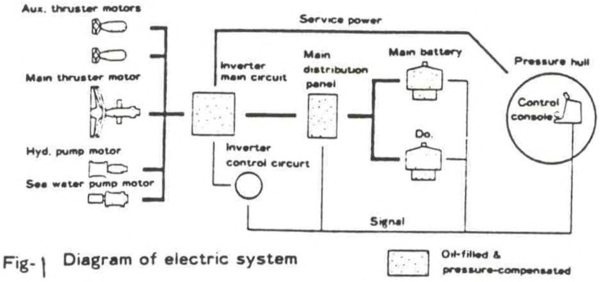

Fig-1 Diagram of electric system

Including almost all cables and penetrating connectors, the electrical equipments, except control circuit parts, are oil immersed for pressure conpensation. For the first time in the world, the main circuit parts (power transistors and large electrotic capacitors) of the transister inverter withstanding the maximam pressure of 1020kgf/cm^2 and an operating pressure of 680kgf/cm^2 have been developed and assembled into practical system.

Hydraulic power source has a capacity of 140 kgf/cm^2 pressure x 12 l/min flow quantity and the line and every equipments are designed to be automatically compensated to the ambient depth pressure. Every hydraulic actuators in the system are tested in the high pressure test tank most recently.

3 Ballasting and Trimming System

The primary and and main ballasting for elevation is acheived by releasing the ballating weight of steel plates installed in four blocks, two for ascending and two for decending. The auxilliary pressure tank can control the weight of the submersible within 150 kgf by charging or discharging sea water with high pressure seawater pump.

Trim ballancing up to 10 degree is attained by transfering suitable amount of heavy mercury to the bow or stern tank with pressured oil flow powered by a pair of axial plunger pumps.

All oil lines and hydraulic equipments are pressure compensated to the ambient depth pressure with a center pressure compensator.

Based on the experience of the " SHINKAI 2000", an unique variable ballasting mechanism is put to use. The ballating control of the auxiliary tank is attained by synchronized switching control of four directional valves, a balancing valve and seawater pump. The valancing valve keeps the output pressure of the pump a little higher than suction side while the directional valves change the flow into or out of the tank. The pump applied in this system is a one of axial plunger type with plungers and cylinders coated with ceramics of high fatigue resistance.

4 Propulsion System

The main thruster installed at the stern part of the submersible can alter its propulsive direction horizontally. Coupled with side thrust by the horizontal thruster at the bow, the main thruster can create the yawing moment and traversing force to arbitrary direction.

The control unit of the propulsion system installed in the pressure hull is so practicaly composed with double control sticks that the pilot can operate the vehicle looking at the external condition through the view ports.

The two vertical thrusters installed at the midship can cantrol its altitude in the speed of 0.5 kt while above horizontal movement is attained.

With the main thruster the submersible can obtain aheading speed of 2.5kt or thrust force of 350 kgf maximamly while the horizontal and vertical thrusters can give the thrust force of 30kgf and 100kgf respectively

5 Observation and Instrumentation

Two manupulators are equipped to realize a good sampling capability. One of them is controlled by the master-slave mechanism which would secure the high degree of freedom in sampling action.

Viewports are still useful means in contact observation. Two TV cameras with high resolution of 500 horizontal lines , a still camera and lighting equipments are also installed in the observation front.

Other monitoring instruments and sensors- the CTDV, the currency meter, the gyroscope and so on- are equipped in their appropriate position.

The redundancy in power source in the submersible makes extra electrical connectors and hydraulic oil port available to temporary payload instrumentation.

6 Environment Control System

The confortable research environment for the crew is also maintained by the constant discharge of oxygen equivalent to the amount of consumption and the absorption of carbon dioxide which is measured in "SHINKAI 2000" system practically.

The condition is continously monitored by the partial gas pressure sensors for each gases and the alarm is to be given to the panel board and simultaniously presented in the Integrated Information Display System.

The life support duration is designed normally 9 hours and 129 hours in the case of emergency.

7 Acoustic Navigation and Imaging

Principally the submersible has double means to locate herself acoustically. One is to locate the position by the acoustical link of her synchronous pinger, transponders at the seabed and the transducers of the support ship on the surface. The location of the submersible measured by the support ship is transmitted to submersible through an underwater telephone. Another mean is to detect her position by herself. Above the seabed the submersible can perceive the response of the transponders identically which has an unique frequency individually and can locate the position just like the manner of LBL positioning.

Besides the major navigational equipments, acoustic systems, such as altitude sonar and observation sonar are to be installed. By a transducer at the bottom of the submersible, crew can monitor her altitude from 1000m to 1m graphycally on the CRT in the cabin.

The observation sonar has two kinds of useful and valuable functions ; radar charting as Plain Position Indicator (PPI) which works within the range of 300m and acoustic imaging which can perceive the object within 110m. In this system acoustic transmitters and receivers are arranged to form a cross linear array. The vertical transmitting array generates a horizontal thin fan beam and a horizontal receiving array a vertical thin fan beam to perform a narrow pencil beam directing the intersection of the two. The two beams are electrically sector-scanned respectively to produce the two-dimensional angular resolution while its range resolution is obtained by measuring the propagation time and phase delay of the acoustic pulse signals.

Consequently the position and shape of underawater objects and also sea bottom profiles can be distinguished.

Operation procedure of approaching and observation to a target is simulated as follows;

(1) Acoustic navigation mainly by yhee surface support ship

(2) Acoustic navigation mainly by the submersible itself

(3) Target identification by the observation sonar

: PPI mode for long distance

: Tomographic imaging mode for short distance

(4) Contact observation by optical means

To secure these acoustical performance, noise spectral level and its frequency distribution of every loaded machinary are evaluated and controlled by the well defined testing procedure. The hydraulic pump with lower operating noise level was selected after the noise monotoring test at sea and acoustic tank

8 Information Monitoring and Data System

During operation following four modes of systems infomation are graphically displayed and monitored selectively with the Integrated Information Display System (IIDS).

:Navigation and manuvoring information such as heading , depth and revolution ratio of thrusters
:Trimming and ballasting condition
:Electrical operation data such as battery consumption, voltage and currency and resistance of the main cables
:Environmental condition

The useful data for operation and maintenance and supporting data for observation and measurement are to be automatically logged with IIDS.

SHINKAI 6.5K Data System is composed of three principal components; the S6.5K Data Collector, the S6.5K Video/Picture System and Top Lab. Replay System.

The S6.5K Data Collector is mainly composed of IIDS which displays and memorizes periodically sampled data among the operational and environmental data for futher reference.

As S6.5k Vodeo/Picture System, the submersible equips two TV cameras. One of them can alter its sight angle holding the same photo angle with a still camera. Two sets of video system can be installed for their recording and acoustical tomographic pictures by the observation sonar are also to be recorded with these video systems.

The upstream interface to the Top Lab. System is restrictedly composed of the Replay PC subset. The mission of these system is to read out the discrete data files of the S6.5K Data Collector and to transfer their format, from MS-DOS to IBM format, in order to link the Top Lab. Data Management system (Top Lab. LAN). and also the file structure of the replay system is open to enable users to edit and establish the disired information out of the files.

9 Reliability and Safty

Since the early stage of concept making of these submersibles, the analytical procedures of FTA and FMEA have been introduced to evaluate and analysis the reliability and safty of their systems.

From the view point of safty, radical design synthsis is conducted in the design of each system and its boundaries. For instance ;

- Battery power source is separated in two independant groups
- The releasing mechanism of main ballast is doubled by hydraulic actuator and chemical gas jettisonning bolts. And also fail-safe concept is introduced against electrical black-out
- Emergency battery unit is installed in the hull to keep the environmental conditioning and communicating capavility with the surface at any situation.
- Design criteria and Testing procedures for pressure resistant hull and view ports are established based on evaluation of thematerial property and thefabrication and assembly technology
- Besides the jettisonable ballast weight, the vehicle is also provided with releasing devices of redundant equipment to realize emergency lift

PROGRESS OF CONSTRUCTION

The pressure sphere hull is completed in Jan. 1988 fitted with the hatch cover plate, electric connectors and view ports. And the final pressure and leakage test is scheduled in coming April at DTRC (David Taylor Research Center) in Bethesta U.S.A..

The submersible is to be fully fitted within this year and its diving test will be conducted in summer 1989.

AUTONOMOUS UNDERSEA VEHICLE TECHNOLOGY DEVELOPMENT

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ABSTRACT

The David Taylor Research Center (DTRC) is presently conducting research and development related to ships and submarines that can have a profound impact on the advancement of autonomous vehicle technology. In addition, DTRC is operating a semi-autonomous unmanned undersea vehicle (UUV), called the Large Scale Vehicle (LSV), for hydroacoustic research at the Acoustic Research Detachment, Bayview, Idaho. This paper describes the LSV program and discusses technologies that are being developed at DTRC for application to autonomous undersea vehicles (AUVs).

INTRODUCTION

Autonomous undersea vehicles are self-propelled, unmanned vehicles that have preprogrammed guidance and logic systems. Once launched, these vehicles can complete their missions without further human interaction. The AUV is a subgroup of the general class of UUVs. A wide variety of UUVs with varying capabilities have been developed for commercial and military use. In the Navy, UUVs are a promising means to extend the capabilities of the submarine and surface ship, particularly in providing connective and remote sensing and surveillance capability at sea. As an additional benefit, UUVs will allow the R&D community to introduce emerging technologies that may be useful in manned submarines, but need to be proven in unmanned vehicles.

The areas of UUV development are divided into four main topics:

- Hull technologies
- Power/propulsion- and auxiliary-systems technologies
- Guidance, navigation, control, communications, and mission logic technologies
- Payload

DTRC's expertise lies primarily with the first two areas--hull technologies and power/propulsion- and auxiliary-systems technologies. This paper describes DTRC's experience with an R&D UUV (the Large Scale Vehicle, LSV) and with clusters of technologies or general technologies that can be applied to future UUVs.

LARGE SCALE VEHICLE

The LSV is a battery-powered, direct-drive dc-motor driven, scale model of a full-sized submarine (Fig. 1). All onboard systems are operated by a ship control computer (SCC); all operations are conducted within a radiated noise range and controlled by an acoustic tracking and communication system (ATACS); see Fig. 2. An onboard instrumentation system records a variety of important parameters: forces, vibrations, strains, pressures and pressure distributions, cavitation, and airborne noise. Acoustical range instrumentation allows for recording and analyzing radiated noise eminations from the LSV. Future capabilities may be provided for determining target strength characteristics, wake surveys, and video monitoring the LSV while surfaced and submerged. For the next several years, the LSV will serve primarily as a platform for testing performance-enhancing hardware being developed for the new-design attack submarine.

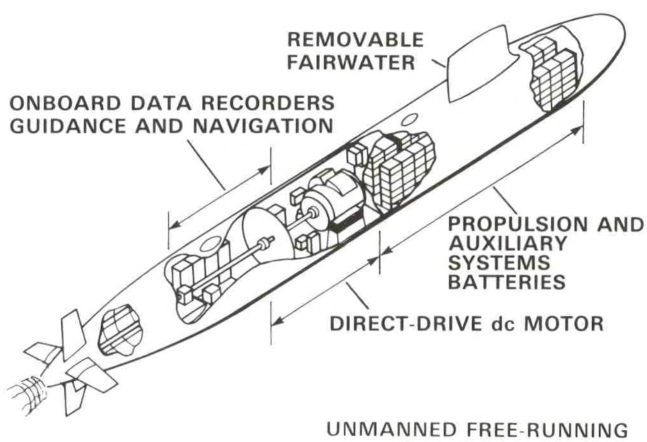

Fig. 1. Large Scale Vehicle general arrangement.

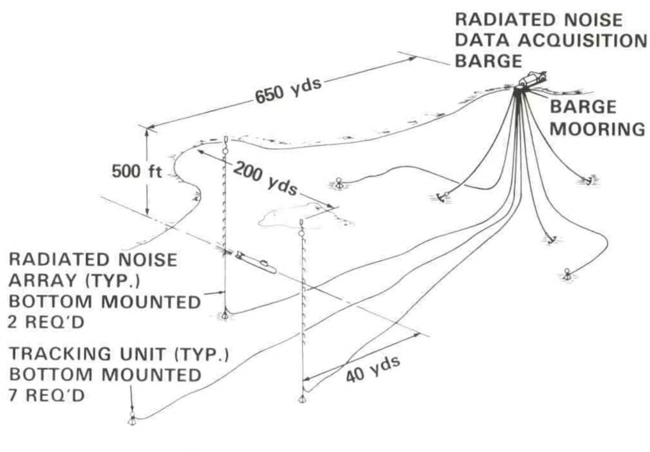

Fig. 2. Radiated noise array installation.

The LSV hull is scaled from the full-sized submarine and has the requisite fairwater and other control surface appendages, which are removable. The pressure hull contains the batteries, propulsion system, auxiliary systems, onboard instrumentation, and the SCC. The fore and aft nonpressure hull house the ballast tanks, high-pressure air flasks, ATACS transducers and instrumentation, and--control and monitoring systems for the propulsor. The hull is approximately 88 ft long, 10 ft diameter, and displaces 155 tons.

The propulsion system consists of main- and loiter-propulsion motors, a drive train, shaft seals, and the propulsor. The system provides propulsive means ranging from a loiter condition to flank speed. The loiter-propulsion motor minimizes drain from the batteries at low transit speeds and provides a backup in case of main-motor failure. Motor speed varies from 350 to 600 rpm. The aft fixtures for the attachment of the propulsor to the nonpressure hull are designed to allow relatively easy replacement of alternate propulsor candidates. The main propulsion motor is rated at 3000 hp.

The electrical system comprises three battery systems and systems for propulsion, hydraulics, trim and draining, and cooling and ventilation. The main battery provides propulsion power to the vehicle. A 28-V instrumentation battery serves the guidance, navigation, and control electronics system. An emergency battery is provided in the event the main battery fails; battery charging and shore power systems are also incorporated.

The guidance, navigation, and control (GNC) system includes the components necessary for maneuving the LSV while on the acoustic range. The GNC system is preprogrammed to direct the LSV in a variety of maneuvers. All operational parameters are recorded by GNC instrumentation.

The SCC controls the LSV during on-range maneuvers. LSV reactions to commands are monitored continuously and compared to expected responses and to emergency recovery procedures initiated when threshold values are exceeded. An emergency mission abort command may be transmitted through the ATACS. The SCC controls the inertial navigation system, which provides output of acceleration, velocity, position, heading, and attitude readings.

Instrumentation and control systems that interface with the SCC include motor control, battery monitoring, power distribution, ventilation control, trim and drain monitoring and control, cooling water, compressed air, hydraulics, steering and diving, casualty monitoring, and communication links.

An RF modem link provides a secondary means of communication to the LSV while surfaced.

The LSV is stored and maintained on an LSV support barge which houses shops, shore power, cranes, shiplift facilities, and a computer center. Much of the analysis of the recorded data can be accomplished on the support barge.

HULL TECHNOLOGIES

DTRC hull technology necessarily requires interaction with a wide spectrum of disciplines, such as acoustics, structures, hydrodynamics, materials, and production technology. In the area of UUV development for the future, the pressure- and nonpressure-hull designs range from conventional ring-stiffened cylinders to hybrid, sandwich configurations using aluminum and titanium, composites of glass, KEVLAR, and graphite, or a hybrid of these materials. The development of these structural-material technologies must always be tempered in the Navy's case by the impact on the acoustic and nonacoustic, hydrodynamic properties, i.e., those propertiés that are vital to the particular mission of the UUV under consideration.

A major thrust for advanced UUV pressure and nonpressure hulls is composite materials technology. The major reasons for this are: the reduction of the hull-weight fraction that allows for increased payload; the transfer ability of manufacturing technology from the aerospace industry for large-scale productions of multiple units resulting in overall reduced costs; the possible transitioning of this technology to manned submarines in the future; and the inherent ability to optimize material and/or structural performance found in composite construction. Table 1 shows the potential payoffs of composite pressure hulls.

Table 1. Potential payoffs of composite hulls.

Payoffs	Impact on:
Reduced signature	Acoustic system Electric system Magnetic system
Rapidly expanding industrial base	$10 billion a year industry $1 billion a year in domestic industrial R&D investment
Improved design capability	Development of complex shapes Development of net shape Development of hybridization
Highest strength and weight	Allows heavier weapons payloads Allows vehicle to be submerged to greater depths Allows vehicle to attain greater speed
Lower acquisition and life-cycle costs	Lower costs due to using multiple domestic sources Low finished article cost Low overhaul costs due to the use of noncorroding materials

It is important to remember that composites should be considered when building structures. The development of this technology will not be easy because there are major problems with the following: the elastic response of thick sections in compression; the procedures for curing thick sections; the difficulty in providing the required hull penetrations; and reliable defect techniques. DTRC is actively pursuing R&D in composite structures technology using a stepwise approach whose ultimate goal is the production of composite pressure hulls for combatant submarines. Intermediate goals include the manufacture of high pressure air flasks, control surfaces, non-pressure hull components, machinery and foundations, and pressure hulls for UUVs.

Development and certification of the hull structure to meet requirements of operating depth, shock resistance, and weight-to-displacement criteria are only the beginning in the overall incorporation of a balanced design of the AUV. Another aspect of the problem is the powering and resistance of the entire vehicle. Optimum hull shapes for hydrodynamic efficiency are notoriously difficult to pack with the necessary equipment. Marrying the hull form to the propulsor is critical to the success of the AUV design. Alternate means of lowering resistance and powering requirements in AUVs are being developed and evaluated at DTRC. Active and passive boundary layer control and advanced propulsors are two active areas of research.

Given the proposed missions for UUVs being developed for the Navy, the acoustician must be actively involved from the very beginning of the R&D effort. In the area of composites, with the ability to tailor the structural and material characteristics during construction, the possibility for incorporating novel acoustic silencing features is greatly enhanced. Imbedded viscoelastic dampers, and decoupling and absorbing materials are examples of these technologies. Once the design is matured, acoustic testing can be accomplished to verify the design concepts used.

Nonacoustic signal reduction is an area receiving increasing emphasis at DTRC. Electromagnetic, infrared, radar, and wake signatures generated by the UUV will become more critical in the context of achieving the eventual absolute minimization of the nonacoustic signatures. Here again, composite hull technologies can be used to achieve dramatic reductions.

The analytic tools used in hull development are supported by the testing facilities resident at DTRC. Structural and material experimental efforts can use a variety of pressure chambers, including the use of the Deep Ocean Pressure Simulation Facility, shown in Fig. 3. It is capable of accommodating whole vehicles up to 27 ft in length and 10 ft in diameter and in pressures to 10,000 psi. Hydrodynamic and acoustical studies may be carried out in a model basin, a maneuvering and seakeeping tank, several wind tunnels, circulating water channels, and an anechoic flow facility. Acoustic testing facilities are being used in Bayview, Idaho. A Large Cavitation Channel is being constructed in Memphis, Tennessee.

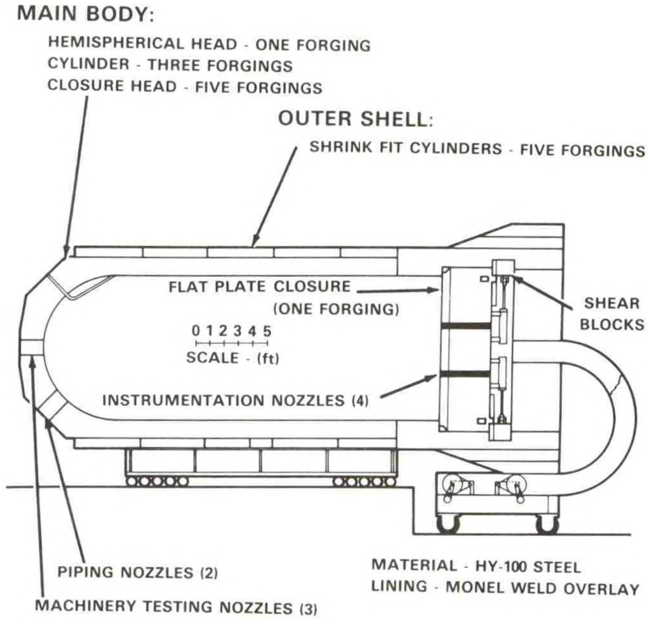

Fig. 3. Schematic diagram of Deep Ocean Pressure Simulation Facility.

PROPULSION AND AUXILIARY MACHINERY TECHNOLOGIES

DTRC is presently pursuing an integrated electrical drive system for surface ships and eventually submarines. Today's designs focus on liquid-cooled conductors used in propulsion generators and motors, and in power conditioning equipment with direct cooling semiconductor devices providing high voltage, high power services. Future designs will focus on the use of superconducting technology to reduce size and weight and provide simpler control and higher efficiency. DTRC has nearly 20 years of development experience in advanced superconducting electric drive systems (Fig. 4). and now has demonstrated a 3000 hp design at sea; Figs. 5 and 6. This technology, now being developed for Navy ships, could offer opportunities for higher propulsive power density

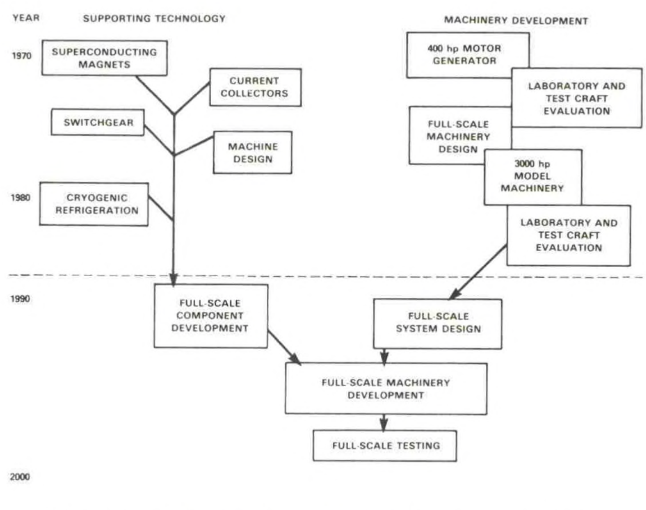

Fig. 4. Development experience in superconducting electric drive.

for AUVs, especially if higher transition temperature materials such as metal-ceramic oxides recently discovered could be adapted for use in electric drive components. These higher transition temperature components will significantly improve the logistics requirements, simplify cryogenic designs, reduce the refrigeration requirements, and offer a range of superconductor applications. Figure 7 graphically

Fig. 5. Superconducting Electric Device Testcraft.

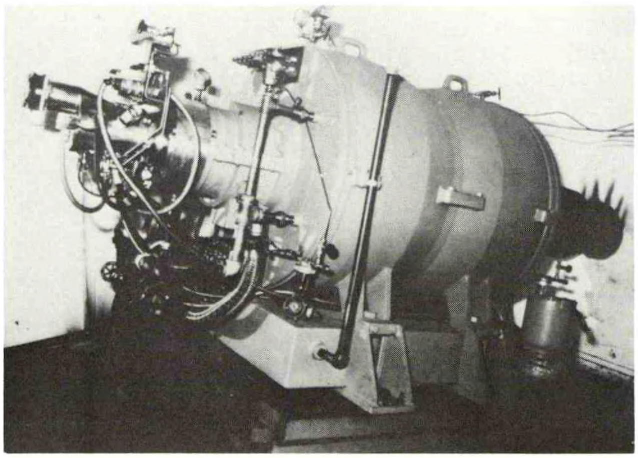

Fig. 6. 3000 hp superconducting motor.

shows the areas where superconductor technology could be adapted to AUVs. DTRC has identified critical machinery technologies and maintains programs in each of the areas leading to a fully integrated system.

Limitations in battery technology can be reduced by the introduction of superconductivity to auxiliary motors and power cables, markedly improving overall system efficiency.

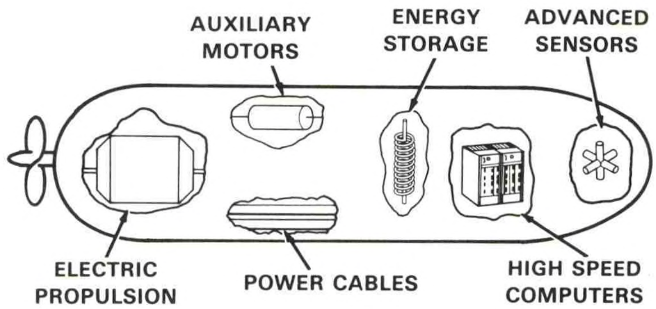

Fig. 7. Superconductivity revolution potential AUV applications.

SUMMARY

The Navy will be using AUV technology in the form of the LSV for the next several years. (The initial program will be to develop manned systems by testing the unmanned system. Scaling the size of the LSV can be performed in both directions. Presently we are scaling from a model to a larger manned system. In the future, the Navy could use the same technology to scale down to a smaller unmanned system.) Minaturization, implying a very sophisticated system, must come with technology to reduce size, weight, and complexity. Composite, materials and superconducting propulsion and auxiliary technologies can offer benefits which will meet the performance goals for both the Navy and industry. These technologies are advancing at the David Taylor Research Center and we expect to play major roles in the future development of AUVs.

TRAINING OPERATION OF DEEP ROV DOLPHIN-3K

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ABSTRACT

Dolphin-3K, the largest and the deepest ROV in Japan, which is also the deepest non-launcher type ROV in the world was completed in August 1987. The depth record of Dolphin-3K was 3,429 meters during seagoing test, then the system delivered from MES(Mitsui Engineering and Shipbuilding Co.Ltd.) to JAMSTEC(Japan Marine Science and Technology Center). Training operation by staffs of JAMSTEC was succeedingly carried out in August, 1987. 6 dives were successfly conducted onboard the SWATH ship KAIYO(2,853 tons) except for minor troubles with sensors. In the late 1987 to early 1988, NATSUSHIMA(1,553 tons) which is a support ship of the manned submersible SHINKAI 2000 was modified and DOLPHIN-3K system was installed on her. Then the 2nd training operation was carried out at Suruga Bay, depth rating 1,342 to 2,075 meters. 12 dives were carried out in the operation and the total dive number were 31 including test operation by MES. The total dive time was 145 hours and the total bottom time was 61 hours. This paper shall describe the performance and the operational capability of the DOLPHIN-3K during those training operations.

INTRODUCTION

The vehicle is planning to use for scientific reconnaissance surveys and rescue of the manned submersible SHINKAI 2000 which is operated by JAMSTEC. The purpose of those training operations were to exercise the most adequate and safe method of operation mentioned below.

(1) most safe method of launch and retrieval.
(2) operation using DP(dynamic positionning) ship and non-DP ship.
(3) exercise of route tracking using both ships, and also to complete most adequate operation manual.
(4) training of vehicle operators, manipulator operators, operation supervisor and operation director.
(5) training of rescue of manned submersible.
(6) exercise of bottom survey and sampling.

Training operations was carried out by staff members of ROV Research and Development Group, Deep Ocean Exploitation Technology Department, some members of Operation Departmennt were included as trainees.

SPECIFICATIONS OF THE DOLPHIN-3K

Main specifications of the DOLPHIN-3K is shown in Table-1 and the detail of the vehicle is shown in Fig.-1. More detail specifications of the system was already reported (1), (2).

THE RESULTS OF TRAINING OPERATION

1st training operation was carried out in August, 1987 onboard the SWATH ship KAIYO which has DP capability. 1 launch and retreaval and 6 dives were successfully carried out except for minor troubles with sensors. 6 dives were carried out in Sagami Bay, depth rating 415 to 1,892 meters(Table-2). 3 diving site were chosen because of their varied topography and bottom community. The 1st site was a place of clam community which was found around subduction zones. Rich living and dead Caryptogena was found in the site with a kind of stone crabs and some gastropod. 7 function master-slave manipulator functioned very well and water, clam , rock and sediment samples were collected. Excersize of hill climb and route tracking were also tried and went well. During the operation, full DP of KAIYO or automatic headding keeping mode were used and both functioned well.

12 dives were carried out onboard NATSUSHUMA in Feb.1988 at Suruga Bay, depth rating 1,370 to 2,075 meters. Fig.-2 shows lauch of DOLPHIN-3K using dumper and lift winch installed under the A frame of NATSUSHIMA. Both manual station keeping and forward steaming mode of operation were exercised. NATSUSHIMA could keep her position on the circle of about 200 meter diameter when keeping station manually. Launch and retreaval, sampling and documentation training and route tracking training which were necessary capabilities for scientific reconnaissance surveys were carried out. Transponder search which is needed for rescue of manned submersibles was tried 6 times. The procedure of the transponder search is as follows.

(1) Fly vehicles about 300 meter distance from a transponder by SSBL transponder navigation display and position data.
(2) The direction of the transponder is displayed on the CRT of acoutic direction finder, a pilot fly vehicle manually by the display. Automatic acoustic direction keeping is functioned about 200 meter from the transponder, then the pilot drive vehicle forward direction until CRT of OAS(Edo Western, Obstacle Avoidance Sonar) shows a shadow of the transponder. OAS can catch the transponder distance about 50 meter.
(3) The pilot fly vehicle until to see the transponder by TV. The altitude of the transponder from bottom is 20 meters, the pilot descend the vehicle at a sinker chain. The vehicle catch a rope of transponder by manipulators as a simulated works of rescue of manned submersible.

Fig.3 shows a photo of sinker weight and rope of transponder and manipulators, depth about 1,380 meters.

Training operation using DP, SWATH ship and mono-hull non-DP ship was successfully carried out, training of rescue shall be continued in this year.

REFERENCES

(1) Hattori,M. "SEA GOING TESTS OF DEEP ROV, DOLPHIN-3K" Proc.,ROV '88,in press.
(2) Nomoto,M.and Hattori,M. "A Deep ROV "DOLPHIN-3K": Design and Performance Analysis" IEEE Jour.of Oceanic Eng.,vol.OE-11, No.3, July,1986

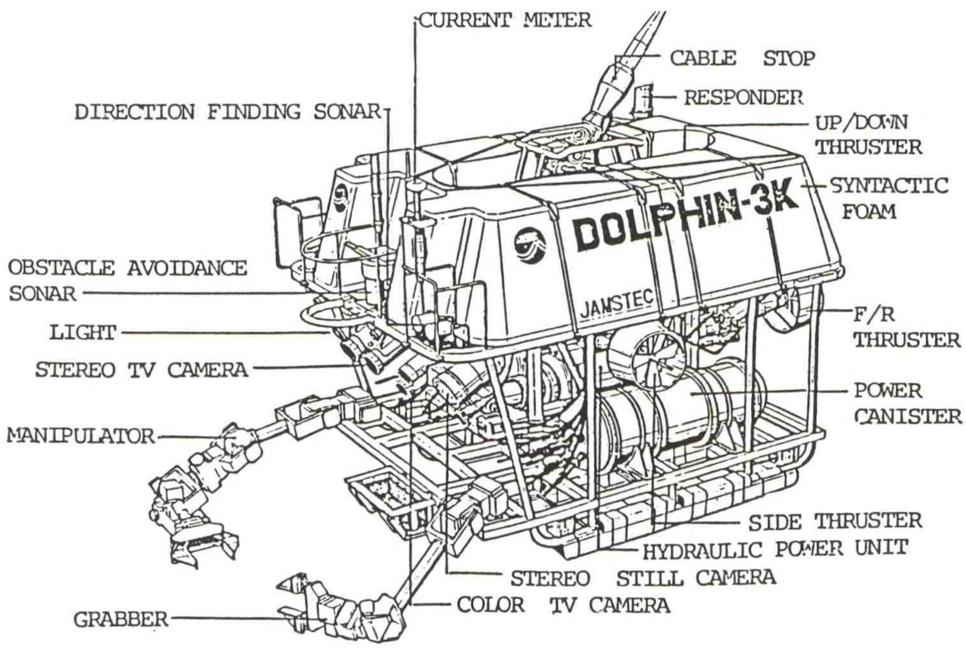

Fig.-1 Detail of the DOLPHIN-3K vehicle

Table-1. Main specifications of the DOLPHIN-3K

(1) Dimension	285(L)x194(W)x196(H) in cm	
(2) Weight	3700 kg(in air) -10 kg(in water)	
(3) Operational depth	3300 m	
(4) Payload	150 kg	
(5) Speed	Designed	Measured max.
forward	3 kt	3.29 kt
reverse	2 kt	2.08 kt
lateral	1.5 kt	1.69 kt
up/down	1 kt	up 0.98 kt down 1.30 kt
rotation	30^{o}/sec.	35^{o}/sec.
(6) Propulsion		
for-rev	2 x 15 HP(11.3 kw)	
lateral	2 x 9.5HP(7.1 kw)	
vertical	2 x 9 HP(6.8 kw)	
(7) Hydraulic system	Hydraulic system composed of 40 kw 2250 v 3 phase AC motor and piston pump which provides hydraulic power to thrusters, manipulators, cutters and pan & tilt units.	
(8) Instrumentation	Color TV camera with pan and tilt unit, low light b/w stereo TV camera with pan and tilt unit,low light b/w after TV camera with tilt unit,5x500 w light, 1x250 w light, 35 mm stereo still camera, 150 w strobe, current meter, master-slave manipulator(7d.f.), rate control grabber(5d.f.)	
(9) Navigation	Obstacle avoidance sonar, direction finding sonar,altimeter, gyrocompass angular rate sensor, trim sensor, depth sensor	
(10)Shipboard component	Control/navigation van, high voltage transformer, deck handling system	
(11)Cable	30 mm (in diameter) optical-electro-mechanical cable, 5000 m (in length) Breaking strength :16.5 tons	
(12)Total shipping weight	46 tons	

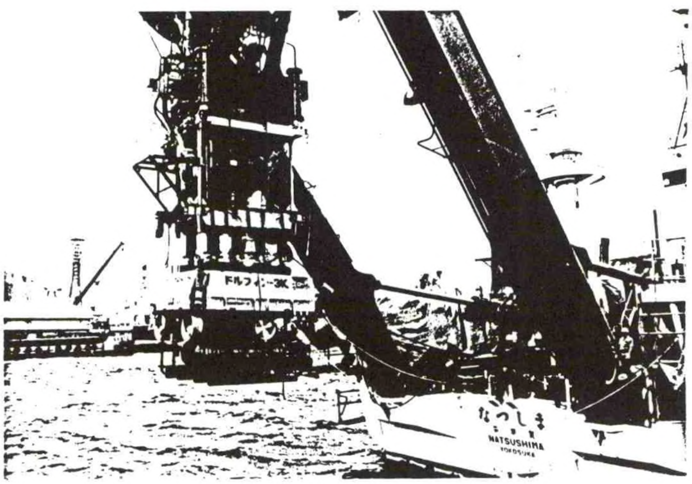

Fig.-2 Launch of DOLPHIN-3K from NATSUSHIMA

Table-2 DOLPHIN-3K Training Operation

DIVE NO.	DATE	SEA STATE	MAXIMUM RATED DEPTH	INWATER TIME	BOTTOM TIME	REMARKS
1	22 Aug.87	4	1,181 m	4h 28m	1h 41m	Sampling and documentation training. KAIYO
2	23 Aug.87	2	1,186 m	6h 26m	3h 26m	Water, clam, rock, sediment samples.
3	24 Aug.87	1-2	1,180 m	6h 04m	3h 26m	Steap sea cliff area.
4	25 Aug.87	4	1,892 m	5h 32m	1h 17m	Center of Sagami Trough.
5	26 Aug.87	2	415 m	3h 20m	1h 04m	Rocky bottom area.
6	27 Aug.87	3	421 m	7h 03m	6h 24m	Route tracking.
7	8 Feb.88	2	1,370 m	6h 04m	2h 23m	Off Heta, Suruga Bay NATSUSHIMA
8	10 Feb.88	2	1,394 m	5h 01m	2h 18m	Fault,ripple mark
9	11 Feb.88	3	1,409 m	4h 48m	2h 33m	Transponder search
10	12 Feb.88	3	2,047 m	6h 15m	1h 45m	Steap sea cliff climb
11	13 Feb.88	2	1,406 m	5h 00m	2h 33m	Route tracking
12	14 Feb.88	2	1,394 m	3h 44m	1h 16m	Transponder search
13	15 Feb.88	3	2,075 m	4h 31m	33m	Very fast current
14	16 Feb.88	3	1,426 m	6h 08m	3h 38m	Transponder search,hill climb, route tracking
15	19 Feb.88	2	1,342 m	4h 48m	2h 19m	Hill climb
16	20 Feb.88	2-5	1,380 m	5h 44m	2h 33m	Transponder search
17	21 Feb.88	3	1,394 m	5h 10m	2h 21m	Transponder search,route
18	23 Feb.88	2	1,387 m	3h 34m	1h 48m	tracking
Total time				93h 06m	43h 18m	Total of training operation
Total time				145h 27m	61h 32m	Total of all operation

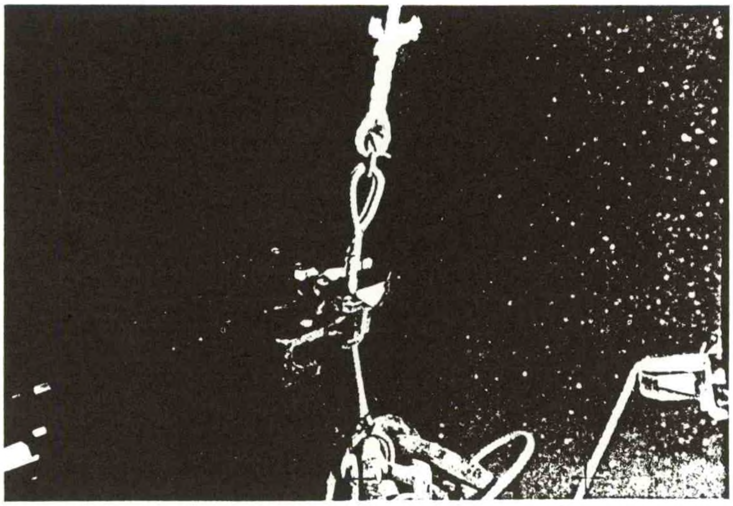

Fig.-3 A picture shows the manipulator and the grabber working with sinker weigth and rope of a transponder, depth 1380 meters.

CURRENT ACTIVITY AND FUTURE TRENDS IN THE U.S. ROV FIELD

By
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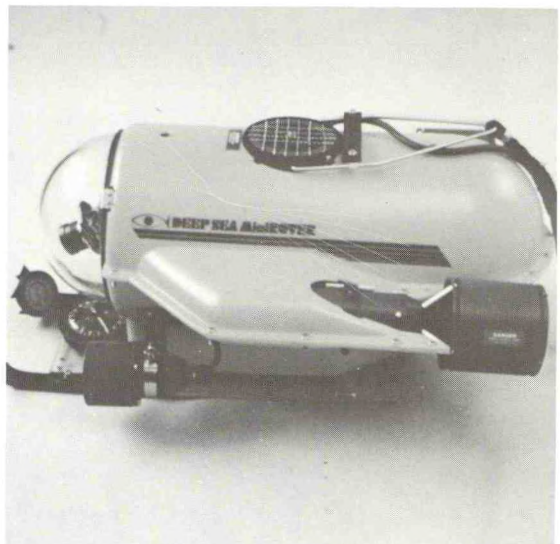
There appears to be two divergent trend directions developing in the ROV field. Over the past several years, the mainstream mid-sized U.S. work vehicles have continued to be developed, i.e., Perry-Recon IV, Straza-Scorpio, as well as others from the foreign market, OSEL-Rigworker, SUBSEA-Pioneer, ISE-Hysub/Hydra. These vehicles

1. PERRY RECON IV WITH TETHER MANAGEMENT SYSTEM

have met the needs of the offshore oil industry. They have in fact replaced much of the manned activity underwater, both in submersibles and in manned diving. The down turn in the oil industry has resulted in an excess ROV capacity and as a result has forced sale and lease prices down.

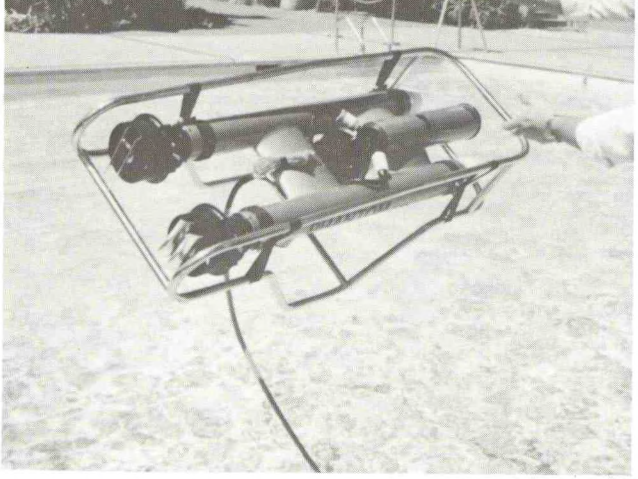
To meet this lower operating cost incentive many new low cost ROV's (LCROV) have been developed. With the advent of these new LCROVs many new tasks and many new markets have become viable. This paper will deal mainly with the new LCROVs available in today's marketplace.



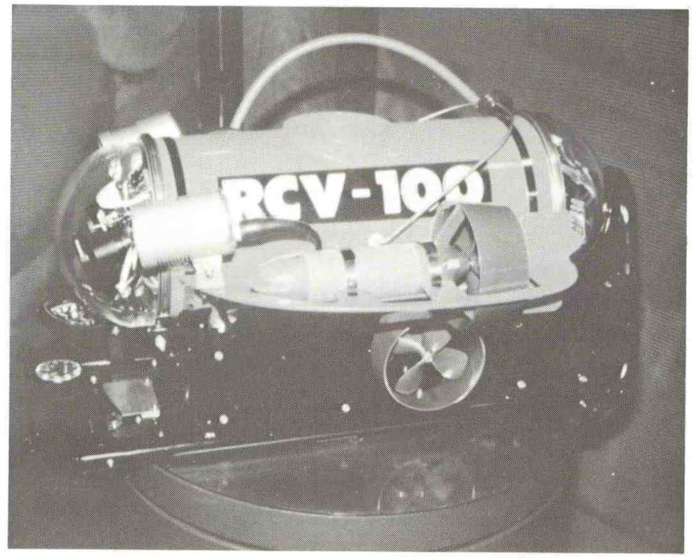
2. BENTHOS MINIROVER

The other extreme from the LCROVs that are in operation and development is the special purpose development of a few very large ROVs, i.e., Perry-Triton (4,200#), Straza-Gemini (4,500#), and perhaps the largest one of all, the ISE-Trapr (20,000#). In this large vehicle area some 10 to 12 have been built. In the LCROV area some 250 have been built, hence the emphasis here on the LCROV class.

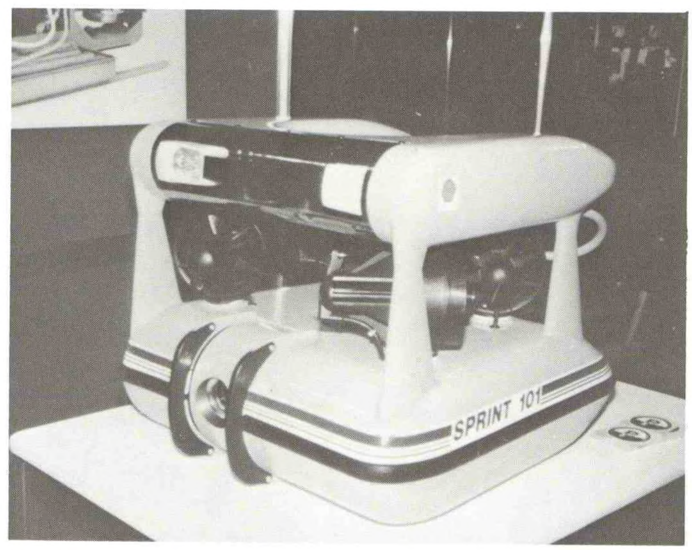
LCROVs are first of all low cost--ranging from about $15,000 to $50,000 on average or as high as $100,000 to $400,000 depending on the system size, capability and instrumentation options. LCROVs are generally quite small and one of their market penetration attributes is that a sophisticated launch and recovery system is not usually required. In extremes, one or two people just throw the unit into the water. This means that the support craft requirements are reduced from the typical offshore oil vessel, to Boston Whaler and Zodiac sized boats. Typical LCROV sizes are shown in Table (1) at the end of the paper.



3. DEEP OCEAN ENGINEERING PHANTOM--HAND LAUNCH



4. HONEYWELL/HYDROPRODUCTS RCV 100

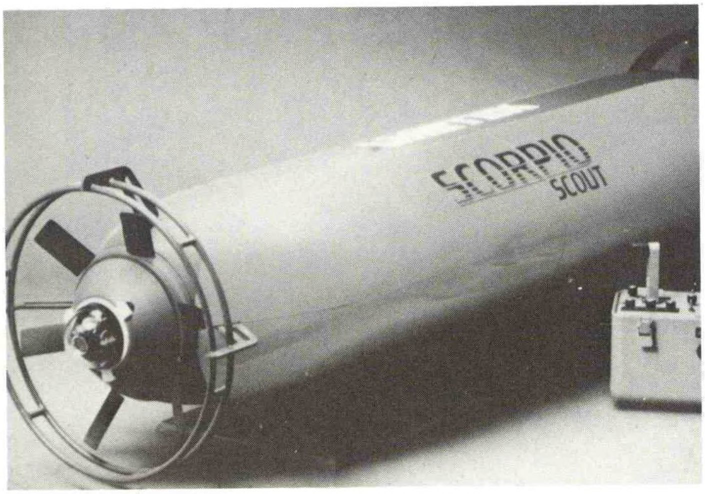


5. PERRY--SPRINT

The size, shape, and configuration of these LCROVs are all somewhat different from company to company. There appears to be no "one best" type of design. The basic instrumentation suit of all LCROVs includes an underwater TV system for use on observation, inspection and visual documentation tasks.

Other instrumentation packages can be carried as optional equipment by many of the LCROVs. These can include a second TV system (color or low light level), still camera, sonar, etc.

For vehicle control many automatic functions are available through state of the art computerized control systems, i.e., auto-depth, auto-heading, etc. The LCROV control systems generally have the operator looking at the vehicle's TV picture with an additional vehicle status display of speed/depth/heading. Operation of the vehicle is accomplished through one or more "joy" sticks that control the thrusters directly or through a computer interface.

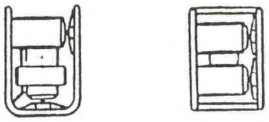


6. AMETEK STRAZA
SCORPIO SCOUT

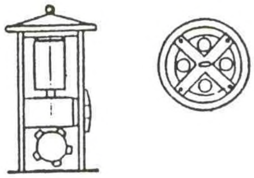
The larger deeper capability vehicles often have a tether management system (TMS) (Wet winch and vehicle garage) that enables maximum vehicle performance to be achieved at the vehicle's maximum depth. These TMS units can sometimes get large in size and the support ship size requirements grow accordingly.

In general, the LCROVs' small size has enabled them to get into places that are not usually viewed or if required, have been viewed with much trouble and high cost. Typical of this type of viewing activity is internal pipe inspection for water treatment plants, sewage plants, hydroelectric power plants and nuclear power plants.

Several LCROVs have been developed specifically for nuclear equipment inspection. The Deep Ocean Engineering Phantom 300N and Phantom NW are examples. Since they are so small they go under the name of Phantomoids.



PHANTOM 300N



PHANTOM NW

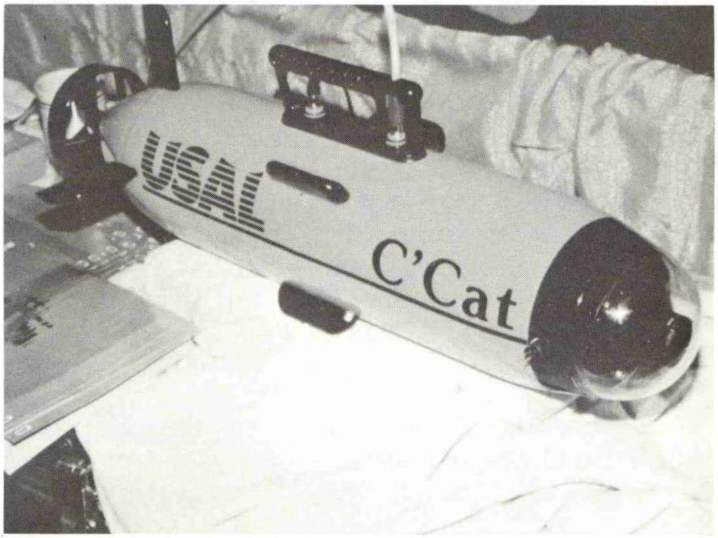
7. PHANTOMOIDS

The market for LCROVs in this "internal" type of inspection roll includes the plant construction company to see that it was fabricated and installed properly; the operating company (or municipal government) to see that its in acceptable running condition; and the repair company, to get an idea of what is wrong, and how it can be fixed.

LCROVs have also been used in almost all types of water for countless different tasks. Typically cities with lake front or river exposure have used them for facility inspection, search, and environmental data collection. In this latter roll the LCROV is attractive since environmental groups or even individuals can afford to own or lease them. Environmental video documentation can be made "before and after" on construction sites to show that the environment was--or was not harmed.

Shipping interests have used the LCROV for ship and dock inspections. Repair yards are using them to determine the extent of underwater ship damage and to visually watch the underwater aspects of dry docking or lift hardware placement.

In perhaps an extreme case a LCROV (from Australia) is offered as a personal recreational "toy." At the price of $5,200, it could almost be considered an accessory for a cruising yacht. Its use would be for under hull inspection, anchor site and anchor placement inspection, and perhaps the most "important" use of all the entertainment value to the owner and his/her guests to see what is down there on the (shallow) bottom of the sea.

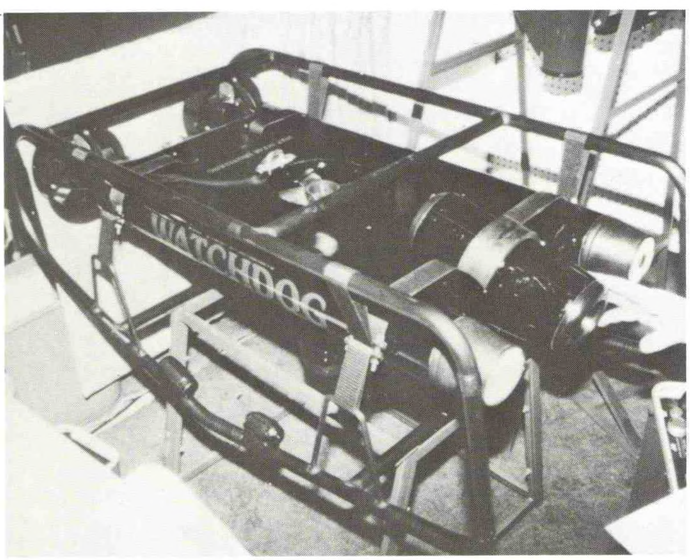


8. C-CAT--RECREATIONAL ROV

In addition to the civil, scientific, and recreational uses of LCROVs, there has been an increasing interest in their use by the military. In particular, their use as low cost alternatives to the usually expensive tasks of mine identification and neutralization. For this application the larger LCROVs are more applicable such as Sea Rover, RCV 425 and Phantom HVS4. These vehicles have the speed/power capability and the payload to enable them to do the shallower, less demanding portion of the port/harbor/coastal water mine neutralization task, while operating from small (low cost) ships or boats of opportunity.

To complete the ROV picture in the U.S. mine defense area is the mid-sized and mid-priced Pluto system and finally the higher priced larger MNS system by Honeywell/Hydroproducts.

In another military (or security) application Deep Ocean Engineering offers a ruggedized version of the Phantom 500. Under the name of "Watchdog", this black vehicle offers inspection and under hull monitoring capability for ships at anchor in non-friendly locations. An underwater "bull horn" permits communication with friendly or non-friendly divers/swimmers. The craft frame has been designed to enable the vehicle to inspect the hull of a ship while sliding along the hull like a sled. Thus avoiding the problem of free swimming maneuverability while getting 100% hull coverage.



9. PHANTOM WATCHDOG

Over the past four years the LCROV numbers in the marketplace have grown significantly. Benthos of North Falmouth, Massachusetts, has produced over 100 of the Minirover/Sea rover vehicles. Deep Ocean Engineering of San Leandro, California, has produced over 100 of the various phantom vehicles. Perry, Straza and Hydroproducts together have produced some 75 LCROV. It may well be that soon the number of LCROVs produced will equal or surpass the total number of all of the larger sized ROVs produced. It is perhaps interesting to note that among the earliest of the ROVs introduced was the RCV 125/225. With its small size it was perhaps showing the way into the ocean and enabling us to see what's down there.

ACKNOWLEDGMENT:

The author wishes to express his appreciation to those individuals and companies that provided technical information and illustrations for this paper.

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Jon Newman/Ken Sebok - Perry Offshore
Robert McKee - Honeywell/ Hydroproducts
Lawrence Gray - Benthos

TABLE 1
LC/SMALL ROV SIZE CHART

Name	Vehicle Weight Lbs	L (in.)	W (in.)	H (in.)	Thrusters (No.)	Operating Depth ft
BENTHOS						
MiniRover MK I	50	26	18.5	12.5	3	500
MiniRover MK II	70	34	18.5	16.5	4	600
Sea Rover	121	48	27	18	4	900
DEEP OCEAN ENGINEERING						
Phantom 300	71	38	20	18	4	300
Phantom 500	78	55	19	22	3	500
Phantom HD	130	59	23	24	4	1000
HONEYWELL HYDRO PRODUCTS						
RCV 100	56	31.5	22	14	3	330
RCV 225	180	--	26	20 (DIA)	4	1350
RCV 425	200	47	39	23	4	1000
PERRY						
Sprint	150	24	24	27.5	5	2000
STRAZA						
Scorpio Scout	200	72	--	20 (DIA)	2 (TPS*)	1000
USAL (Australia)						
C Cat	26	28	--	6 (DIA)	1	164

*Tandem propulsion system--cyclic and cycloydal control

ADVANCES AND FUTURE APPLICATIONS IN BOTTOM-CRAWLING VEHICLES

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Significant advances have been made during the past decade in vehicles for the remote inspection of the deep ocean floor (>4 km.) These include the DEEP TOW system at the Scripps Institution of Oceanography (SIO) [Spiess and Lonsdale (1982)] with a capability for providing still and television photography, sidescan sonar, magnetometry and a variety of other remote sensing techniques within tens of meters of the bottom. The ARGO/JASON system developed at Woods Hole Oceanographic Institution provides a capability (at shallower depths) for detail inspection that was demonstrated recently in the exploration of the wreck *Titanic*. Although these systems are extremely valuable for providing detail observations of remote and inaccessible locations, a need is now arising for an ability to *work* on the ocean floor - that is, to be able to take physical samples, to install, replace or repair instruments and to revisit a precise location after long intervals.

An example of such a need arises from the recognition that eventually the deep ocean floor will be mined for manganese nodule minerals. These mining operations will certainly produce massive plumes of fine sediment that will fall on the adjacent area. Because natural sedimentation rates are very low compared to the rate expected from the mining, there is concern for the impact of this process on seafloor life - particularly the animals living just below the surface of the sediment. The National Oceanic and Atmospheric Administration (NOAA) has funded a study of this potential environmental impact with SIO as the lead research organization. A preliminary experiment was conducted at a depth of 1200 m in August, 1987. A second preliminary experiment at 4000 m depth will be undertaken early in 1989.

The full experiment, in which a large area of the ocean floor in the manganese nodule region south of Hawaii will be covered with a controlled thickness of mud, will take place in 1990. A year later, the site will be revisited for further evaluation. All of these experiments follow the same pattern. Fine mud, dredged from the actual site of the experiment, is treated to remove large animals. This mud is then mixed with seawater to make a thick slurry and pumped into an enclosure on the bottom. The mud settles to form a layer of the desired thickness. After an appropriate interval (days to weeks) cores are taken in the treated area and compared to cores taken from adjacent, untreated areas to determine the lethal effects on the animals living in the sediments. This procedure requires a level of position accuracy, fine control and lifting capability that cannot be provided from a ship on the surface. Therefore, it was necessary to utilize a remote work vehicle capable of operating at great depth and of moving about on the bottom as it performed its work functions.

The work vehicle chosen was the RUM III (Remote Underwater Manipulator) developed at SIO by Prof. Victor C. Anderson. [see Figure 1] This system operates from a surface platform (ORB) which is towed to the location and maintains position either through a three point moor or thrusters. The ORB has a moonpool capable of handling the RUM III vehicle, allowing launch and recovery in reasonably high sea states. RUM is connected to ORB by a lifting cable that incorporates a coaxial power/data link. RUM is about 2 m wide, 2.5 m long and 2.5 m high, and weighs 2.5 tons in air and one ton in water.

The vehicle moves about on broad smooth tracks, suitable for deep ocean mud bottom conditions. It has a manipulator boom that operates from a central tower capable of 400 deg rotation. The arm has two articulated joints and is terminated in a hand with wrist bending and rotation capabilities. The turret rotation uses a high pressure hydraulic rotary actuator. The arm segments are operated by low pressure cylinders with sea water as the operating fluid. [Horn et al.

(1983)] The hand and the drive tracks are electrically operated. All drive motors operate in pressure-compensated, oil-filled enclosures. Only the electronics, including several microprocessors used for onboard communications and control, utilize pressure resistant enclosures. [See Currier (1985) for a discussion of the control system.] The vehicle frame is made from titanium structurals and the manipulator arm from fiberglass-epoxy tubing and structural shapes.

RUM III contains a unique tether cable management system that isolates the vehicle from heaving motions of the ship. It is not feasible to allow the cable to be slack because of a tendency to form loops which will cause breakage on subsequent tensioning. Therefore, a passive cable accumulator system is provided that will accommodate up to 10 m of cable. A constant tension of 50 kg is maintained over the full 10 m travel. [Anderson and Horn (1985)] Two TV cameras are provided with independent pan and tilt capabilities to allow the operator on the surface to judge distances for precise manipulator control. On board instruments include a compass, roll and pitch measurements, tether angle determination, voltage and current, temperature in critical compartments, valve position, etc. There are plans to add a 180 degree scanning sonar to aid in finding objects on the sea floor.

The present schedule for RUM over the next few years involves operations on soft, smooth mud bottoms. However, for future operations, there is considerable interest in a capability to operate in rough, rocky areas - such as those associated with fault zones and spreading centers. Under these conditions, tracks will not be effective. A future version of RUM is envisioned with flexible wheels, similar to the Lunar Rover, for short distance traversing in rough terrain. For longer distance repositioning, the vehicle will be lifted clear of the bottom by its tether and moved to a new location by moving the surface support ship.

RUM III offers a unique capability to operate at very great depths and to do useful engineering tasks. It has already demonstrated its ability to install and remove instruments, to take cores and a number of other tasks requiring both strength and dexterity. The cost of operation, on a per-day basis, is about 1/10 that of the submersible *Alvin*. In addition, RUM can operate on a full 24 hour work day and remain on the bottom for many days at a time, if necessary. Thus, the cost per hour of *bottom time* may be as little as 1/100 of the cost of a submersible. A detailed review of seafloor work tasks, including those discussed here, is contained in Spiess (1987).

REFERENCES:

Anderson, V.C., & R.C.Horn, 1985. Passive Cable Accumulator for the Deep Seafloor ROV, RUM III. Proc. Oceans '85 Conf., Mar. Tech. Soc., San Diego, CA, Nov 12-14, 1985. pp 993-1000.

Currier,R.E., 1985. RUM III Vehicle Control System. Proc. Oceans '85 Conf., Mar. Tech. Soc., San Diego, CA, Nov 12-14, 1985. pp 1045-1051.

Horn, R.C., V.C. Anderson & B. Madsen, 1983. Seawater Hydraulic Manipulator Boom for Rum III. Proc. ROV '83 Conf., Mar. Tech. Soc., San Diego, CA, Mar 14-17, 1983. pp 60-65.

Spiess,F.N., 1987. Seafloor Research and Ocean Technology. Mar. Tech. Soc. Journ., v.21, n.2. pp 5-17.

Spiess,F.N. & P.F.Lonsdale, 1982. Deep Tow Rise Crest Exploration Techniques. Mar. Tech. Soc. Journ., v.16, n.3. pp 67-74.

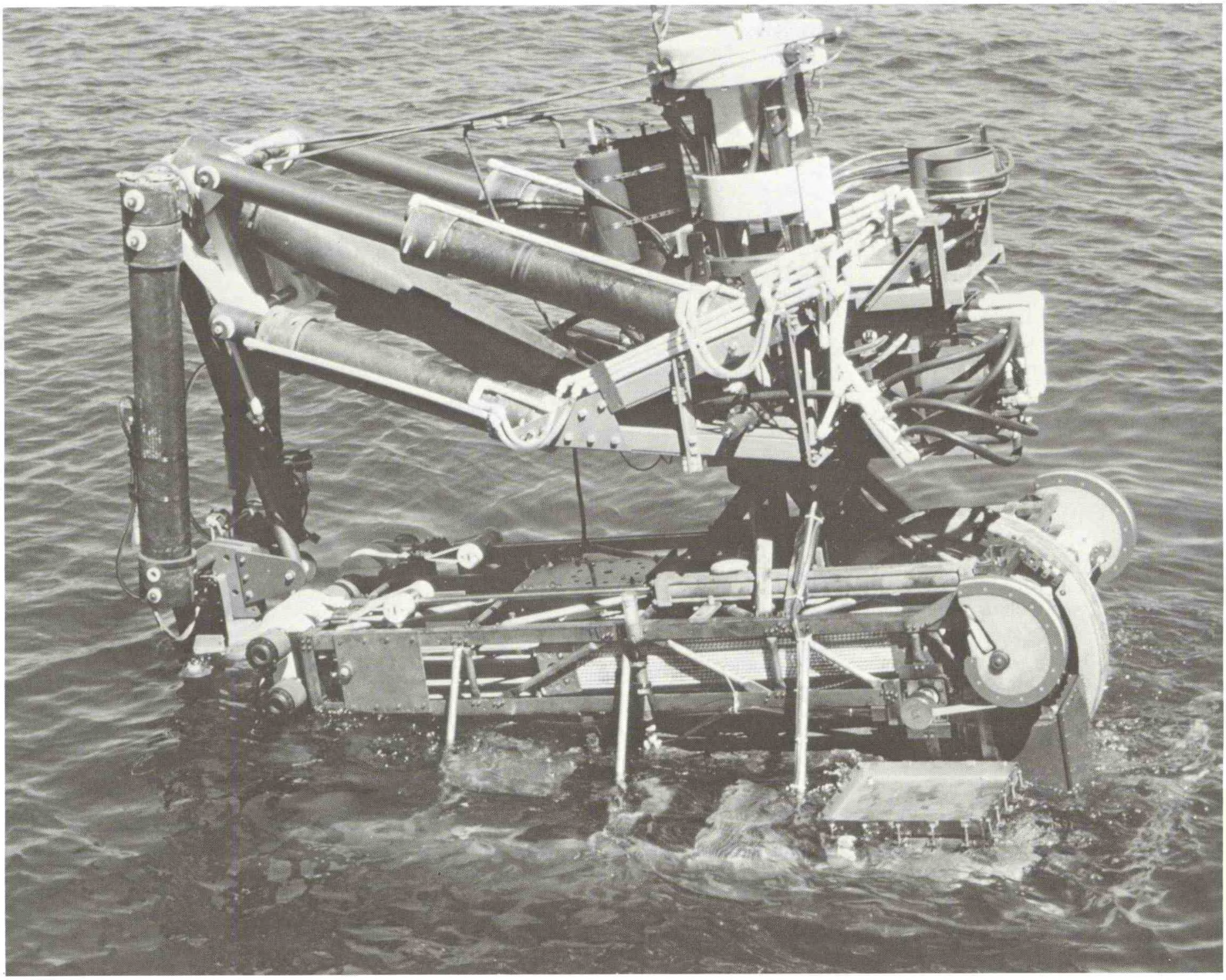

Figure 1
The deep seafloor ROV, RUM III, prepared for loading onto the support ship ORB

DEVELOPMENT ON AQUATIC WALKING ROBOT FOR UNDERWATER INSPECTION

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ABSTRACT

An experimental model and a prototype model were made for development of underwater inspection robot. The experimental model is overground test robot that is not made watertight. The model was used for basic research and a debug tool for program development. The prototype model made watertight was developed after tests of the experimental model. The model is the first walking robot in the world that has succeeded in walking on sea bed. The hardware and soft ware of the robots are described herein. The principal features of the models are as follows. The robots are six-legged articulated "insect type" robots known as "AQUAROBOT". Each leg has three articulations and is driven semi-directly by a DC motor that is built in the leg and have a touch sensor on the foot. The robots can walk on uneven ground and can walk in any direction without changing its quarter.

1. INTRODUCTION

Many ROVs (remotely operated vehicles) have been developed but most move while floating in the water. It is difficult for ROV to maintain a stationary position and direction. ROV are good on observation with a TV camera but are weak in their capacity to measure objects with accuracy.

There are some vehicles that can move on the sea bed with wheels or crawlers. These vehicles can maintain their positions and directions stationary but movement of the vehicles makes the water so muddy that the TV cameras can not be used.

There is no underwater robot in the world that has the functions of observing and measuring in the water. However, we thought that the walking robot controlled by a computer could walk on an uneven sea bed without making the water muddy.

Types of walking robots [1,2] were researched and made for testing. The aim of this research is to develop a robot that can walk on uneven places where wheels cannot be used.

The robot is not watertight and the structure and mechanics of legs are not suitable for watertight designs. The technical level for walking robots are far from practical use and there are no real plan of use of the robots. Moreover, there is no underwater walking robot in the world and so We therefore challenged the development of an underwater walking robot to carry out the underwater inspection works.

We developed an experimental model robot in 1985 and a prototype model robot that is made watertight in 1987.

Fig.1 shows the expected work of the underwater inspection robot.

2. HARDWARE OF THE ROBOTS

The weight of experimental model and prototype model are 280kgf and 700kgf respectively. The difference of weight comes from the watertight design and size. The structures of the robots are almost same.

2.1 body

The body is hexagonal in shape and made of anti-corrosive aluminum. The legs are installed on the sides of a hexagonal frame and some sensors installed on the body.

2.2 Legs and Articulations

The minimum degrees of freedom to move the point of a leg anywhere is three. Therefor, a leg consists of three articulations. Fig.2 shows the leg structure of the robot. The rotating axis of the first articulation that is nearest to the body is vertical and the axis of the other articulations are horizontal. The foot and a leg are linked with a ball joint. A foot has a touch sensor. The length of the thigh and the shank of experimental model are 25cm and 60cm respectively. Those of prototype model are 50cm and 100cm respectively. The legs are made of anti-corrosive aluminum. The articulations are driven by DC motors with gears.

2.3 Motors

The motors of the robot are electric and driven by 70 Volt DC power. Each motor has an encoder that generates 100 pulses per revolution, and harmonic gears with a ratio of 1/160. The two kinds of motors are selected. The motor for the first articulations is 40 watt and the motors for second and third articulation are 70 watt.

2.4 Motor Control System

A motor driver is used for each motor. The usage changes the DC motor into a pulse motor that can be simply controlled by pulse signals. The motor with the driver can then be controlled by pulses from a computer.

2.5 Sensors

Three kinds of sensors are used for the robot. There are six touch sensors, two inclination sensors and a compass. The robot can therefore walk keeping the inclination and direction of body constant by the sensors.

2.6 Cable

A Cable of the experimental model is consist of many metal wires. An optical fiber link is introduced in the prototype model. The link improves S/N ratio and makes the cable long. The diameter of the cable is 42 mm and the length is 100m. A pair of opt-electric transform devices are built in the robot body and the control box. The prototype model has a large body for the device.

3. SOFTWARE OF THE ROBOTS

The structure of the AQUAROBOT control program is shown in Fig.3. The program consists of operating and walking algorithm programs which are independent each other but which are interfaced by a robot language. A BASIC compiler and assembler are used to develop the control program.

3.1 Robot Operating Program

This Program receives commands from walking algorithm program and produces detailed commands for the motor drivers and sends pulses to the motor drivers according to the detailed commands. This system shows the robot profile by graphic image on a CRT and shows the location and direction of robot by numbers at every step of leg motions. A operator on board can recognize how robot is in the water. Even if the robot is not connected to the computer, the system run independently. This function can be used as simulator of robot motions. This system also checks whether the usage of the robot language is correct. Both the simulator and the checking functions are used as the debug tool for the development of walking algorithm program.

3.2 Robot Walking Algorithm

The main purpose of this program is to understand the command from human operator and to calculate the coordinate values of the points of leg end (PTP) to execute those commands.

AQUAROBOT can walk on irregular terrain with the body kept horizontal at the constant level by stopping the lowering of legs when they touch the terrain surface, according to the information from touch sensors.

The irregular terrain walking program has several functions as follows.

a) Body inclination changing function

The body of AQUAROBOT can be kept at any inclination by this function. When AQUAROBOT is walking on an inclined terrain with the body kept horizontal, the feet might not touch the terrain surface. In these case, the body must be kept inclined to same direction of terrain inclination. This function is easily realized because the control program includes coordinates transformation subprogram for cartesian coordinates, and which does not add more complexity to the calculation.

b) Terrain profile measuring function

All the motions of the legs are controlled by computer, enabling every position of the legs to be known. The terrain profile can be measured from the locus of the feet while walking on irregular terrain. This is one of the most important advantages of walking robot as it can not only move, but also measure by its legs.

c) Landing point changing function

When a foot can not touch the terrain surface even the leg is lowered completely, the walking program considers that landing at that point is impossible, and changes landing point. By using this function, AQUAROBOT does not get its legs stuck in grooves or holes.

4. WALKING TEST

4.1 Experimental Model Robot

a) on the Flat Terrain

As the first stage, the walking test using the flat terrain walking program was carried out on the concrete floor of the laboratory. This program was developed so as to inspect the fundamental performance of the experimental model. This program does not use outside sensor information such as touch sensors, inclinometers and a solid state flux gate compass but only inside sensor information such as the encoders of actuators.

The maximum walking speed is about 7.5m/min., and the maximum rotating rate is 445 degree/min. on flat terrain.

The experimental model can walk with one person on the body.

b) on the Irregular Terrain

A walking test using the irregular terrain walking program was carried out on a rubble mound. This program is developed for walking on irregular terrain by adjusting leg motion by using sensor information feedback. It can compensate for errors due to slip of the feet, or distortion of the terrain.

The rubble mound for the walking test was constructed with real rubble for port construction by the divers who are actually working in Tokyo Bay area. The weight of the rubble is distributed from 10kgf to 200kgf. The roughness of horizontal plane is +5cm as completed mound (which is same as actual one), and +15cm as a mound under construction (which is one half of actual one) because the leg length of the experimental model is one half of practical one. The inclination of slope is 4:1.

The experimental model can walk on both the horizontal planes and slopes as shown in Photo.1.

The maximum walking speed is 1.7m/min. on the horizontal plane.

When walking on the slope, the body inclination changing function and the walking parameter presuming function were found effective. Without the body inclination changing function, there was difficulty in walking up the slope because the feet of stroking legs touched the terrain surface. The time taken to walk up the slope was reduced from 30min. to 10 min. with the use of walking parameter presuming function.

c) Durability

The experimental model had been displayed at the Expo.'87 in Sendai, Tohoku from 18th Jul. to 28th Sep. in 1987. The walking demonstration of each walking pattern and each operation mode with flat terrain walking program and that with irregular terrain program on the schematic model of rubble mound are shown several times a day. There was some troubles, but the number of days when the experimental model could not make any demonstration for the whole day was only 2. The reason of that accident was the breakage of connecting cable between articulations and robot body. This was fixed by replacing the cable and did not cause serious mechanical disorder.

The ratio of the inoperable time was 8.4% for over the whole period. Taking it into consideration that the experimental model had been used for walking test over 2 years before the Exposition, it is proved that the experimental model has excellent durability.

4.2 Prototype Model Robot

An underwater walking test was carried out in pure water in the test pool 3m deep. The prototype model being tested are shown in Photo.2. The effect of the hydraulic force upon the walking speed and the articulation torque is mainly tested in the test pool. In the preliminary test, walking speed exceeds 1.8m/min.

A field test was carried out in Dec. 1987. The prototype model was operated on the underwater rubble mound in the port area of Yokosuka to examine walking performances in the course of actual port construction work.

A underwater TV camera with ultrasonic ranging device and a newly developed transponder system were fitted to the prototype model in the field test to investigate the performances of total robot system.

REFERENCES

1) Hirose,s.,Nose,M.,Kikuti,H., Umetani,Y.,1983,"Adaptive Gait Control of Duadruped Walking Vehicle",Proc. of the 1st Int'l Symp. of Robotics Research

2) Marvin Russell,Jr ,1983,"ODEX1 the First Functionoid", Unmanned Systems,Vol.2,No.2

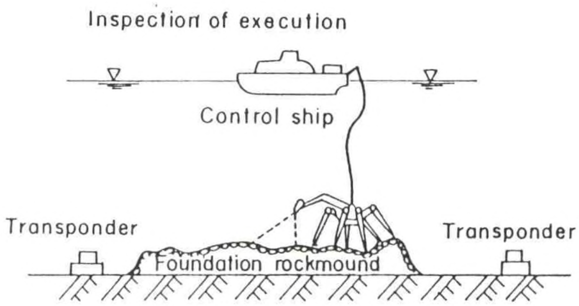

Fig.1 Underwatr operation of the robot

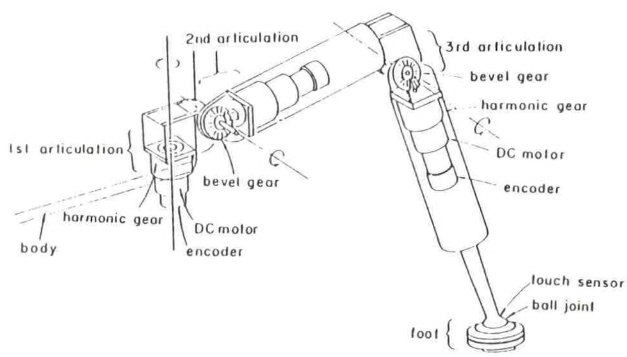

Fig.2 Stracture of a leg

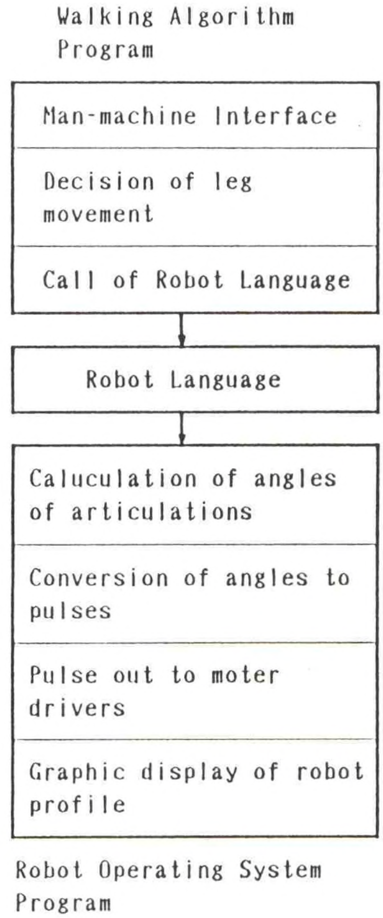

Fig.3 Stracture of the robot control program

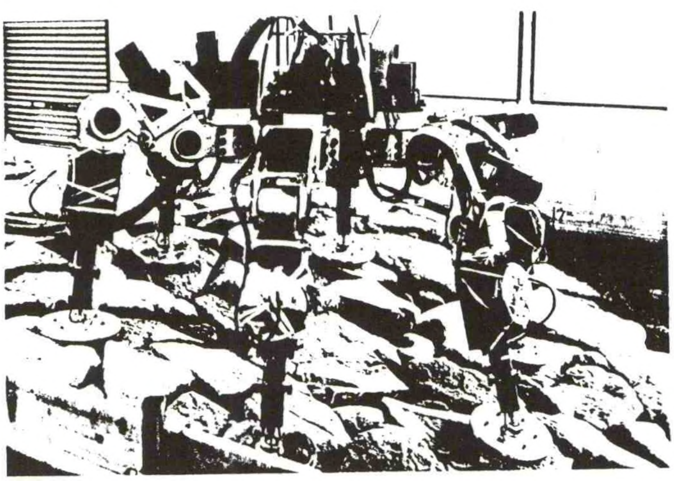

Photo.1 Walking on the slope of ruble mound

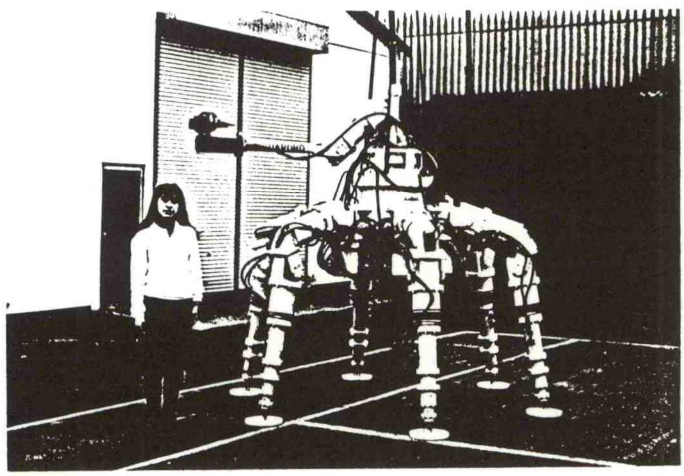

Photo.2 Prototype model

ADVANCES IN ROBOTIC/TELEOPERATED SYSTEMS

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ABSTRACT

The Naval Ocean Systems Center is actively developing the technology base required to provide remote presence to teleoperated systems. This paper briefly describes the status and some recent accomplishments of ongoing efforts in key technology areas. Remote presence depends in large part on the degree of fidelity achieved in providing sensory data from the remote, unmanned robot to the operator. Thus our development efforts continue to address the components and subsystems required to achieve realism in feedback. These include vision systems, more dexterous manipulators and end effectors, controllers with kinesthetic feedback, datalinks and vehicle systems. Emphasis is being placed on the attainment of sufficient experimental apparatus at the total system level to permit experimental verification of the performance improvements provided by teleoperated systems which incorporate extensive remote presence characteristics.

CURRENT DEVELOPMENT EFFORTS

The accomplishments described by Hightower [1], [2], at the 14th meeting of the UJNR Marine Facilities Panel provided the foundation for the development of the first major prototype systems now under development for test by the U. S. Marine Corps. A laboratory orientation, training, and demonstration device (TODD) has been built, and a TeleOperated land Vehicle (TOV) is being prepared for field evaluation.

TELEOPERATED DEMONSTRATION DEVICE (TODD)

The TeleOperated Demonstration Device (TODD) was built for the dual purpose of providing Marine Corps personnel with an introduction to the concept of remote presence and to provide a platform for evaluating experimental viewing systems. TODD is shown in Figure 1. Control of the TODD was accomplished with a small suitcase-sized control station complete with Head-Motion-Coupled (HMC) TV and binaural hearing. A 3mm fiber optic cable connected the control station and the vehicle which supported a full duplex (1.3 and 1.5 micron) TDM/pulse code modulated telemetry system operating at 160 megabits per second over a single fiber. TODD proved to be a valuable demonstration system for the concept of telepresence. TODD made it relatively easy to change cameras, lenses and HMC viewing arrangements. However, because of the differing optical geometries, available components, data link electronics, operator comfort, and economic considerations, there is a limit to the number of options that can be explored.

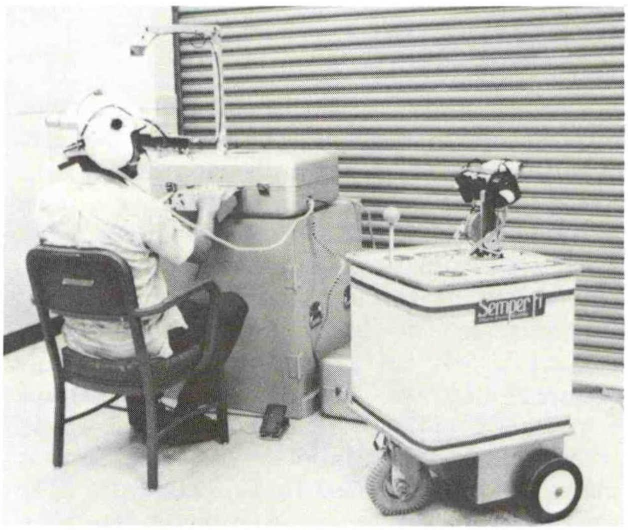

Figure 1. The Teleoperated Demonstration Device (TODD) vehicle shown to the right of the operator seated at the suitcase controller.

TOV - A TELEOPERATED LAND VEHICLE

The TeleOperated Vehicle (TOV) is a rough-terrain land vehicle being developed for the United States Marine Corps in order to explore the military utility of telepresence system concepts in realistic, mission-oriented environments. For the Marine Corps application, an anthropomorphic head with pan-and-tilt motion coupling, binaural hearing, and 60 degree wide stereoscopic video have been installed onto a High Mobility Multi-Purpose Wheeled Vehicle (HMMWV). This vehicle with the telepresence system installed is shown in Figure 2. A high degree of spatial correspondence has been achieved with the TOV viewing system.

Figure 2. High-Mobility, Multi-Purpose Wheeled Vehicle (HMMWV) with the telepresence system installed.

A systematic program of driving performance assessment is being conducted concurrently with hardware development for the TOV, [3]. The program consists of two phases: 1) fundamental mobility testing on a level, paved, clearly marked course, and 2) advanced mobility testing through marked courses across rough terrain. The fundamental testing program is based largely on a factor analysis of many measures of low speed, on-road driving performance, [4]. A battery of objective driving measures is administered which taps six dimensions of low speed maneuverability. The driving battery is easy to set up and administer.

It provides an efficient means of testing and improving new display and control concepts. The graph in Figure 3 is an example of results from eight drivers on one of the fundamental mobility test courses. This graph is a plot of driving performance (time to complete a large, oval-shaped slalom course) as a function of four alternative viewing conditions. For the "Direct" condition, an operator drove the vehicle on-site with no occlusion to his normal field of view. This condition provided a valuable baseline of performance against which any remotely operated system can be compared for its degree of telepresence. For the "Masked" condition, the driver's direct view was occluded so that he only saw that part of the visual field provided by one of the display systems tested. Two helmet-mounted displays shown in Figure 4 were also tested. As can be seen in Figure 3, Display One, a relatively high resolution spatial correspondence stereoscopic display was found to be clearly superior to Display 2, a lower resolution stereoscopic display in which the image size is reduced to one-third of normal.

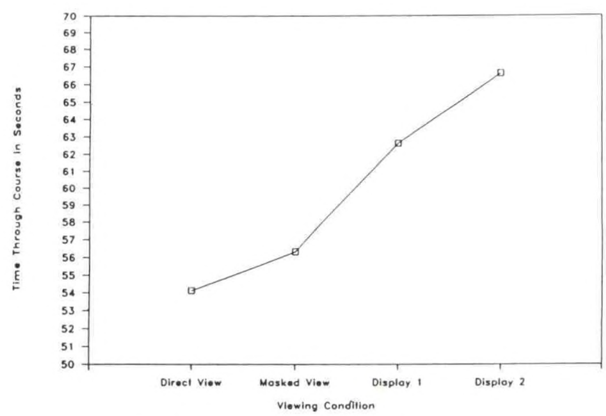

Figure 3. TOV Mobility Testing results. Slalom Course Times for Five Viewing Conditions. Display 1 and Display 2 are shown below in Figure 4.

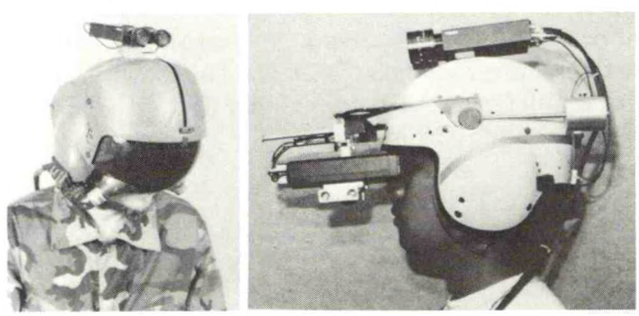

Figure 4. Helmet mounted video sensor/display configuration used in TOV mobility testing. Display 1 at left and 2 at right.

At publication time, performance data of system in full teleoperated mode are not available.

FIBER OPTIC DATALINK

The video bandwidth requirements of systems with remote presence are easily accommodated by fiber optic datalink capability. Adapting the optical fiber for use in the anticipated environment and conditioning the high-bandwidth signals for transmission over the optical fiber are the challenges to the developer. Our efforts focus on fiber and cable construction, methods of canisterization for cable payout and high speed digital telemetry system design.

Fiber construction is attacked on two fronts: first to achieve optical characteristics that minimize the attenuation due to microbending of the fiber and secondly to reduce the diameter of the fiber thus minimizing the total volume required for a fiber optic data link. Figure 5 illustrates the level of improvement in microbending losses that can be expected through proper control of mode field diameter in the optical fiber [5 and [6]. A reduced diameter fiber with excellent microbending characteristics is shown in Figure 6 in size comparison with a standard-size telecommunication fiber.

A number of fiber optic cable constructions were compared across a battery of tests selected to screen candidate cables for the TOV land vehicle system [7], [8]. The cables were tested for their sensitivity to, or survival of impact, temperature, abrasion, tracked vehicle crossings, compression, tension, and short radius bending. Cables found suitable for the TOV System incorporate a polyurethane jacket, fiber with minimum sensitivity to microbending, nylon buffer coating, and kevlar strength members applied under individually controlled tension.

The self-dispensing payout canister for the TOV vehicle utilizes a precision-wound, right-cylindrical spool and inside payout. The canister shown in Figure 7 is molded polyethylene. Spool stack-stability is ensured by a lightweight foam filling the volume between the fiber spool and the canister. Precision-

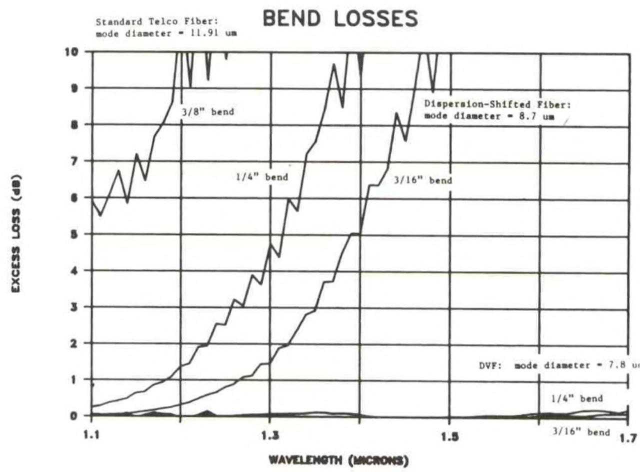

Figure 5. The experimental DUF fiber with the smallest mode-field diameter exhibits minimal attenuation increase due to microbending.

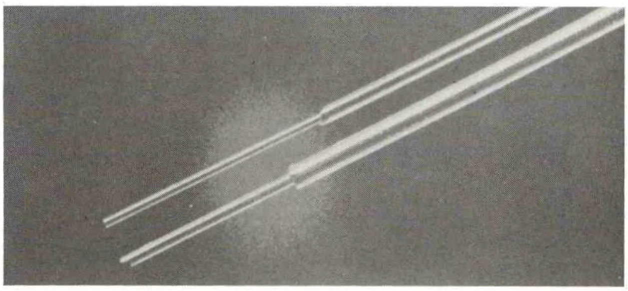

Figure 6. The 90-μm DVF (right) and conventional 125-μm fiber left.

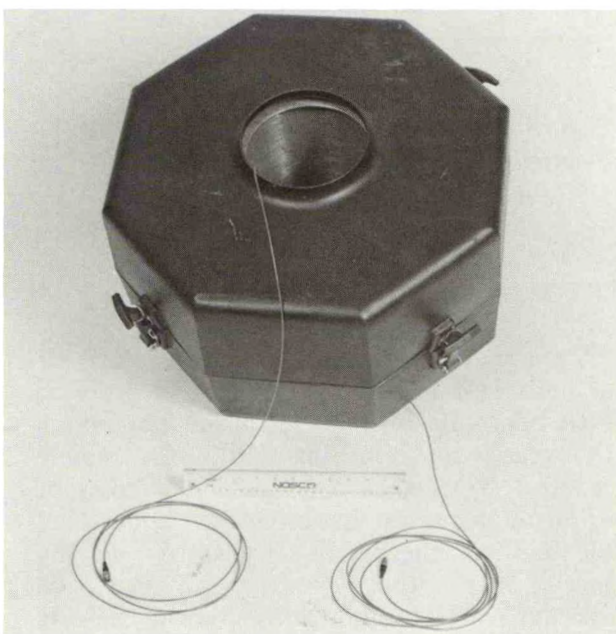

Figure 7. Self-dispensing, payout canister for fiber optic data link cable.

wound and random-wound exterior payout spools have also been successfully tested, but system consideration resulted in selection of the precision-wound inside payout.

The TOV datalink system provides continuous, two-way communication between the controller and the remote vehicle. Datalink bandwidth requirements are dictated primarily by the video bandwidth to be transmitted. The TOV datalinks permit two, color-video NTSC-formatted signals from the remote system, and one video signal from controller to remote location. Stereo voice, instrumentation status signals, and control signals are also provided in both directions. This is accomplished with a 200 megabit per second serial data stream from the vehicle to the controller and about half that bit rate to the vehicle [8]. The TOV telemetry subsystem is shown in Figure 8.

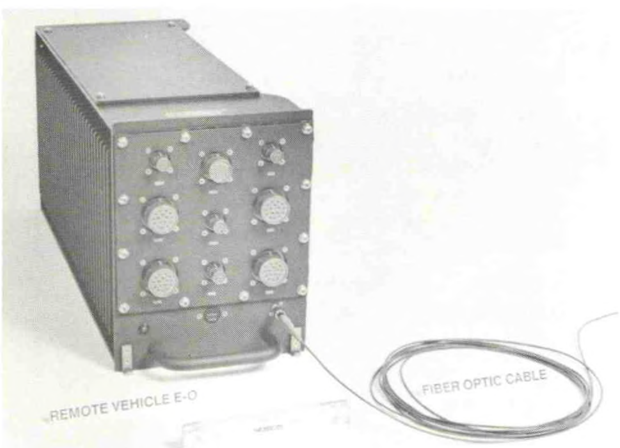

Figure 8. The telemetry electronics and electro-optics for the TOV system are contained in a ruggidized housing.

STEREOSCOPIC VIDEO DISPLAYS

Stereoscopic video sensors and displays are often built into telerobotic systems in order to provide operators with an accurate perception of the spatial relationships within the remote work site. NOSC has conducted a number of experimental studies in order to understand which features inherent in stereoscopic viewing systems have the greatest impact on performance. One interesting hybrid viewing system was built and tested by NOSC scientists [9]. It consists of a stereoscopic pair of TV cameras transmitting images to a beamsplitter polarizing display. The system is referred to as a hybrid because one eye is presented with a high-resolution black-and-white image while the other is presented with a lower resolution color image. All other features of the images (i.e. linearity, brightness, contrast, screen size) have been equalized or balanced to the extent possible. Results of performance testing with the hybrid viewing system suggest that high-resolution, black-and-white imagery presented to one eye will fuse with lower resolution color information presented to the other eye to produce a perception of three-dimensional space which contain color along with a perceived resolution intermediate between the color and black-and-white channels. Figure 9 shows the video display, master-slave manipulator, and taskboard used in the hybrid stereoscopic display. The hybrid viewing system is capable of providing three different views of the remote scene depending on the perceptual requirements of the task and the operator's preference. The three viewing options are: 1) monoscopic black-and-white in high resolution, 2) monoscopic color in low resolution, and 3) a hybrid black-and-white and color stereoscopic view with intermediate resolution. Recent efforts have been directed toward the selection of appropriate parameters for remote terrestrial reconnaissance, and for the assessment of fatigue effects produced by prolonged usage of such viewing systems.

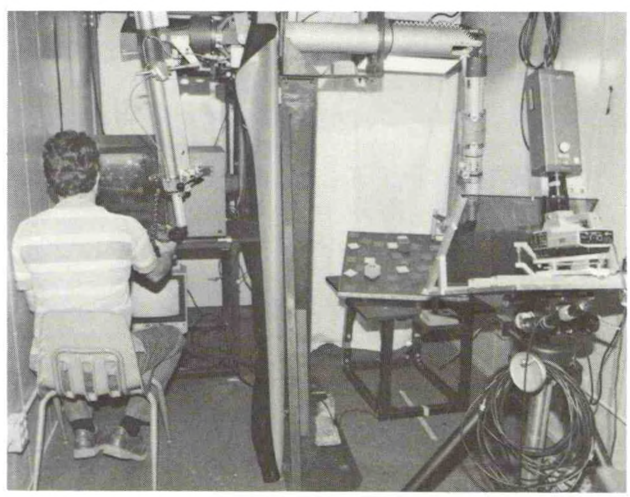

Figure 9. Hybrid stereoscopic color/black and white, master-slave manipulator and taskboard setup.

FUTURE EMPHASIS

NOSC will continue to transition the results from the basic science and engineering efforts into teleoperated systems offering enhanced operational utility. Prime emphasis in the scientific area will be placed on all aspects of the man-machine interface with the goal of providing human factors engineering data with which to improve performance of remote presence, teleoperated systems. Engineering efforts will be concentrated on improved vision systems and dexterous, spatially-correspondent manipulative systems incorporating kinesthetic and haptic feedback.

Cooperative scientific and engineering efforts are continuing with the National Aeronautics and Space Administration, the U.S. Air Force, the U.S. Army, the Defense Advanced Research Projects Agency, the University of Utah, and the University of Wisconsin. All efforts concentrate on the achievement of a balanced, teleoperated systems technology which integrates improved visual auditory, haptic, and kinesthetic feedback into the man-machine interface and bring us one step closer to realizing our goal of high fidelity remote presence.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the United States Navy, the United States Marine Corps, the Defense Advanced Research Projects Agency, and the National Aeronautics and Space Administration for their continued support. We also thank all our colleagues at the Naval Ocean Systems Center whose dedicated efforts we have presented. We are particularly grateful to Dr. E. H. Spain, S. A. McArthur and N. T. Kamikawa for their comments and suggestions and to Messers D. Colburn, C. Peterson and Ms M. Guidry for outstanding graphic support.

REFERENCES

[1] Hightower, J.D. and Smith, D.C. "Teleoperator technology development. In Proceedings of the 12th Meeting of the United States-Japan Cooperative Programing Natural Resources, San Francisco, CA 1983.

[2] Hightower. J.D., Smith, D.C., and Wiker, S.F. "Development of remote presence technology for teleoperator systems." Paper presented at the 14th Meeting of the United States-Japan Natural Resources Committee, Marine Facilities Panel, Bethesda, M.D., September 1986.

[3] Spain, E.H. "Assessments of maneuverability with the TeleOperated Vehicle (TOV)". In Proceedings of the Association for Unmanned Vehicle Systems Annual Symposium. Washington, D.C., 20-22 July 1987.

[4] Olsen, P.L., Butler, B.P., Burgess, W.T. and Sivak, M. "Toward the development of a comprehensive driving test: Low-speed maneuvering." Ann Arbor, MI: University of Michigan Highway Safety Research Institute Report UM-HSRI-82-4, February 1982.

[5] Kamikawa, N.T. "Reduced-Diameter Optical Fiber." San Diego, CA. Naval Ocean Systems Center, Technical Document 1040, 1 October 1986.

[6] Kamikawa, N.T. Rast, H.E. and Chang, C.T. "Fibers for Air-Deployed High-Speed Payout Links" in Department of Defense Fiber Optics Conference '88, McLean, Va., 22 March 1988.

[7] Stamnitz, T.C. "Status of GATER/TOV Cable Testing." San Diego, CA., Naval Ocean Systems Center. Internal memorandum, 20 October 1986.

[8] McArthur, S.P. and Nobunaga, A.S. Personal communication. Naval Ocean Systems Center, Kailua, HI. February 1988.

[9] Cole, R.E., Pepper, R.L., and Spain, E.H. "Visual system parameters influencing teleoperator performance." Paper presented at the International Scientific Conference on work with display units, Stockholm, Sweden, May 1986.

COASTAL OCEAN SPACE UTILIZATION

INFORMATION FOR DECISIONMAKING IN THE COASTAL OCEAN

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Decisions made over the next 10 years about the management of environmental quality in the coastal ocean of the United States of America (USA), Japan, and other nations of the world, will determine whether this resource base will continue to provide important goods and services into the 21st century. The "coastal ocean" is those waters extending from the head of tide within estuaries to the edge of the continental shelf.

The coastal ocean and adjacent coastal land areas that drain into its waters are being developed at a rate that exceeds the capabilities of the public and private sectors to make decisions that manage human activities so that environmental quality of the coastal ocean is maintained or improved. For example, in the USA population density in coastal counties is about 270 people per square mile compared to about 45 people per square mile in non-coastal counties. Coastal population density has increased about 80% over the past 30 years. Along the Atlantic coast the population density is almost 435 people per square mile (in comparison, the population density of Japan is about 825 people per square mile). This relatively stressed condition affects both environmental quality in the coastal ocean and the coastal economy. The direct environmental effects include a pattern throughout the USA, but especially in the near the urbanized areas of Northeastern coast and West Coast, of elevated levels of chemical contamination in coastal and estuarine waters and sediments and the living resources that inhabit them, closures of shellfish harvesting areas due to pollution, closures of marine recreational areas and loss of other recreational opportunities due to pollution, shoreline erosion, and loss of habitat, e.g., wetlands and seagrasses. Direct economic effects include the loss of millions of dollars of revenues from commercial and recreational fishing and other forms of marine recreation.

Intelligent management of the use of the coastal ocean requires reliable and timely information. The National Oceanic and Atmospheric Administration collects and interprets data to provide information and knowledge to decision makers at all levels of government, to business managers, to environmentalists, to researchers, and to the general public. Through its programs on the coastal ocean, NOAA brings together the expertise of scientists, engineers, and analysts to identify and analyze existing and future problems and to draw implications for U.S. policy.

It has unique capabilities to provide information for the management of the coastal ocean throughout the USA. It conducts research and monitoring programs on the effects of human activities on the quality of the environment of the coastal ocean, on living resources, and on their habitats. Its collective scientific expertise, research laboratories, and data collection capabilities (from ships to satellites) are unparalleled. It develops plans for the management of selected species of commercially important fish, including the conservation of their habitat. It protects endangered or threatened marine animals and their critical habitats and manages a national program of marine sanctuaries. It provides Federal resources to State governments to implement coastal management programs and to purchase lands for and manage a national program of estuarine research reserves. However, despite these existing NOAA programs, the state of the coastal ocean is deteriorating -- and it's getting worse.

What's the nature of this problem and what can be done about it?

The Decisionmaking Problem -- Some "Facts of Life"

• The coastal ocean is the most productive, most valuable, and most heavily used area of the marine environment -- and the area at most risk from human activities;

• Estuaries, adjacent coastal land areas, and the coastal ocean are closely linked physical, chemical, and biologic environments that must be considered jointly in public policy decisionmaking and the research and assessment activities to support it.

• Significant gaps exist in existing knowledge of the physical, biologic, chemical, and economic characteristics of the coastal ocean. Much of the knowledge and information that does exist is not in a form useful to decisionmakers.

• Resources are and will remain insufficient at all levels of government to analyze all areas of the Nation's coastal ocean in detail. However, it may not be necessary to do so, if maximum use can be of data, information and expertise.

• Billions of dollars of both public and private funds will continue to be invested in activities such as enacting legislation and developing regulations, developing and implementing management plans, installing and operating pollution control equipment and other measures, conducting waste disposal operations, modifying the physical environment, monitoring, responding to emergency events, and assessing and compensating for damages.

• The information available to make these decisions remains incomplete, inadequate, and inaccessible, at all levels of government and in the private sector. Most decisionmakers and scientists continue to address specific problems in selected parts of the coastal ocean on a piece-meal basis;

• As a result, policies for managing the coastal ocean remain fragmented and disjointed. A great deal of information is available for several of the largest and most "visible" estuaries of the USA, but much less is known -- as a whole -- about the other ones, or about adjacent coastal lands and waters that comprise the Nation's "coastal ocean."

• More importantly, very little information about the value of the national resource base that these areas collectively represent has been made available for decisionmaking.

• Significant gaps exist in knowledge of the physical, biological, chemical, and economic characteristics of the coastal ocean. Much of the knowledge and information that does exist is not in forms useful to decisionmakers.

• Most researchers, analysts, and decisionmakers continue to give insufficient attention to the multiplicity of, and significant differences in, information needs for various levels of decisionmaking. Information needs for decisions at various levels of government vary significantly in information content, scale, accuracy, and detail.

• Resources are, and will remain, insufficient at all levels of government to analyze in detail all problems of the coastal ocean. However, maximum use should be made of existing knowledge, information, and technology.

The Nature of the Problem

The resources of the coastal ocean are only part of the total range of resources available to society. While nothing is particularly unique about these resources compared to any other natural resources, certain characteristics should be recognized. First, the resources of the coastal ocean have historically been "common property" or "open-access" resources, and few or no controls have existed over who can use them or to what extent they can be used. A common property resource is a stock that potentially yields a flow of goods and services of economic value, that is owned by a collection of individuals or whose ownership has not been defined, and whose use is, in principle, open to all. In the case of some fisheries, for example, open access to these resources has lead to over-use of at least some part of the coastal ocean resource base.

Open access to resources of the coastal ocean can lead not only to improper rates of use, but also can affect the total allocation of resources used to produce all of the goods and services desired by society. For example, in the rush to extract fish, oil and gas, manganese nodules, or energy from the thermal gradients of the ocean, nations often waste resources. The resources required to extract these goods and services from the ocean might be used better in other parts of the economy.

A second characteristic is that the use of some of the common property resources of the coastal ocean is carried out under private property rights. The U.S. Government, as the trustee of the common property resources within its Exclusive Economic Zone (EEZ), transfers the rights to these resources to private ownership for a specified time period, often under special conditions, to allow their exploitation. For example, tracts on the outer continental shelf are leased by the U.S. Department of the Interior to private industry to explore for and develop oil and gas resources; Federal and state pollutant discharge permits are issued to municipalities and individual industries to allow use of the coastal ocean as a medium for waste disposal. Therefore, the adverse effects that result from the private use of these resources arise from explicit decisions made by various agencies of different levels of government in relation to the tradeoffs between and among the uses of the resources of the coastal ocean.

This characteristic of the exploitation of common property resources is not unique to the coastal ocean and is, in fact, similar to the management of public lands. In the coastal ocean, however, the problem is more complex than is generally the case on most public lands. Since the majority of our population and economic activities are located in or near coastal areas, the potential for conflicts among competing resource uses is correspondingly greater than in the relatively less intensely used public lands of the interior regions of the USA.

A third characteristic of resource use problems in the coastal ocean is the occurrence of external effects among and between users of the resources. While these external effects or externalities occasionally are beneficial -- as might be the case if the disposal of domestic sewage enriches fishing areas -- the effects are usually detrimental. Accidental spills and operational discharges from marine transportation adversely affect fisheries; sewage outfalls adversely affect shellfish harvesting; fixed oil and gas production platforms interfere with marine traffic.

At least three classes of use conflicts exist: 1) conflicts over development of a single resource; 2) conflicts among uses of coastal ocean space; and 3) environmental externalities or pollution from one use affecting other uses in the same or different locations. Examples of conflicts within development of a single resource include: competitive development of a fishery; congestion in shipping lanes; and the development of oil or gas from a common pool. Examples of existing or potential conflicts between and among different uses of the same coastal ocean area include interactions among fishing, transportation, oil and gas production, military activities, recreation, waste disposal, and research within the same space. The final class of external effects arises when pollutants generated and discharged in the use of one resource affects the use of other resources. An example is a restriction on shellfish harvesting due to high concentration of fecal coliform bacteria that are discharged into coastal waters by industrial operations.

A fourth important characteristic of the problem is its international nature. Again, while this characteristic is not unique to management of the coastal ocean, it often makes the resolution of use conflicts a difficult problem.

The management problem is to determine the "best" mix of goods and services to be produced from any given region of the coastal ocean over time, where "best" may be defined, for example, as the mix that results in the maximum net social benefits, subject to whatever constraints may be imposed. A constraint could be the requirement that a specified quantity of a specified good or service be produced in a region over time, e.g., the requirement that fish catch be maintained at so many tons per annum for specified species. In such a case, the management strategies developed for the region would have to either limit or preclude the production of goods and services that might inhibit attainment of the fish catch requirement, or specify technological modifications to their associated production processes. A technological modification might entail specifying processes for handling the disposal of drilling muds and fluids and formation waters discharged from oil and gas exploration or other development activities in the region. A service that might be precluded or limited is waste disposal, i.e., ocean dumping of solid materials and sludges in the region.

Determining the best mix of goods and services to be produced in a region of the coastal ocean is a dynamic problem. What constitutes the best mix will change over time, assuming that prior decisions have not resulted in irreversibilities that would preclude the production of certain outputs from a region. In addition, the mix of goods and services desired from any region will change as a result of:

- Changing interests of society, as interpreted by the legislative branch, the courts, and the executive branch, and as reflected in legislation, policy statements, rules and regulations, plans, and programs;

- Increasing knowledge of the basic physical, chemical, and biological processes in coastal ocean ecosystems and of the interrelationships between and among the various goods and services that can be produced in any region;

- Changing technology of producing goods and services;

- Changing values of goods and services in relation to other sources of the same or substitute goods and services;

- Changing demands for goods and services that can be produced from a region; and

- Changing governmental regulations,

export policies, import policies, and adherence to international conventions.

The recognition of regions of the coastal ocean as producers of multiple goods and services is a fundamental point that is critical for developing a framework. Regardless of how the objectives of a strategy are stated, e.g., to maximize oil and gas output from a region, or to preserve the critical habitat of specified species, or to achieve a specified level of ambient water quality, the inevitable fact remains -- few if any regions of the coastal ocean are likely to be dominated by only one output. Output levels for a mix of goods and services will be the logical management objective in almost all regions, except perhaps for some types of protected areas.

A Framework for Coastal Ocean Decisionmaking

Figure 1 represents one view of the way in which human activities interact with the coastal ocean. The critical elements are indicated by boxes and the causal relationships by arrows. This conceptual diagram represents the coastal ocean and its natural systems, human activities, and management actions related to human activities as a comprehensive, interrelated system. To understand and manage the effects of human interactions with the coastal ocean, information is required on the physical, chemical, biological, and economic components of this model -- and their interrelationships.

Human uses of the coastal ocean (e.g., fishing, recreation, minerals extraction, and waste disposal) is driven by the nature of the goods and services demanded by society, their relative values, and costs of production. Each of the activities, in turn, uses some combination of factor inputs (e.g., labor, raw materials, capital, energy, and water) to produce a given product or service. In this process, since no production process is 100% efficient, various pollutants are produced and discharged in various quantities into the environment of the coastal ocean. Once in the environment, these pollutants undergo various physical, chemical, and biological processes, e.g., transport, decomposition, and accumulation. These processes transform the time and spatial pattern of pollutant discharges from the various human activities into a resulting time and spatial pattern of ambient environmental quality. Since uses of the coastal ocean often take place simultaneously at the same location, conflicts among uses of resources can also arise.

The resulting effects on ambient environmental quality (e.g., water quality, sediment quality, quality of living organisms) impinges directly or indirectly (e.g., through the food chain) on receptors--humans, other animals, and materials. The effects on the receptors, i.e., "damages," as perceived by society, and the responses of individuals and groups to the perceived damages, provide the stimulus for action.

Once a problem has been perceived, initial action often takes the form of legislation in which broad goals are outlined. Translation of the legislation into action by executive agencies in the form of rules, regulations, and guidelines usually requires the specification of operational objectives, e.g., the achievement and maintenance of a specified level of ambient water or sediment quality or the allowable discharges from an ocean activity. The management strategy to achieve these operational objectives involves considerations of technological options, incentives or disincentives, and institutional arrangements for implementation. Alternative strategies, once identified, are evaluated by criteria such as effectiveness (e.g., is the desired level of ambient environmental quality achieved or is the biological damage avoided?), the direct costs of the strategy (including administrative costs) and the indirect costs (e.g., employment, increased costs of consumer goods, and dislocation of people), as well as the distribution of the costs and benefits, legal considerations and timing considerations. Constraints on the implementation of the strategy, such as budgetary limits or lack of legal authorities, must also be considered during the evaluation phase. Once a strategy has been chosen, implementation takes placed through management actions (e.g., permits, licenses, or leases), economic incentives or disincentives (e.g., charges, subsidies, and taxes) or other means. Implementation, in turn, is followed by enforcement, monitoring, and surveillance.

Whatever coastal ocean strategy is implemented, it should be periodically subject to evaluation with feedback to decision-makers (e.g., legislators and their staffs, executive agency officials and their staffs, and budget officials) so that they can make predictably necessary adjustments to the strategy. The entire process is a repetitive one with continuous feedback and recognition of the relationships of each step.

The NOAA Program

Increasing population and rising standards of living, both in the United States of America and other countries of the world, are leading to increased demands for goods and services. At the same time, land-based resources are becoming relatively more scarce and costly. Attention is now being directed toward marine and estuarine areas to supply not only increasingly larger outputs of the traditional products and services obtained from the resources of these areas -- for example, fish and shellfish, transportation, recreation, and waste disposal -- but also goods and services previously produced on the land -- for example, oil and gas, hard minerals, and space for industrial operations. As economic activities move into these areas on an increasingly larger scale, conflicting uses compete for limited resources, damage the natural environment, and under- or over-use valuable resources. What has formerly been a relatively simple problem of exploiting or managing these resources individually, has now become a highly complex one of deciding what mix of goods and services should be produced from the resources of any given marine or estuarine region at any point in time -- and over time. This general statement of the problem is appropriate whether the area of interest is all coastal waters of the USA or Japan, or the Gulf of Mexico, Puget Sound, or Tokyo Wan.

Analysis of alternative mixes of goods and services, development of marine and estuarine resources management strategies, and the evaluation of the consequences of implementing alternative management strategies is increasingly important to the decisionmaking process. In order for this type of analysis to generate useful information for decisionmaking, a comprehensive, consistent, and coherent framework for assessment is required.

Since 1979, NOAA has been compiling information on important characteristics of the coastal ocean of the USA. This information is being organized in the context of a national program of "strategic assessments" of potential conflicts among the multiple uses of resources within these areas. The assessments are characterized as strategic because they develop information appropriate for setting and modifying national objectives to: 1) develop and conserve resources of the coastal ocean; 2) identify various means to achieve these objectives; and 3) evaluate the potential effects of their implementation.

The NOAA program brings together four general types of information relevant to decisionmaking: 1) physical and chemical characteristics of resources and their surrounding environment; 2) biological characteristics, including species distribution, abundance, life history, and habitat requirements; 3) economic characteristics, including land use and pollutant discharges; and 4) ambient environmental quality conditions.

NOAA Computer-based Capabilities

A key to developing useful information and practical assessment capabilities is the recognition that a number of factors, many for which knowledge is incomplete and highly uncertain, affect almost every resource use decision in the coastal ocean. In this decisionmaking context, where incomplete knowledge and uncertainty exist, assessment capabilities are required that enable the analysis of different assumptions, about both the state of scientific knowledge and alternative management strategies. The new NOAA information bases and assessment systems are designed to apply these capabilities to resource use decisions in the coastal ocean.

An innovative feature of these capabilities is their emphasis on building "expert systems" that use available information and knowledge in an efficient and easily understood manner. The operating principle is to guide users through "menu-driven" computer programs that logically organize various levels of details and combinations of data aggregations and graphic presentations. Another important feature is the emphasis on an explicit "audit trail" capability so that the quality of the information itself can be evaluated.

Each of the information bases is organized geographically so that characteristics can be compared, computer-mapped, and assessed across combinations of spatial units. For example, to date we have organized the following types of information into a consistent, integrated set of analytic capabilities: 1) information on selected characteristics of the entire Exclusive Economic Zone (EEZ) of the USA, including physical environments, biotic environments, economic activities, environmental quality, and jurisdictions; 2) information on the distribution and abundance of over 300 species of fishes, invertebrates, reptiles, and mammals within the EEZ; 3) physical and hydrologic characteristics of 100 estuaries and adjacent coastal waters; 4) land use and population within drainage areas of these estuaries; 5) nutrient discharges and agricultural pesticide discharges into the coastal ocean; 6) coastal wetlands; 7) distribution and abundance of estuarine living resources; and 8) public investments in marine recreations in coastal areas.

No Short Cuts

Development of a body of information on the coastal ocean and operational capabilities to use it intelligently has been underway in NOAA for almost 10 years. Among the lessons that we have learned is that there are simply no short cuts to developing these capabilities systematically and carefully. The operational task of integrating disparate data bases and analytical capabilities is a difficult one requiring creativity, consistency, and continuity. The analytic capability to combine, compare, analyze, and portray information about the coastal ocean in a comprehensive manner provides NOAA and other parts of the marine scientific and resource management communities with a basis to organize information on the effects of alternative policies and communicate it in a timely manner.

As the products and services of this NOAA program are applied, tested further, evaluated, and refined, they should provide previously unavailable opportunities for improving the process through which important decisions on the use of the coastal ocean are made.

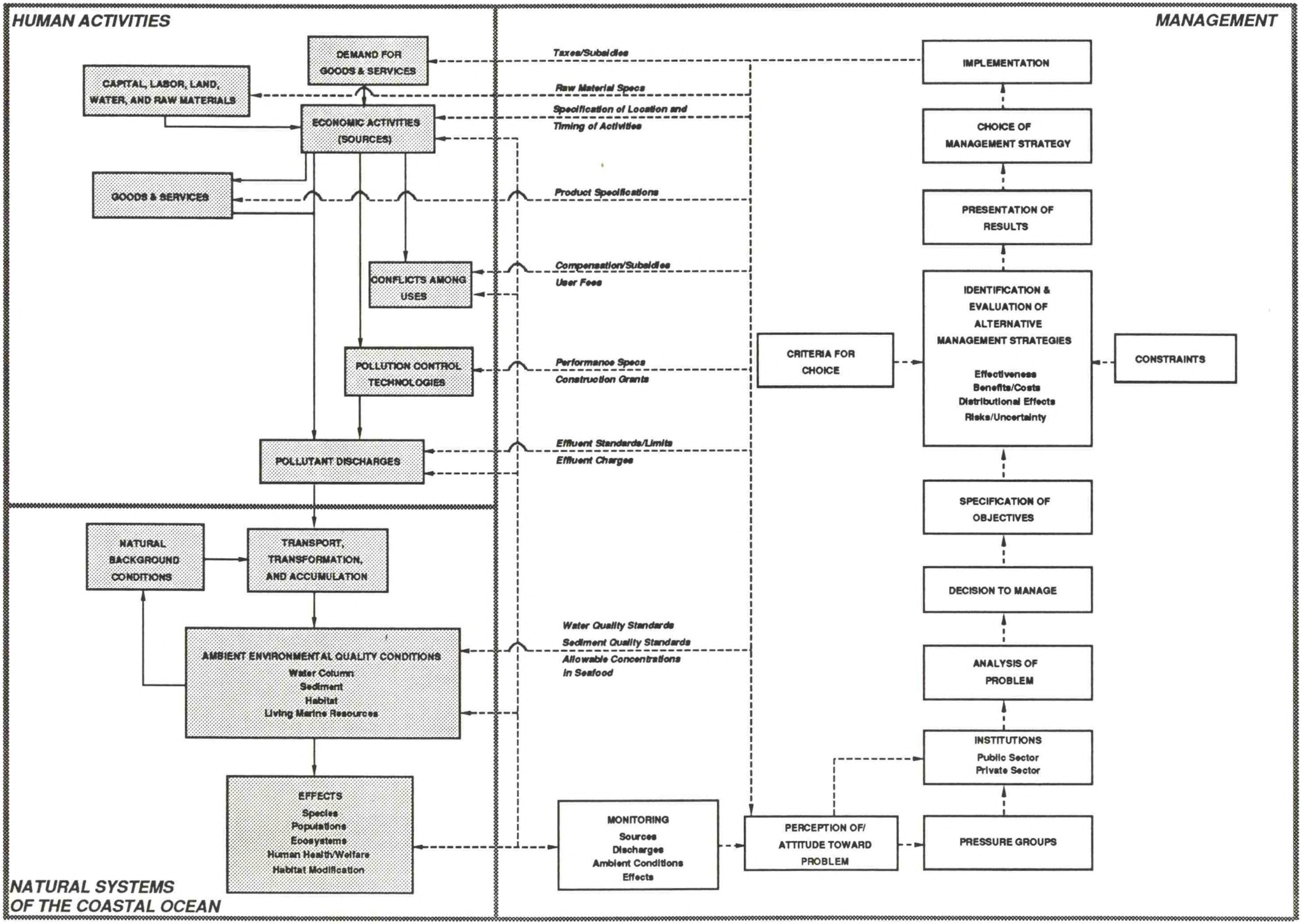

Figure 1. A Framework for Coastal Ocean Assessment and Management

COASTAL MAPPING IN JAPAN

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1. Introduction

In recent years, exploration and exploitation in coastal waters around Japan have become brick. To cope with this rapid growth of the activity in coastal waters, the Hydrographic Department of Japan (HD) has been conducting a survey project since 1973 to publish "Basic Maps of the Sea in Coastal Waters" at the scale of 1:50,000. The 1:50,000 scale basic maps are available for areas within 12 n miles from the coast. And 1:10,000 series are produced by HD for special areas where harbour construction, ocean engineering and other industrial activities are to be carried out.

The survey vessel 'Takuyo' (2,600 tons), which is large class survey vessel of HD , was build in August 1983. It makes it easy to carry out hydrographic survey in coastal waters around an uninhabited island located far from main islands. And the HD of Japan has been conducting a survey programme to prepare the basic maps for Oceanic Islands (uninhabited Islands).

Part of the above series' purpose is to help determine the baseline of territorial waters and provide information necessary for their contorol and development. It is the goal eventually to cover the whole of their soverreign waters(545 map sheets).

2. Method of surveys

The survey for the project will cover the whole of their soverreign waters. The coastal waters with in 12 miles around the Japanese island is divided into 545 districts which are 96 x 63 cm in size at 1:50,000 scale.

The spacing of surveying lines is 900 meters, along which bathymetric survey and seismic profiling are done continuously. The method of positioning depends upon electromagnetic position fixing system. Soundings are obtained by a echo-sounder.

One of the most critical and interesting aspects of its production lies in the interpretation of relatively scarce amount of survey data in comparison with data available for topographic map produced at equal scale. To this day, an adequate surveying technique providing total coverage of the sea floor still remains to be developed. Compliers must analize the few soundings collected along survey lines or local spot soundings, and from these, intepret and interpolate the bathymetric contours. Experienced specialists in marine geomophology are required to perform this complex operation accuarately. Even when contouring is done with great care, limitations related to this scarity of data will sometimes generate different interpretations when sevral compilers are asked to work on the same area.

Geophysical survey is made by a continuous seismic profiler generally done during bathymetric survey. Combined bathymetric /geophysical operations improve the capacitty to gather information with a relatively small increase in cost. The interpritation of data obtained from geophysical surveys, with high frequency seismic profiler (sparker) and 3.5kHz bottom profiler, and bottom sampling leads to the complilation of geological structural map.

3. General Map

(1) Bathymetric Chart

One of the Basic Maps of the Sea series is detailed bathymetric chart published at the 1: 50,000 scale and displaying bathymetric contours every meter where such detail is necessary. Eight bathymetric tints printed with two inks supplement contours. The maps include an elaborate portrayal of coastline forms with a 16-category legend. The land area is portrayed with information obtained from existing topographic maps, and additionally collected data on maritime facilities in land areas.

The intertidal area and marine area includes data on facilities along the coast, marine boundaries, and topographical conditions of the sea floor. This last category supplements bathymetric contours with other symbols for depth points, protrusions, aquatic plants and each bottom sample reflects the nature of the material discovered as well as its granualrity.

Intertidal areas are frequently important in coastal surroundings but cannot be portrayed with a single datum. Monitoring the tidal flats is necessity in flat coasts with high tidal frequency, but steep coasts present a defferent perspective on the issue.

The bathymetric data is employed as a basic tool by various specialist in marine studies, engineering, oceanography, research for energy sources, fisheries, etc.

(2) Topographical Map

The Geographical Survey Institute initiated the Basic Survey of Coastal Area in 1972. One of the resulting map series is the impressively deatailed Topographical Map of Coastal Area also published at the 1: 25,000 scale. The land area is portrayed with information obtained from existing topographic series. This map has the same single datum , the Mean Sea Level of Tokyo Bay which is also used on topographic series, for measurement of depth and elevations.

4. Thematic Map

(1) Geological Structural Chart

Geological Structural Chart is a one of results of basic survey in coastal waters. The structural chart is produced from seismic profiling data.

Geological structural chart is published in colour, because of their numerous geological formation categories, and the concern to achieve adequate visual discrimination between them. Their legends and symbols present many similarities with those found on geological maps of land areas. Point and line symbols are used in conjunction with surface patterns and color tints. The geological sections are provided to show geological features of seabed interpreted from records of seismic profiler.

In addition to the symbols used to encode geological variables, basement depth contours are normally printed on geological map of marine areas.Basement depth contours show surface topography of seabed burried under alluvium. Distributed areas of alluvial layers are shown by hach lines, and thickness of alluvial layers is shown in meter.

(2)Side-scan Sonar Mosaic Map

Side-scan sonar mosaic map shows nonselective details requiring interpretation by user. This type map is available for selected coastal area.Side-scan surveys are mainly carried out as a part of survey project for development of acuacultural resources.

Mosaic map is compiled at the scale 1:5,000 - 10,000 with side-scan sonar record collected along pallarel survey lines. Mosaic map includes some cartographic enhancements to help the user - marginal informatin, an overprinted line drawing (depthcontours, coastline) and names.

(3) Tidal Current Chart

Tidal current chart shows current direction and speed in knots. Data are based on predicted times and velocities at a selected location. The charts are available for the inland sea and major bays.

5. Digital Mapping

Coastal mapping will be affected by the current technological shift toward digital cartography and geographical information systems. The digital map is a recent addition to map classification. Digitizing project in coastal waters is carried out by Japan Oceanographic Data Center. The use can retrieve selected information either in map or list form.

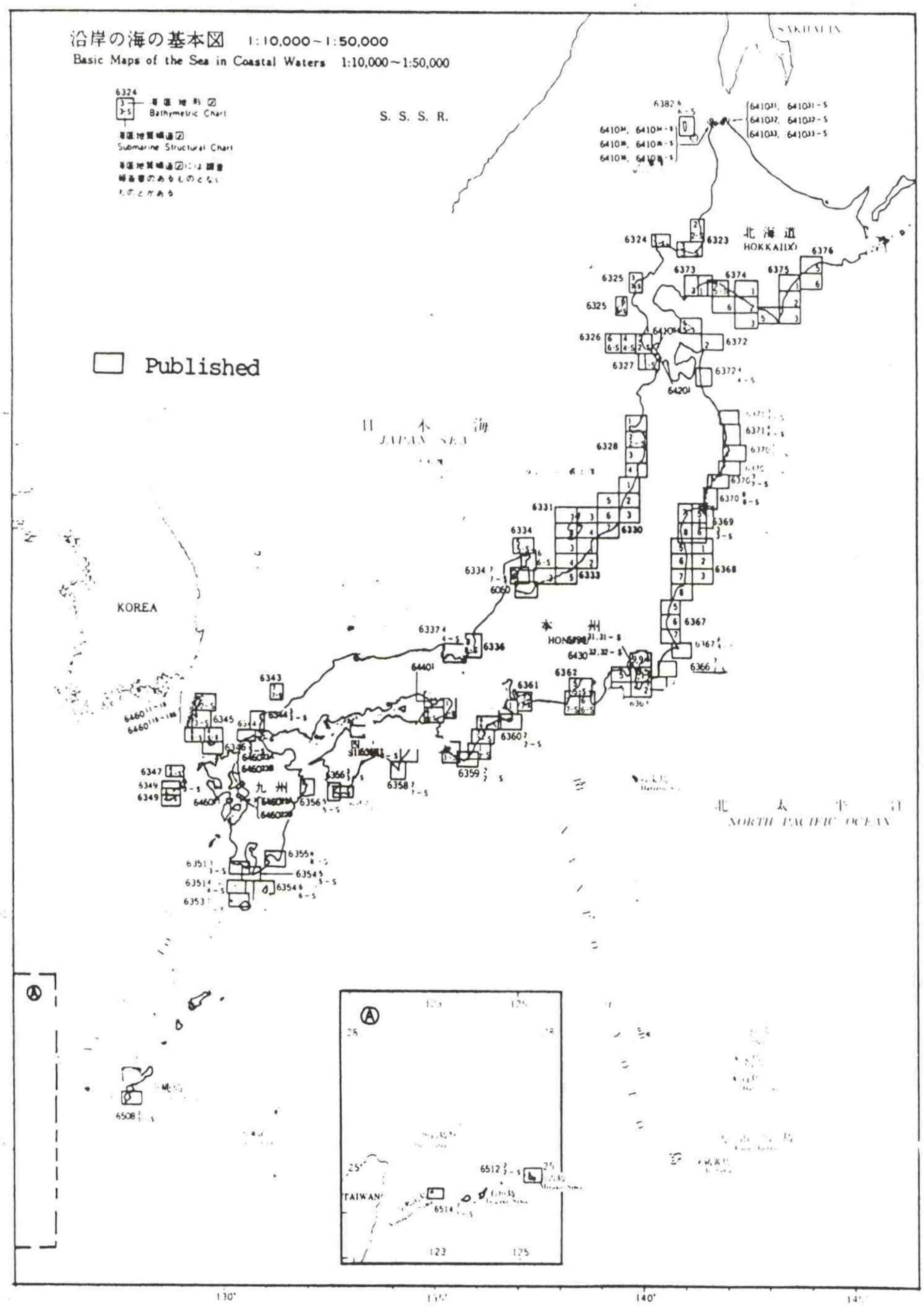

Figure 1.
Survey Districts of 'Basic Map of the Sea in Coastal Waters'.

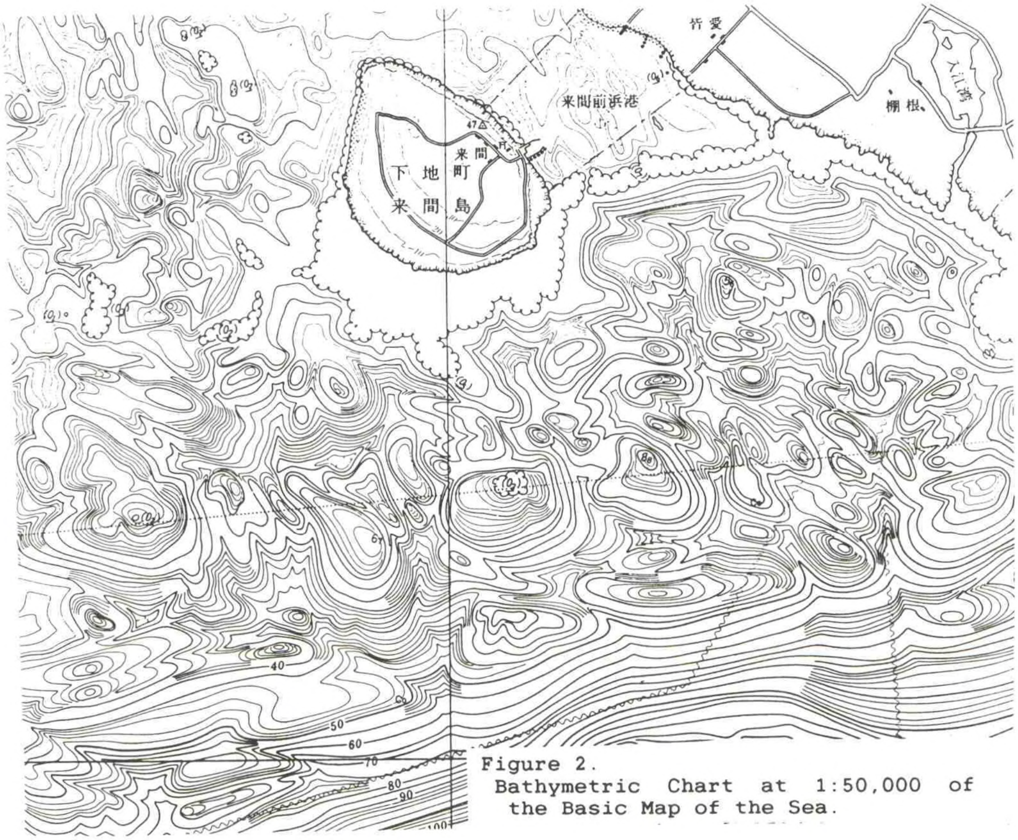

Figure 2.
Bathymetric Chart at 1:50,000 of the Basic Map of the Sea.

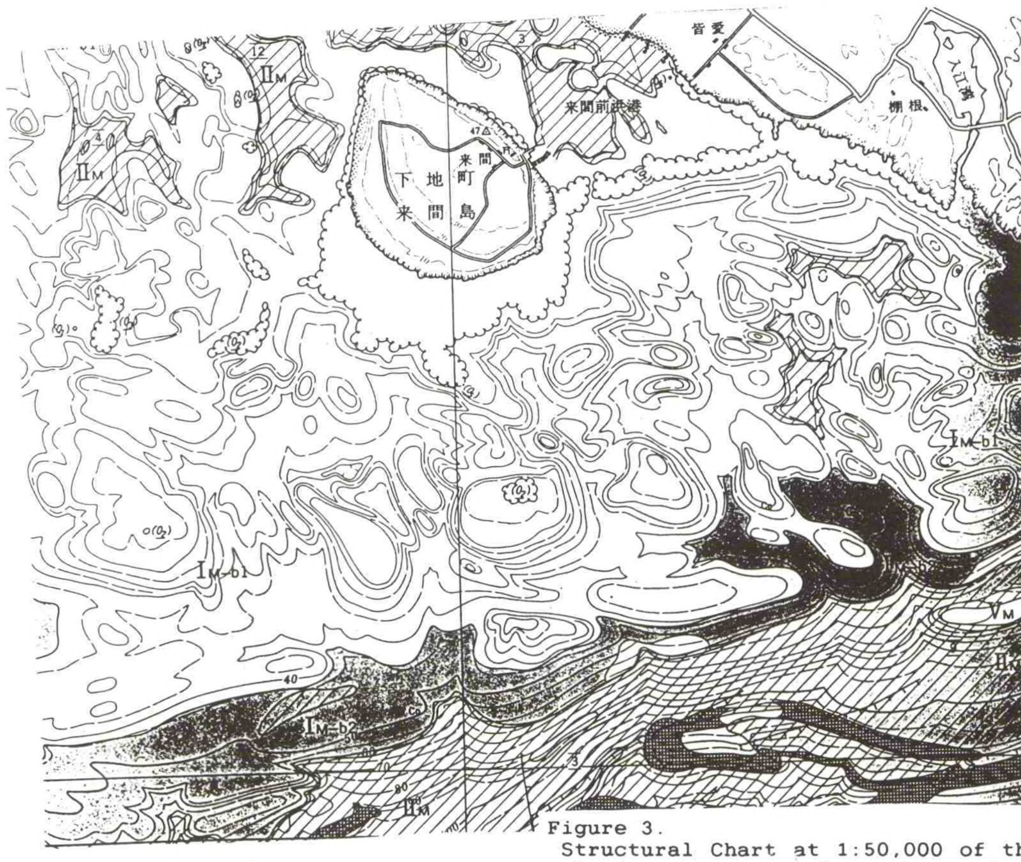

Figure 3.
Structural Chart at 1:50,000 of the Basic Map of the Sea.

CHANGING SEA LEVELS--TECHNICAL AND POLICY CONSIDERATIONS

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INTRODUCTION

One of the many challenges of the future shared by the United States and Japan is the phenomenon of rising sea level. A policy and technical framework for responding to rising sea level is needed because, in both countries, a large and growing proportion of the population, facilities, and development is located on the coast. Drawing on recent work of the Marine Board of the National Research Council (National Research Council, 1987), this paper addresses the causes of sea level change, its effects, and appropriate engineering and policy responses.

THE PHENOMENON OF SEA LEVEL CHANGE

For nearly a century, tide-recording stations around the world have measured a steady rise in sea level. The predominant change ranges from 1-5 mm/yr. The changes measured are the result of eustatic (global) phenomena as well as relative (more local) changes.

<u>Eustatic</u> sea level rise over the past century has been about 12 cm. The causes of this phenomenon are generally attributed to the melting of land-based glacier ice and the steric expansion of near-surface ocean water due to global ocean warming. The rate of change of eustatic sea level rise is projected to increase in the future, as the result of global warming.

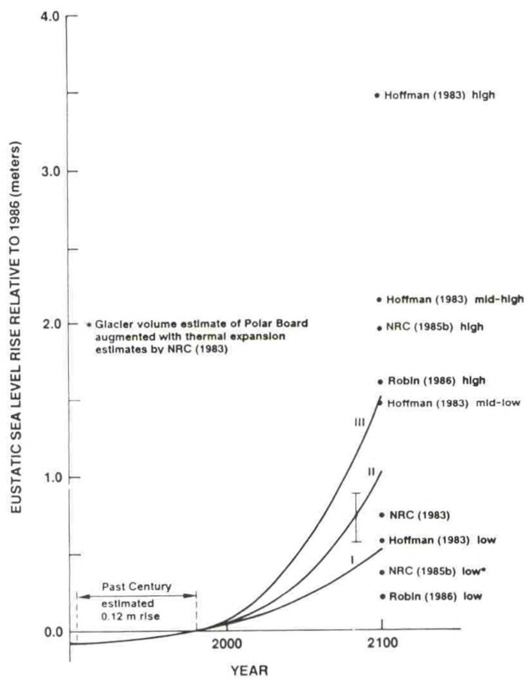

Figure 1.
Eustatic sea level rise scenario adopted in this report compared with other estimates.

<u>Relative</u> sea level change at a particular location is the local change in land elevation. The causes of relative sea level change are one or more of the following factors (in a given location):

- eustatic rise of world sea level;
- crustal subsidence or uplift of the land surface;
- due to neotectonics, that is, contemporary, secular,

structural downwarping of the earth's crust;

- seismic subsidence of the land surface due to sudden and irregular incidence of earthquakes;

- auto-subsidence of the land surface due to compaction or consolidation of soft, underlying sediments, especially mud or peat;

- man-made subsidence due to structural loading as well as groundwater and oil and gas extraction;

- variations due to climatic fluctuations. These changes are related to changes in the size and location of subtropical high pressure cells.

Relative sea level is rising and beach erosion is being exacerbated in many parts of the world, including many areas of the United States and Japan (see Figures 2 and 3).

Specific examples of changes and the physical phenomena that have caused them are illuminating. Relative sea level at Juneau, Alaska is dropping at the rate of 13.8 mm/yr. This reflects the rebound (rise) of the land with unloading of the land following the melting of glacial ice. In contrast, 90 years of tide gauge data in New York Harbor indicate that sea level is rising at about 2.7 mm/yr. Deducting about 1.2 mm/yr as the eustatic component, 1.5 mm/yr remains as a probable crustal subsidence factor. The lowering of land affects the bedrock of the whole region and is not affected by human activity. Long Beach, California presents yet another contrast. In the 1950s, Long Beach Harbor commenced a sudden, substantial, relative sea level rise trend, submerging appreciable parts of Terminal Island, a major industrial facility in the harbor. This subsidence was diagnosed as a short-term local phenomenon related to the withdrawal of oil, natural gas, and water from an underlying oilfield.

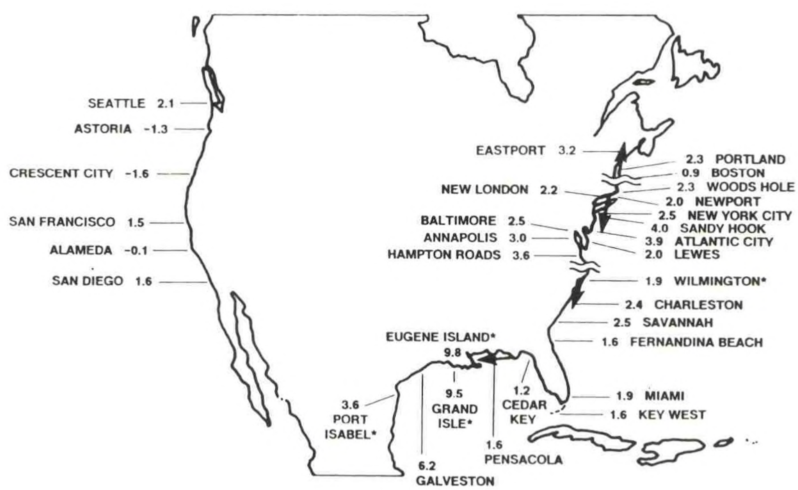

Figure 2.
A summary of the present best estimates of local relative sea level changes along the U.S. continental coastline in mm/yr. The gauges are based on the tide gauge records over different intervals of time during the period 1940-1980. Much regional variability is evident. Source: Adapted from Stevenson et al. (1986).

In Japan, long-term relative sea level changes reflect tectonic activity (subduction at convergent plates) to a much greater extent than local volcanism, faulting, or glacial rebound. Short-term fluctuations in sea level are caused by oceanographic processes, primarily the meander of the Kuroshio Current.

These examples demonstrate that sea level change must be considered in three contexts--local, regional, and global.

Figure 3.
Estimates of relative sea level changes along the Japanese coastline in mm/yr. Source: Based on tide gauge data. Adapted from Aubrey and Emery, 1986.

EFFECTS AND RESPONSES

The effects of sea level rise are evidenced by flooding and erosion. The magnitude of these effects depends on a number of factors, including whether the shoreline is a sandy coast, a bluff, a tidal inlet, or wetlands. The magnitude of effects is also influenced by the presence of any stabilizing structures and population density and activities.

There are three situations in which the effects are greatly magnified:

- sandy beaches on the outer coast exposed to ocean waves. Natural processes may cause beaches to erode 1 m or more for a 1 cm rise in sea level;

- the wedge of saline water through estuaries and tidal rivers may advance as much as 1 km for a 10 cm rise in mean sea level. This will be of special concern for drinking water supplies and coastal ecosystems during droughts;

- salinity intrusion in coastal aquifers where the landward displacement of the salt- and freshwater interface is a large multiplier of the sea level rise. Current problems of salinity intrusion into groundwater supplies will be increased with only a relatively small rise in sea level.

Potential problems associated with sea level change can be categorized into two classes: those of the open coast where both water level and wave action are concerns and those of inland tidal waters where wave action is usually much less severe. Wave action effects are so complete and potentially devastating that they require special expertise for structural design. As a result of erosion along the open coast, structures not designed for such forces may become exposed to wave action.

Shoreline changes have economic and environmental impacts that require decisions to define a proper response. For example, for sandy shorelines the possible remedies to erosion range from shoreline stabilization (through beach restoration or protective structures) to retreat from the shoreline. Each is technically feasible, but the appropriate response will usually be dictated by a combination of economic and environmental concerns.

The three general responses to sea level rise are to stabilize the shoreline, either through beach nourishment or by new or augmented coastal armoring; to retreat from the shoreline; or to control the rate of sea level rise. (This latter response would involve massive water diversions or deliberate limiting of global warming; these strategies are strictly hypothetical at the present time and are not discussed further.)

Whether to defend or to retreat depends on several factors, including the future sea level rise rate and the cost of retreat. The former is poorly known, and the latter will vary from place to place.

Engineering Responses

Engineering responses to sea level rise have been devised in many locations. Galveston, Texas has constructed a series of seawalls and groins since the town was demolished by a major hurricane in 1900. Additional diking has been recommended in the future to maintain the existing urban city.

The foremost international example of a people coping with high relative sea level is the Dutch. The most recent engineering work to control flooding is the Delta Project. Sixty-four massive storm surge gates permit tidal flows into three major estuaries but provide flooding protection during major storms.

Between 1976 and 1980 the resort community of Miami Beach, Florida placed 14 million yds^3 of sand dredged from offshore on 10.5 miles of beach.

The subsidence described earlier in Long Beach, California amounted to 6 m in places, with considerable damage to harbor facilities, pipelines, culverts, buried cables, and other structures. This damage required substantial remedial efforts. Water was injected into depleted wells to restore and maintain pressure in the various strata comprising the field.

Dikes were built in areas of extreme subsidence. Damaged facilities were reconstructed, bridges were repaired, and oil wells that had suffered casing damage were redrilled.

Japan also has employed numerous engineering responses to sea level rise. The Japanese Bureau of Ocean Development is currently involved in 800 assignments to save sections of Japan's coastline from erosion (Haberman, 1988).

Retreat

In areas where the long-range cost of environmental damage due to shoreline stabilization is unacceptable, it is advisable for development to retreat or move back from the shore. The three basic ways to retreat from an eroding shoreline or flood-prone area are to move buildings as the shoreline approaches, attempting to maintain elevation above sea level; let coastal development be overtaken as nature takes its course; or avoid coastal development altogether in vulnerable areas. Several communities in the United States such as those in North Carolina and Maine have adopted this latter approach in recent years. The first approach, moving buildings to maintain height above sea level, has recently been recommended as the preferred response to save the Cape Hatteras Lighthouse in North Carolina (National Research Council, 1987b).

The retreat option was given a boost recently in the United States. The Housing Act of 1987 provides for payments to property owners in advance of loss for demolition or relocation of structures in imminent collapse as a result of erosion. The Act also prohibits federally subsidized insurance or disaster assistance for structures constructed on land previously determined to be subject to erosion within the next 30 years (1-4 dwellings) or 60 years (all other structures).

Putting a policy of retreat in place can be accomplished in various ways. Areas with low density coastal development can rely on building codes, setbacks, zoning, and land use plans. More developed communities have to address the issues of existing buildings and shoreline stabilization structures. Implicit in the philosophy of retreat is the belief that cost-effective coastal protection is not viable for the given locale. Since the state of the art of coastal erosion mitigation is evolving rapidly, any retreat decision should be reviewed periodically.

STRATEGIC DECISIONS

Sea level rise forces people who live on the coasts to face a number of important decisions. In the past, keeping the coastal infrastructure above the historical slow rise in sea level for the most part has been achieved through normal maintenance and abandonment of facilities. Faced with accelerated sea level rise in the future and increased coastal development, a more considered and planned approach to the protection or abandonment of coastal facilities and communities is needed. A clear understanding of the natural processes underlying shoreline erosion and knowledge of the efficacy of coastal structures are important factors in choosing a response strategy. Additional site-specific considerations are the economics involved, as well as the social and environmental costs.

For well-developed coastal communities, with a high density of building and expensive shoreline facilities such as harbors and resorts, the strategy of choice in all likelihood will be to protect the existing infrastructure. For eroding shorelines that are less-developed, the decision becomes more difficult, because the costs and benefits of protection must be weighed against those of retreat.

Responding to changing sea level will take on greater urgency and relevance in the future as several apparently irreversible trends combine to render the coastal zone more hazardous as a site for major investment. These trends include:

- increasing human settlement, services, and installation in coastal areas susceptible to inundation, erosion, or destruction due to increases in relative sea level, storm surges, and tidal crescendos;
- land subsidence;
- the steady increase of atmospheric greenhouse gases, which is theorized to enhance global warming, thus contributing to glacial melting and eustatic sea level rise.

Coping with these trends will require:

- research, data acquisition, and analysis of the specific effects of sea level rise in relation to other environmental changes and the response of specific coastal works to rise; and
- review and coordination of national and regional policy concerning the coastline, especially to take account of new knowledge.

Prediction of climatic, oceanographic, and geologic processes that are potentially hazardous to coastal structures within 10-50 years and the ability to warn the public of hazards are also needed.

Design procedures for coastal structures should include a review of data on past water levels, including the maximum level, and then should provide some margin of safety to cover uncertainties. In some cases, e.g., docks, structures conservatively designed with expected lives of 50 years or less should not be signifcantly affected by sea level rise even if a rise is not considered specifically in the design. Other structures, such as sea walls and hotels on the open coast, would be vulnerable to even a small rise.

Where possible, considerations of sea level changes should be incorporated into coastal land use planning. Areas designated primarily for industrial use may not be significantly affected by required coastal protection. However, designated uses contingent on the continuation of existing environmental features, such as shoreline conditions, may limit shoreline response options. For example, coastal armoring of a formerly sandy beach may reduce the environmental desirability of the area.

Construction of almost any conceivable protection against sea level rise can be carried out in a relatively short period of time. Therefore, if a substantial increase should occur, there will be time to implement protective measures. However, in areas where such protection would not be justified, a cost-effective abandonment of facilities would require decades to implement.

The risk of accelerated sea level rise is sufficiently established to warrant consideration in the planning and design of coastal facilities. However, the phenomenon of sea level rise is relative, and its effects are site-specific. For this reason, strategies to respond to sea level change, either by constructing defenses or through mitigation, necessarily need to be developed on a case by case, site-specific basis. Blanket, nationwide solutions will be inappropriate, because they cannot take account of the numerous environmental, physical, technical, economic, and social factors that converge at the local level.

REFERENCES

Aubrey, D.G. and K.O. Emery. 1986. Relative Sea Levels of Japan from Tide-Gauge Records. *Geological Society of America Bulletin*. 97, 194-205.

Haberman, Clyde. 1988. Japanese Fight Invading Sea For Priceless Speck of Land. *New York Times*, January 4, 1988, 1.

Hoffman, J.S., D. Keyes, and J.G. Titus. 1983. *Projecting Future Sea Level Rise; Methodology, Estimates to the Year 2100, and Research Needs*. U.S. EPA, Washington, DC.

National Research Council. 1985. *Glaciers, Ice Sheets, and Sea Level*. National Academy Press, Washington, DC.

National Research Council. 1987. *Responding to Changes in Sea Level: Engineering Implications*. National Academy Press, Washington, DC.

National Research Council. 1987. *Interim Report--Committee on Options for Preserving the Cape Hatteras Lighthouse*.

Robin, G. de Q. 1986. Changing Sea Level. In *Greenhouse Effect, Climatic Change, and Ecosystems*. John Wiley & Sons, New York. p. 323.

PORT RENAISSANCE PROJECT

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1. WHAT IS THE PORT RENAISSANCE PROJECT?

In Japan, most foreign trade cargoes are carried by maritime transport. The maritime sector also carries about 50 percent of domestic cargoes. And Japanese ports and harbours have played an important role not only as a space for physical distribution, but also as a catalyst for the nation's economic growth.

Because of Japan's mountainous topography, attention has been focused, from old times, on waterfront areas including ports and harbours for promoting the development of industry. Numerous heavy industries, especially the steel and shipbuilding industries which supported the nation's rapid economic growth in the 1960s, are mostly located in waterfront areas.

The Ministry of Transport has positively promoted the development of ports and harbours since 1950 as the core of the development of waterfront areas in Japan. However, as the economy of Japan has shifted into a phase of stable growth, the role of the ports and harbours has begun to change.

Today, many of the ports and harbours in Japan need to be redeveloped on an urgent basis.

With the advancement of Japanese industry, highly functional physical distribution facilities including large container berths have been developed. However, in recent years, with the shift of the Japanese industrial structure and the growth of the service sector, many heavy industries have declined. Consequently, many of the older port and harbour facilities located in inner harbour areas have become obsolete.

On the other hand, in accordance with the higher standard of living of the Japanese people, it has become necessary to redevelop inner harbour areas which are located close to city centers not as a space for physical distribution and industrial functions, but rather as recreational areas where the citizens can see and enjoy the sea and the ships.

Thus, the Ministry of Transport has been developing the Port Renaissance Project since fiscal 1986 in order to promote the redevelopment of ports and harbours with the cooperation of both public and private sector bodies, and to develop attractive port areas as an amenity for the local population.

2. DETAILS OF THE PORT RENAISSANCE PROJECT

The Port Renaissance Project is a system designed for the urgent redevelopment of inner port areas of the ports and harbours of large cities through the cooperation of the public and the private sector under master plans formulated by local port administrative bodies.

Since 1986, the Ministry has been granting a subsidy for one-third of the expense required to formulate master plans for this type of redevelopment including land-use plans, facility plans, etc.

Master plans were prepared for 22 ports in fiscal 1986 and for 22 more ports in fiscal 1987 as shown in Figure 1. Many of the required surveys were executed through the organization of committees composed of men of knowledge and experience, concerned local persons and administrative personnel.

Through such committees, it was possible to extensively examine the plans reflecting local opinion, and to form a consensus for implementation of the projects.

Many of the individual works which comprise the master plans are being executed by the port administrative bodies using public funds.

On the other hand, as it is also desirable to utilize the flexible and functional know-how of the private sector, many works are also be executed by private companies or through so-called "third sector" arrangements, which are essentially joint ventures of public and private bodies. In this way, it is possible to extensively utilize the financial potential of private sector firms.

Thus, local government bodies are providing various incentives to the private sector companies which are developing new core facilities such as port operation buildings, passenger terminal facilities, international conference halls and trade fair sites. The incentives to the private sector include financial subsidies, tax benefits, and various other accommodations.

3. EXAMPLES OF PORT RENAISSANCE PROJECTS

Presently, there are about fifty

Port Renaissance projects being planned or contemplated in Japan. Two representative, large-scale projects are the Port of Tokyo Takeshiba Area Redevelopment Plan and the Port of Yokohama "Minato Mirai 21" Plan (Figure 2 & 3)

At the Takeshiba Area of the Port of Tokyo, the deteriorated wharves are being redeveloped. The port administrative body is responsible for the construction of the piers and passenger sheds and for the reclamation, while a "third sector" joint venture is constructing a port operation building, a multifunctional hall and other facilities using investment capital provided by the Tokyo Metropolitan Government and private sector financial institutions. The total project cost is about 80,000 million yen, and the project is scheduled for completion in 1992.

The Port of Yokohama "Minato Mirai 21" Plan comprises redevelopment of the inner port area close to the city center for the development of an international cultural center with the city and port functions harmoniously integrated for the 21st century. As the first phase of the developmen plan, a "third sector" joint venture using investment capital from the City of Yokohama, Kanagawa Prefecture and private sector firms will construct by 1991 an international conference hall, an international trade fair site and other facilities at a total cost of about 39,000 million yen. Development of the peripheral infrastructure will be executed by the state and by the port administrative body.

As seen in these examples, new port areas will be created through the positive cooperation of the public and private sectors. These new areas will provide recreational facilities and various facilities for the service sector which go beyond the traditional concept of a port as a place for the physical transfer of goods and for industrial activities.

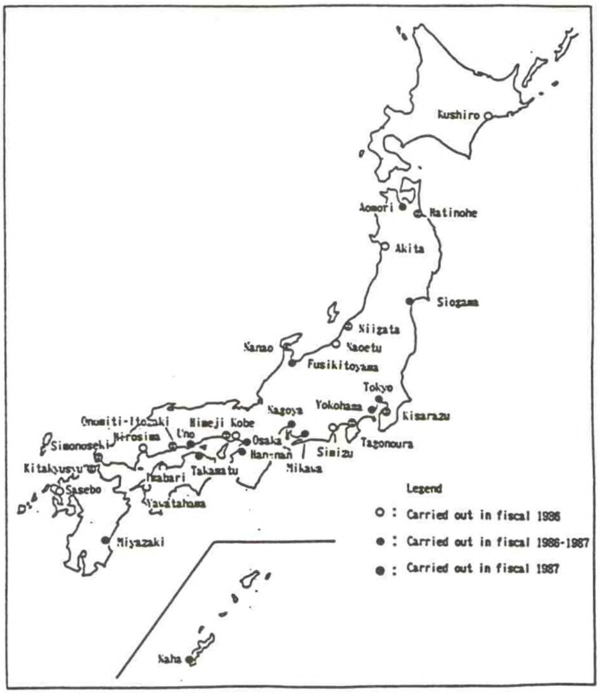

Fig. 1 Port Renaissance Survey Sites (Fiscal 1986-1987)

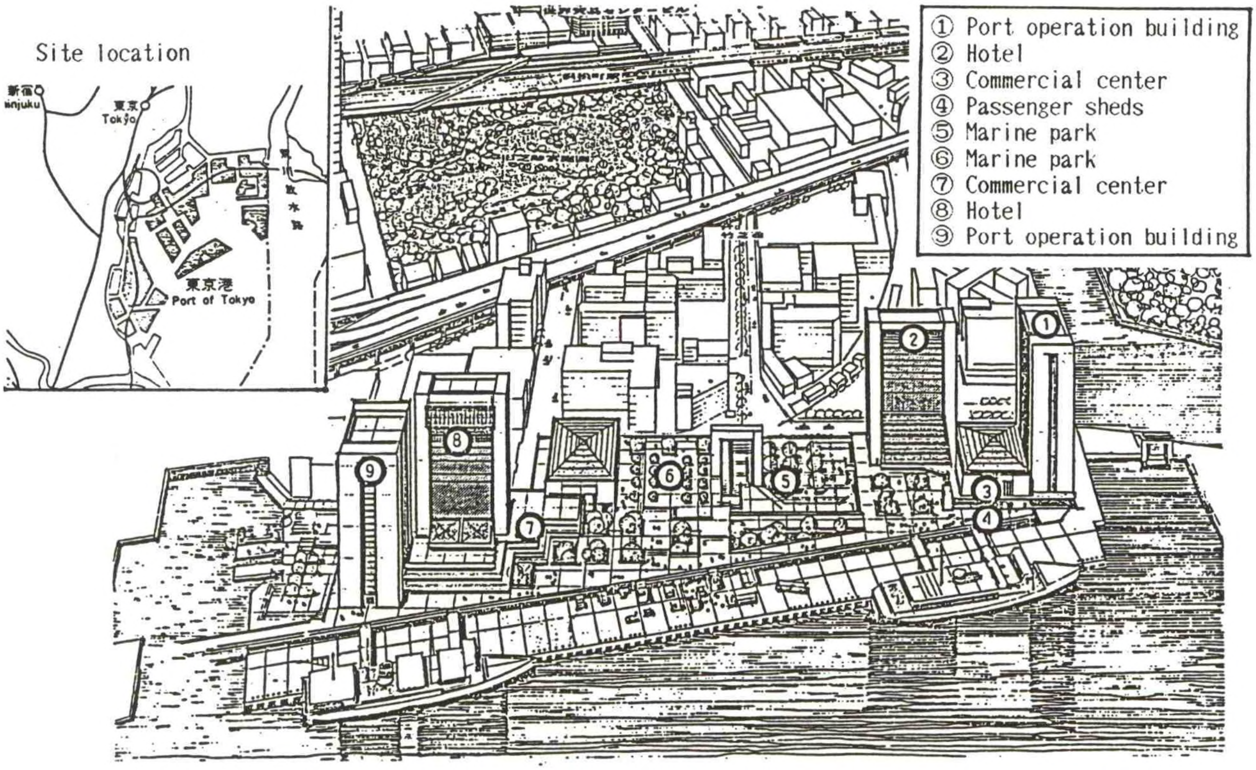

Fig. 2 Port of Tokyo Takeshiba Area Redevelopment Plan

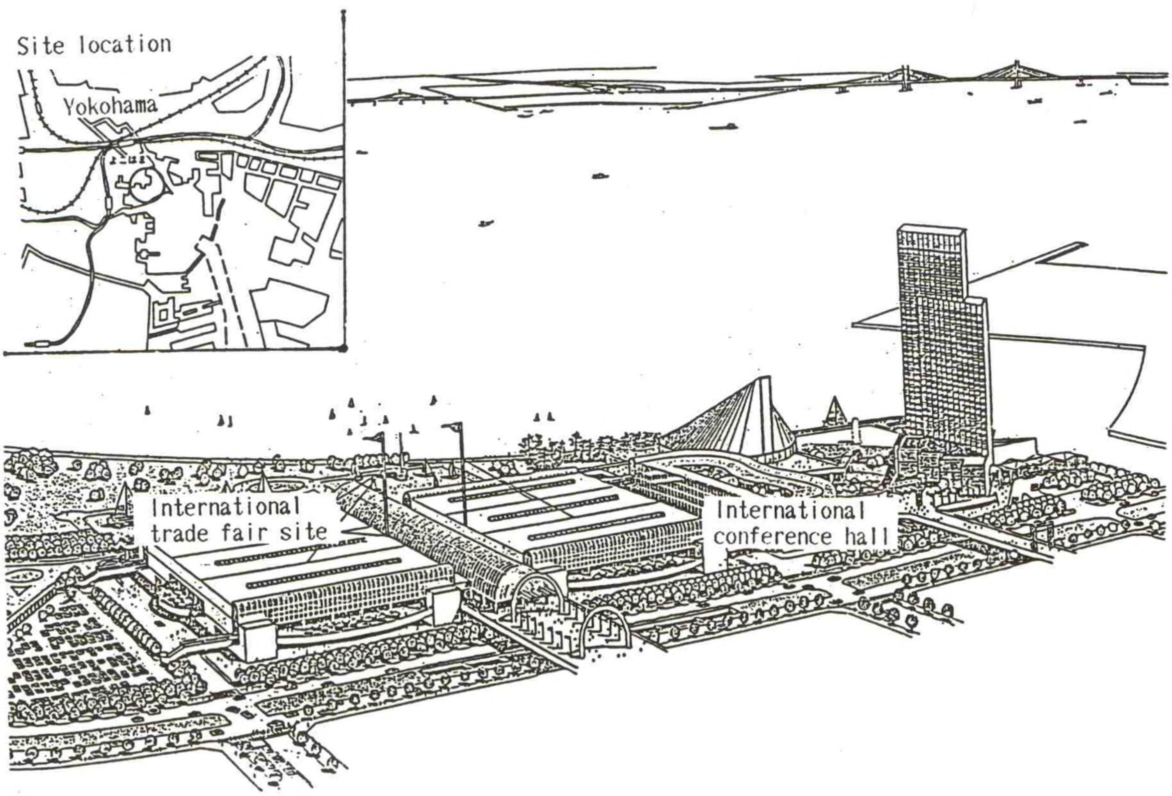

Fig. 3 Port of Yokohama "Minato Mirai 21" Plan

OFFSHORE MAN-MADE ISLAND CONSTRUCTION TECHNOLOGY

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JAPAN

OVERVIEW

This paper takes an overview of the technological issues related to the construction of offshore man-made islands in Japan and discusses their recent trends.

1. MAN-MADE ISLAND CONSTRUCTION IN JAPAN

1.1 HISTORY OF MAN-MADE ISLAND CONSTRUCTION IN JAPAN

Japan is surrouded by the sea and has many steep mountainous regions. For this reason, economic and social activities have actively been carried out in coastal areas. Coastal areas have also been reclaimed as a way of answering the demand for space required for economic and social activities.

After W.W.II, industrial sites for steel, petrochemical, shipbuilding and other industries have been secured by reclaiming coastal areas.

Such reclamation and construction of man-made islands have mainly been carried out along with development of modern ports and harbors. That is, due to the demand to increase the efficiency of sea transportation to key industries located in coastal areas, ports and harbours were required to take in large vessels,and as a result, waterways and basins were dredged, and dredged soil was effectively used in land reclamation to secure industrial and port areas.

Airports and energy supply facilities such as thermoelectric power plants have also been secured by constructing man-made islands.

Moreover, man-made islands are also being used in solving problems caused by concentrated urban activities such as the lack of living space and of sites to dispose of waste.

Table 1 and Figure 1 show representative man-made islands which have been constructed in Japan.

1.2 DEVELOPMENT OF OFFSHORE MAN-MADE ISLANDS

In the past, in developing man-made islands in near shore districts, construction sites were selected which were shallow,where good reclamation materials could easily be obtained through dredging, and where ports and harbors and reclaimed man-made islands could simultaneously be developed. For this reason, urban living spaces, industrial production areas and distribution bases were located close to each other. Although highly economical,the development of these sites resulted in deterioration of the living environment due to the increase of noise, vibration, air and water pollution.

Table 1 Major Man-made Islands in Japan

Name	Use	Water depth (m)	Wave height (m)	Distance from coastline(km)	Soil quality	Construction period	Area (1,000m²)	Construction cost (¥ billion) Island only	Total (incl. land facility)	Per unit area (¥1,000 per m²)	
Ogishima	Industrial land	0-15	3.4	0.4	Clay	1971-1975	5,150	87 (110.3)	979 (1,241.6)	17 (22)	190 (241)
Higashi Ogishima	Harbor facility and transportation facility	0-10	—	0.7	Silt	1972-1984	4,340	87 (99.9)	131 (150.5)*	20 (23)	30 (34)
Yokohama Daikoku	Harbor facility greenery	12	5.5-6.0	0.5	Silt	1963-1985	3,210	91.3 (113.5)		29 (36)	
Nagoya Port Island	Soil dump	6-7.5	2.0	1.2	Clay, silt	1975-1987	1,140	18.6 (20.1)		16 (17)	
Nagoya Kinjo	Harbor facility, foreign trade facility, exhibition hall, greenery	0-5	1.0	1.4	Soft soil	1963-1985	1,910	66.8 (83.1)		35 (44)	
Yokkaichi Kasumigaura	Harbor facility, industrial land	4.5-12	4.0	0.1	Soft soil	1967-1988	3,870	70.8 (81.3)		18 (21)	
Gobo Thermal Power Plant	Power plant site	5-18	17.5	0.2	Sandstone, sandy soil	1980-1983	350	42 (44.6)	286 (303.5)	120 (127)	820 (870)
Osaka South Port	Harbor facility, urban development site, commercial facility, park, greenery	10	3.3	0	Clay	1958-1984	9,370	97 (128)	142 (187.4)	11 (15)	15 (20)
Osaka North Port	Harbor facility, industrial land, waste disposal facility	10	3.3	0.45	Clay	1972-1988	6,150		151 (166.7)		25 (28)
Kobe Port Island	Harbor facility, international exchange facility, urban development site	10-13	—	0.4	Clay	1966-1981	4,360	230 (291.7)	530 (672.2)	53 (67)	122 (155)
Rokko Island	Harbor facility, urban development site	10-14	—	0.2	Clay	1971-1985	5,830		500 (574.3)		86 (99)
Kanda Earth Dump	Dredged sand dump, park	7.5	2.5	3.5	Soft soil	1977-1986	1,530		41.7 (45.1)		27 (29)
Nagasaki Airport	Airport	10-18	2.0	1.5	Clay, basalt	1971-1974	1,630	10.4 (15.3)	31 (45.5)	6 (9)	19 (28)
Mitsui-Miike Island (No. 3)	Vertical ventilation shaft	10	3.3	6.0	Soft soil	1969-1970	6		1.1 (1.51)		183 (251)
Kansai International Airport	Airport	20	—	5.0	Soft soil	1985-	1,200	—	3,000	—	250

Notes: 1) Figures in parentheses are values calculated in consideration of price rises (3% per year).
2) *Including the construction cost for undersea tunnel.

In addition, because coastal areas are used for many purposes such as sea transportation, fisheries and recreation, the suitable areas for developing man-made islands close to shore are limited. So, it is our belief that man-made islands should be constructed offshore. Then it can be possible to reduce the influence on the natural and living environments and to create calm sea areas behind the islands for using the sea more effectively (Figure 2).

However, in constructing offshore man-made islands, the natural conditions such as waves in deeper water are severe and the construction cost is higher. In addition, while the conventional man-made islands have been constructed on good sea ground, future man-made islands may have to be constructed on soft ground. Thus, the conditions of construction may become increasingly difficult.

Therefore, in developing offshore man-made islands in the future, technology to overcome severe natural and economic conditions will be required.

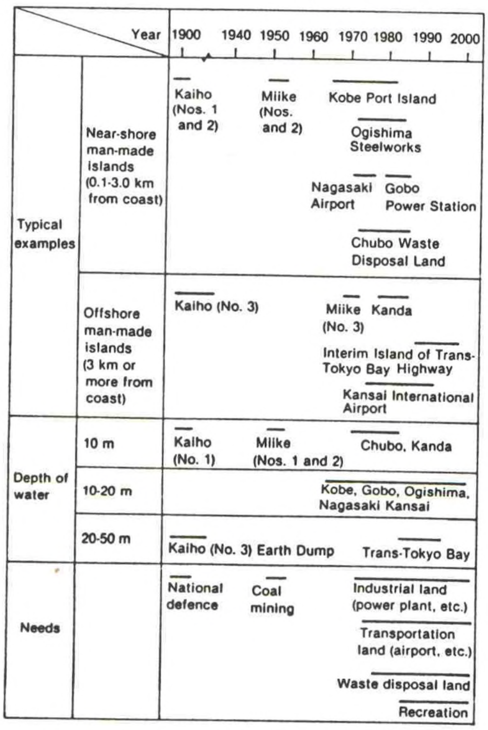

Figure 1 Chronology of Man-made Islands in Japan

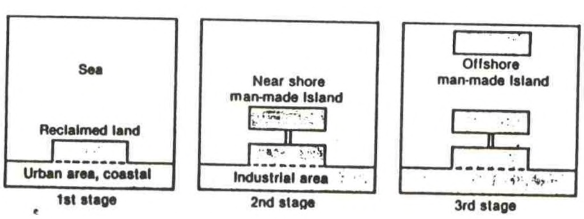

Figure 2 Patterns of Offshore Space Utilization

2. OFFSHORE MAN-MADE ISLAND CONSTRUCTION TECHNOLOGY

2.1 OVERVIEW

When constructing offshore man-made Islands, the optimum structural type is determined based on such things as their purpose and use and the natural conditions of the construction site.

Based on a comparison of the various structural types, construction of man-made islands through reclamation is ordinarily considered the best method.

The technology for constructing man-made islands through reclamation has mainly progressed in the form of dredging and reclamation technology along with the development of ports and coastal industrial sites.

The reclamation works implemented in Japan in recent years have greatly developed the construction technology represented by such technologies as mass reclamation, ground improvement and underwater execution. However, as mentioned above, it has gradually become necessary to construct man-made islands in sea areas with severe natural conditions such as great water depth and soft ground because of the concentrated use of coastal areas and the shortage of suitable construction sites. This section discusses the trends of technologies for constructing man-made islands.

2.2 RECLAMATION TECHNOLOGY

(1) RECLAMATION BY DREDGING

Man-made islands are often reclaimed by dredging if good materials suitable for reclamation can be obtained from nearby sea areas.

In the conventional field of dredging technology, large pump dredging vessels have been developed with a maximum dredging water depth of approximately 80 meters and a nominal dredging capacity of 1,000 m^3/h to achieve such results as dredging 15,000,000 m^3 of sand in the Higashi-ogi Island reclamation work.

Various technologies are being developed to cope with offshore construction sites in the future, such as improving the anti-wave capacities of work vessels.

(2) RECLAMATION USING LAND SOIL

Many conventional cases of reclamation have been carried out using dredged materials as mentioned above. However, due to such reasons as the shortage of good materials on the sea floor around the construction site, increasingly land soils are being excavated and used as reclamation materials. In this case, additional useful land is often created at the excavation site as well through the leveling out of steep areas.

For example, the reclamation work for Port Island at the Port of Kobe used 80,000,000 m^3 of land soil.

The onland excavation sites have been developed into residential areas, academic cities, distribution terminals and parks. Other major examples of man-made islands constructed in this manner include Ogi Island, Rokko Island and the Gobo thermoelectric power plant.

This method has also been adopted for the Kansai International Airport which is now being constructed, and approximately 150,000,000 m^3 of land soil will be reclaimed in 7 years with the reclamation reaching a peak of approximately 56,000,000 m^3 per year. The reclamation materials will be supplied from the three prefectures of Osaka, Wakayama and Hyogo, and programs have been formulated to effectively use the land areas where the soil will be removed.

2.3 GROUND IMPROVEMENT TECHNOLOGY

(1) OVERVIEW

When man-made islands are constructed on soft sea ground, it is necessary to improve the foundation of the sea wall and the reclaimed land.

In addition, when the reclamation material is soft, it is necessary to improve the reclaimed layer.

The method for improving the ground must be carefully selected because it greatly affects the construction costs and period.

The methods for improving the ground can be divided into three groups : to replace the original soft ground with good soil, to increase the strength of the ground by increasing its density and to similarly increase the strength of the ground by adding stabilizers. The following section discusses the principal methods for improving the ground.

(2) REPLACEMENT METHOD

The replacement method is one whereby soft soil is replaced with good sandy soil. It is a simple and sure method and execution control is easy. In ocean works, large and highly efficient dredging vessels execute the large-scale works.

However, the replacement method involves various problems such as disposal of the excavated soil, spread of mud due to dredging and securing of good soil for the replacement, and there is a tendency recently to limit the use of this method.

(3) DENSITY INCREASE METHODS

The density increase methods can be divided into those centering around consolidation and those utilizing compaction. In ocean works, the sand drain method is usually used for consolidation and sand compaction pile method for compaction.

a) SAND DRAIN METHOD

The sand drain method is commonly used as a representative ground improvement method.

The cases in which this method is used are decreasing in recent years because of the difficulty of execution control and because it takes time to increase the strength by consolidation. This method, however, is being reconsidered for such reasons as that in comparison with the replacement method it requires less sand and does not involve the problem of having to dispose of soil and the construction costs are relatively low.

At the Kansai International Airport now being constructed, this method is being used with rational execution control to build three-fourths of the approximately 11Km seawall and the entire reclamation area of approximately 500 ha.

b) SAND COMPACTION PILE METHOD

The sand compaction pile method is one whereby the ground is improved by creating sand piles in the ground by means of vibration load. It can be used both for sandy and clay grounds.

In particular, when it is used for clay ground, it produces an improvement effect by creating a composite ground made up of sand piles and clay, and has the advantage that in comparison with the replacement method it produces less soil which must be disposed of.

(4) DEEP MIXING METHOD

This is a kind of solidification method in which the ground is chemically solidified by stabilizers such as lime and cement which are injected into the soft clay ground and churned.

Compared to the other methods this is relatively expensive. It however has advantages such as the large improvement effect and that it enables rapid construction and produces less soil which must be disposed of than the replacement method.

(5) METHODS FOR IMPROVING THE GROUND OF RECLAIMED LAND.

In improving the ground of the reclaimed land the method suiting the purpose and use is appropriately selected. For example, at Port Island three methods were used depending on the use of the reclaimed land.

First, in areas where there was a sufficient construction term, the preloading method was used to lay 360,000 m^3 of earth on the approximately 5ha area during a period of two and a half years.

Second, in areas where the facilities had to be rapidly constructed, the sand drain method was used.

And in areas where light buildings were directly constructed on the base, the vibration compaction method was used.

2.5 UNDERWATER EXECUTION TECHNOLOGY

In Japan, caisson type structures are often used as composite breakwaters and seawalls. In these structures, a caisson is installed on a rubble mound foundation. For this reason, it is necessary to level the mound and this work is generally being carried out by divers.

However, due to such reasons as the movement of construction sites offshore and the increase of water depth, there is a tendency for the work conditions to deteriorate. It has become difficult to carry out this work in terms of work safety and execution efficiency with the conventional method relying on human power.

As a way of resolving these problems, rubble mound levellers which can throw in and level rubble mounds without relying on human power are now being developed.

Also being developed are underwater inspection robot "AQUAROBOT" which can conduct various measurements and investigations and carry out execution control in place of divers.

3. FUTURE PROSPECTS

The offshore man-made island concept is one that can answer society's diverse needs toward the 21st century such as coping with the demand for land and calm sea areas. In comparison to the conventional method of reclaiming coastal land, it enables effective utilization of coastal resources including sea spaces and can be considered a new frontier in social capital.

The Ministry of Transport has conducted research and investigations on offshore man-made islands since 1980.

First, it conducted basic research on which types of industries are suitable for location on offshore man-made islands, which sea areas are suitable for their construction and on various technological issues. During 1983-1984, the Ministry conducted case studies in 6 areas in Japan. As a result, the Ministry has concluded that offshore man-made islands can be used for many purposes and that it is technologicaly possible to construct large-scale man-made islands offshore.

Based on the results of the basic research, in 1986 the Ministry selected 4 sea areas to be examined as possible construction sites for offshore man-made islands and has been conducting feasibility studies.

At present, in order to turn the concept into actual projects, the Ministry is promoting research and development for further technological progress and systematization of the existing technologies so as to cope with severe natural conditions such as great water depth and soft ground and to enhance the economy and efficiency of the reclamation process.

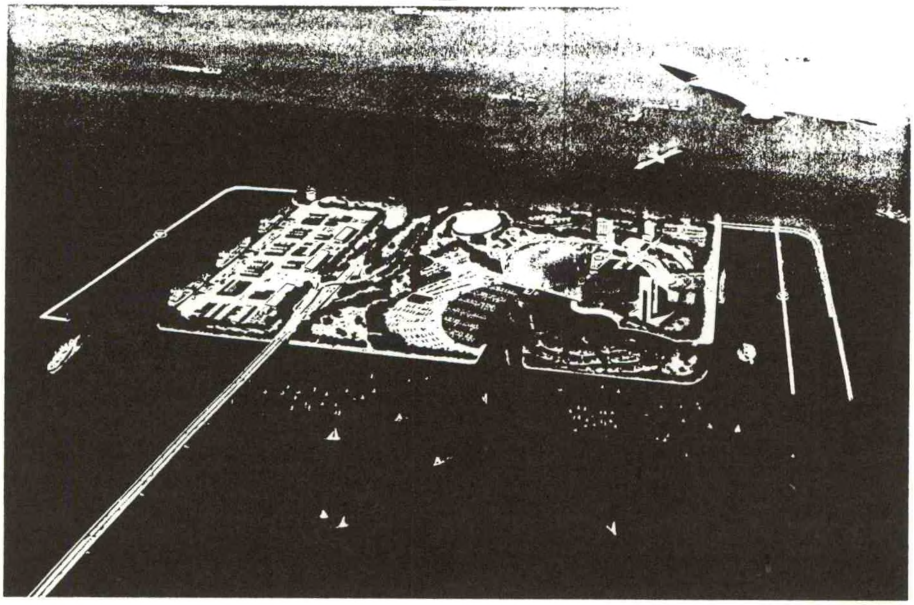

Figure 3 Artists Sketch of Offshore Man-made Island

U.S. ARMY CORPS OF ENGINEERS ACTIVITIES IN FUTURE COASTAL DEVELOPMENT FROM A RESEARCH AND DEVELOPMENT PERSPECTIVE

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ABSTRACT

The U.S. Army Corps of Engineers is the U.S. Government agency responsible for the Federal interest in beaches, ports, and waterways. Significant new policies and legislation in recent years have redefined the interplay between the Corps of Engineers, state and local Governments, and private industry. Cooperative efforts between the Corps and other entities will increase in the coming years. Concentrated efforts to improve the effectiveness of transfer of new technology from the Federal to the private sector are also anticipated.

INTRODUCTION

The U.S. Army Corps of Engineers (CE) has responsibilities which include the Federal interest in beaches, harbors, ports, and waterways. The Corps is organized into divisions, each of which is responsible for a particular region of the country (Fig. 1). Most divisions are further subdivided into districts. Engineering project work is performed in the districts. Division offices are responsible for providing guidance and review of project work.

Proposed CE projects are submitted by division offices for independent review. The review is rendered by the Board of Engineers for Rivers and Harbors for the Chief of Engineers (COE). The COE then submits project reports to the Assistant Secretary of the Army (Civil Works) for approval. Finally, the Assistant Secretary obtains comments from the President (Office of Management and Budget) and transmits the report to Congress for authorization.

In addition to the districts and divisions, the Corps maintains a network of laboratories which conduct research and development in areas of primary Corps concern. The laboratories are: (Figure 2)

- U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi.

- Engineer Topographic Laboratory, Ft. Belvoir, Virginia.

- Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.

- Construction Engineering Research Laboratory, Champaign, Illinois.

The WES is a major complex which includes six separate laboratories as follows:

- Coastal Engineering Research Center (CERC).

- Hydraulics Laboratory.

- Environmental Laboratory.

Fig. 1. U.S. Army Corps of Engineers Division and District Boundaries.

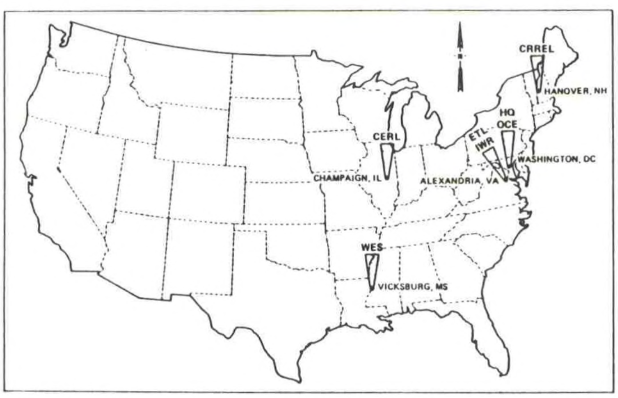

Fig. 2. U.S. Army Corps of Engineers Laboratories.

- Structures Laboratory.
- Geotechnical Laboratory.
- Information Technology Laboratory.

The primary civil works mission of the laboratories is to perform research and development in designated subjects and to assist the districts and divisions when special project needs arise.

The districts/divisions and laboratories are being significantly affected by the U.S. Congress' passage of the Water Resources Development Act of 1986. This legislation and its present and anticipated effect on the Corps are discussed in the following sections.

In recent years, the U.S. Government has stimulated interaction between the Government research and development establishment, and private industry. This policy is expected to continue and to strengthen U.S. industry in high technology efforts. The Government/ private industry interaction and the longer term future of the Corps in coastal development are discussed in the latter part of this paper.

WATER RESOURCES DEVELOPMENT ACT OF 1986

Near the end of 1986, the U.S. Congress passed the Water Resources Development Act of 1986, the first major water resources bill in 16 years. The bill contains projects with a total cost of $16.3 billion. It will serve as the authorization for many Corps projects in the coming years. Many of the projects relate to coastal development such as shore erosion protection, coastal flooding protection, ocean entrance stabilization, and improvement of waterways and ports.

The Water Resources Development Act of 1986 also contains provisions requiring State and local Governments to share in the costs of projects authorized and partially paid for by the National Government. The cost sharing requirements are a major change from past methods of project funding which for the most part involved total funding by the National Government. As a result of this change, the Corps and State/local Governments must work closely together from the very early stages of planning a potential project. The immediate result of the bill has been an increase in planning and design activities which involve CERC and the hydraulics and environmental laboratories in several major projects including beach erosion control, hurricane protection, navigation, and water quality.

FEDERAL AND STATE GOVERNMENT

Another important element of interaction between the Federal (National) and State Governments is the laws and policies affecting the coastal zone. During the past decade, the laws and regulations applying to shore protection in the U.S. have for the most part been written, promulgated, and administered by the individual State Governments. The role of the Federal Government in this matter is basically one of coordination and the provision of matching funds to assist the states in the conduct of their respective coastal zone management programs.

Additionally, the Federal Government must comply with state coastal zone management programs except where there is an overriding National interest. Due to differing natural conditions as well as socio-political and economic factors between states and regions of the U.S., there are significant differences between the various state laws and regulations. In the area of shore protection, for example, some states allow the construction of different types of shore protection measures, while others prohibit some or all conventional measures except beach nourishment. Where prohibitions exist, Corps operating offices and research laboratories often face great challenges in finding both functional and economic solutions to coastal protection problems.

GOVERNMENT AND PRIVATE SECTOR

Another important and changing aspect of coastal development is the interaction between the National Government and private industry. Since major coastal projects are often large in scope and significantly affect the public interest, the National Government will continue to have an important role in such projects. Though the Corps usually contracts with private industry to accomplish coastal project work, research and development have primarily been conducted by Government laboratories.

In recent years, the Government has moved in the general direction of increased contracting with private industry in all activities. However, the nature of coastal development in the United States is such that few private companies can build and maintain the facilities and expertise needed for broad research in the coastal zone. On the other hand, the Government, through its research and development activities at CERC and other laboratories, is able to maintain excellent state-of-the-art facilities. One example is the CERC directional wave basin (Figure 3), which cost over $1 million in 1982. Few private companies can make capital investments on this scale and remain profitable in coastal development activities.

The Corps has traditionally made its facilities available to private industry when:

- the facilities needed are unique (not available in the private sector).

- the use of the facilities does not interfere with ongoing Corps studies.

Private users were required to pay the cost of using government facilities.

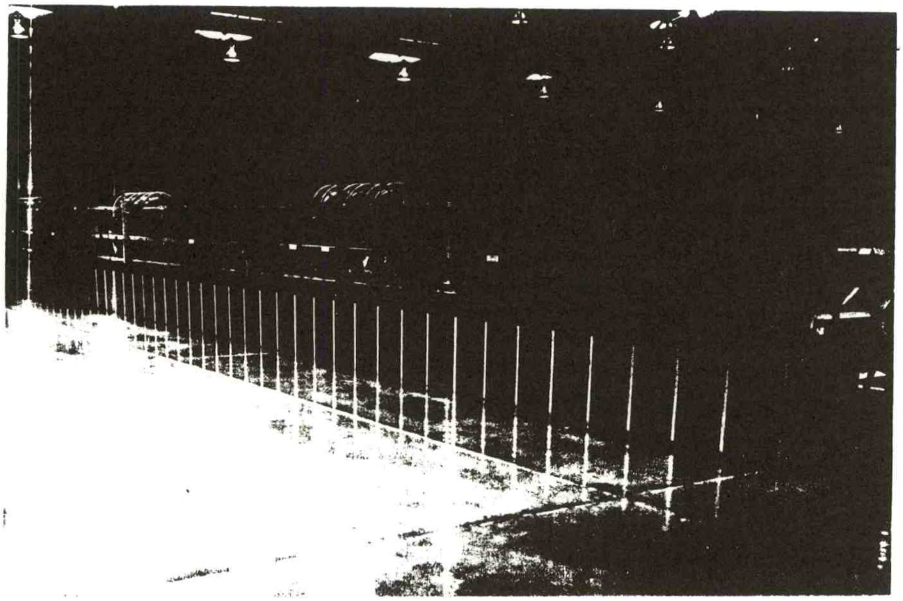

Fig. 3. CERC directional wave basin.

The Federal Technology Transfer Act of 1986 gives federal laboratories a broad authority to enter into cooperative research and development agreements with the private sector. The cooperative work may include personnel, services, property, facilities, equipment, or other resources from both parties. This authority represents a significant policy change. The Act has already stimulated additional interaction between WES and the private sector, and its impact is expected to increase in future years.

RESEARCH AND DEVELOPMENT TECHNOLOGY

Another area of interaction between the private and federal sectors is in the exchange of research and development technology. Products developed by Corps research laboratories under the civil works program are intended to benefit the Corps and also the planning and engineering communities at large. The U.S. Congress has taken steps to stimulate the transfer and effective use of research and development technology from federal to

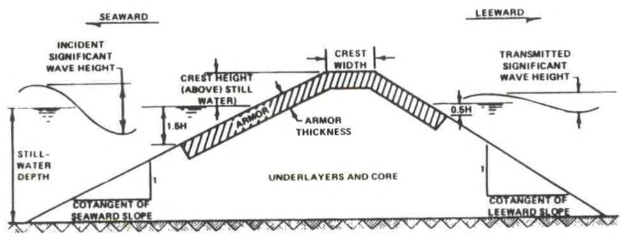

Fig. 4. Parameterized breakwater cross section for MACE program.

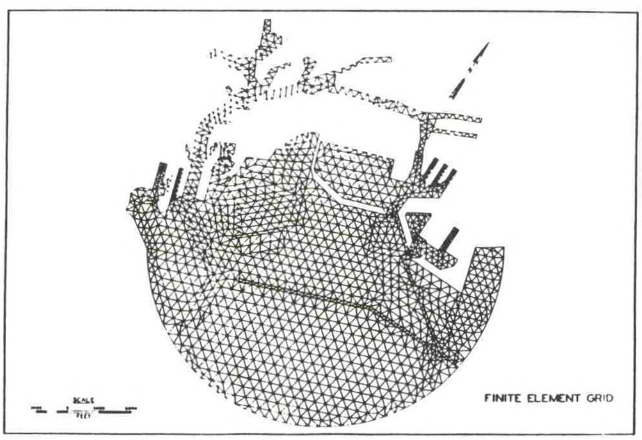

Fig. 5. Numerical grid for a harbor.

state and local governments and the private sector (including the Federal Technology Transfer Act of 1986). Federal research and development efforts are now examined to assess the potential for technology transfer. Those efforts with high technology transfer potential are identified and special attention is given to means of accomplishing the transfer.

One area in coastal research at CERC which has produced very successful technology transfer to the private sector is the Microcomputer Applications in Coastal Engineering (MACE) program (Figure 4). The MACE has developed a series of user-friendly microcomputer routines to perform a wide variety of coastal engineering calculations. The MACE floppy disks have been provided on request to numerous private and non-Federal organizations. More complete numerical models have also been successfully transferred, such as a numerical model for wave motion in harbors (Figure 5). The CERC has also begun development of an Automated Coastal Engineering (ACE) system to give Corps offices an integrated, interactive micro computer-based design capability.

LONG TERM FUTURE

The importance of coastal development activities is almost certain to grow significantly in the long term future. Several processes promoting interest and activity can be identified. Ocean commerce will continue to be an essential mechanism for the movement of goods and materials and water borne commerce can be expected to increase significantly in the long-term future. Moreover, the concentration of population in the United States is gradually increasing in coastal areas relative to the interior of the country. With increasing coastal zone population comes increased industrial as well as recreational uses of coastal areas.

The inescapable conclusion is that conflicting pressures for coastal development for both commerce and recreation will intensify. Our challenge in the Corps of Engineers is to best satisfy the diverse, sometimes conflicting requirements. We will continue to work with State and local Governments and private industry to maximize the use, enjoyment, and preservation of our valuable national asset, the coast.

ACKNOWLEDGEMENT

The tests described and the resulting data presented herein, unless otherwise noted, were obtained from research conducted under the Coastal Research Program of the U.S. Army Corps of Engineers by the U.S. Army Engineer Waterways Experiment Station, Coastal Engineering Research Center. Permission was granted by the Chief of Engineers to publish this information.

AT-SEA EXPERIMENT OF A FLOATING PLATFORM

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ABSTRACT

The technology of the basic element to realize the construction of the huge floating platforms has been established by the fundamental and applied research in various fields including tank tests and theoretical calculation. The purpose of the at-sea experiment is to verify the element technology which has been developed so far, as well as to confirm the safety and reliability of the huge floating platforms.

Preparatory experiments, concerning operational checkup of the measuring equipments which have been set on the platform and the holding power of the mooring system, have been completed. The design procedures and the performance estimation results were described in the previous UJNR report. Taking into consideration of these results at-sea experiment has started in the Japan Sea about 3km off of Yura port, Yamagata prefecture on September in 1986. The research items are the technology on design, construction, maintenance, survey and reliability of mooring system.

CONSTRUCTON, TOWING AND INSTALLATION

The size of the platform for the use of ocean space utilizatioon in the future would be, for example, 1600m long and 650m wide in reality. It is impossible to carry out the experiment using such a huge structure because of the economic point of view. Therefore, it is reasonable to verify the basic characteristics of its part. The test structure (Fig.1) is the semi-submersible platform (length;34m, breadth;24m, height of the main structure;13.5m, draft;5.5m, displacement;531t), 1/3 of the full scale, being consisted of 12 columns with footings which support the upper-deck. The steel is used in the main structure and the concrete with sprayed resin mortar is also used in one of the columns. The structure was named "POSEIDON" after the initial of "Platform for Ocean Space Exploitation".

It was constructed at Naruto, Tokushima prefecture. Being towed about 850 miles for 9 days via Shimonoseki through the Seto-inland Sea, it was installed in the test area on July in 1986 (Fig.2). During the towing of the structure towing load was measured. The towing load proved to be 15.0t at the speed of 4.98kt. The result turned out to be relatively agreeable with that of the tank test.

The test structure has been moored in the direction of 292.5^{0} from north, WNW, which corresponds with the superior direction of waves by the seasonal wind in winter. The two chain lines are attached on the each corner at the offshore side and one line on the each corner at the shore side. The initial mooring force was adjusted while measuring the angle between the mooring chain and the vertical side of the footing.

The anchor is a quick-hold type and 2 kinds of anchors, 15 and 10 ton-type have been used. Mooring line consists of the ϕ72 grade 2 chain up to the position of 55m from anchor and ϕ50 grade 3 chain up to the structure. The total length of the mooring lines is 250m.

Japan Marine Science and Technology Center (JAMSTEC) performed the TLP sea test by utilizing the prototype floating platform. The targets of the test are set to grasp the fundamental design procedure of a tension leg platform and prove the feasibility of TLP. JAMSTEC aims at construction of an ocean stable labolatory which is expected to become a valuable deepsea laboratory as a long-term observation and a base of developing undersea work systems.

The prototype tension mooring system is designed to match with the environmental conditions of the test area (Fig.3). The platform is not originally designed for TLP, and moreover the test structure is made so small as the motions of the platform and the mooring line tensions can be measured in relatively mild sea conditions upon keeping enough stability in survival conditions.

The critical wave height is proved to be 7.5m by the 1/40 scale model test. The greater waves will crash the upper structure causing shock loads in the tension mooring lines. The snap load in the waves of a 100-year storm is estimated 120 ton. The ϕ50 grade 4 chain is utilized as the tension mooring line. The breaking strength of this chain is 280 ton. The 10m-length part of each is a rubber-chain. This is a chain filled and covered with rubber. This was applied in order to absorb the shock loads and prevent the mooring line from local abrasion.

The lower end of the mooring line is connected to the sinker. The sinker consists of the steel frame and 16 concrete blocks weighing 536 ton in water.

MEASUREMENT AND ANALYSIS SYSTEM

(1)Measuring items: This full-scale experiment can approximately be devided into the following 6 groups from the point of research theme.

(1)Measurement of environmental conditions (2)Measurement of motion of the structure (3)Measurement of the mooring force (4)Measurement of the strength of the structure (5)Measurement of the hydrodynamic interaction such as relative wave height or impact pressure (6)Mea-surement of corrosion and paint

(2)Measurement system: The measured data are automatically recorded on board. There are two kinds of recording data system. One is a measurement at regular time in every 6 hours. The other is a measurement at temporary time in which continuous measurement can be started by the command sent from the shore in the case of rough weather. Further, the measured data are backed up and can be monitored on the shore. The system has the capacity of recording the 40 items data for about 30 days at most. The cassette MT is used to store the data from the hard disc on board.

The electric power is supplied through the underwater cable from the shore to the structure. The uninteruptible power supply apparatus and the electric generater are equipped as a measure against the cutting off the electric current.

(3)Analysis system: Wind and wave data are always necessary while carrying out the experiment. The statistic analysis is carried out in every one hour about waves and in every three hours about wind direction and speed.

Concerning other data some kinds of analyzing procedure are usually done using super-computer after recording the data. The statistic analysis, frequency analysis and spectrum analysis are also done in order to get the independent characteristics of each measuring item.

RESULTS OF ANALYSIS

(1)Wave spectrum: Many kinds of equations which represent wave spectrum have been proposed so far. Fig.4 shows the measured wave spectrum in comparison with ISSC standard wave spectrum of Pierson-Moskowitz type which is usually used as deep sea waves and JONSWAP spectrum equation which is used as the waves of the area of limited fetch.

The measured wave spectrum of large wave height in winter turned out to be closely alike JONSWAP type rather than ISSC type. In addition, Maximum wind speed was 26 m/sec and maximum wave height was 11m at test area in a whole year of 1987.

(2)Estimation of directional wave spectrum: The directional wave spectrum analyzed by the Maximum Likelihood Method is shown in Fig.5. The data measured at 6:00 on 24, January in 1988 were obtained from the 3 supersonic wave height meter set on the sea bottom. The wind had been coming from NW or WNW direction at the speed of 10-15 m/sec on that day. The component wave can surely be predicted to propagate with the same direction as the wind direction considering that the main peak of the directional spectrum locates around the direction of NW.

(3)Heave and pitch motion: Motion response function has been estimated selecting the data of 1m, 3m and 5m significant wave height and wave direction of WNW or W. Theoretical values were calculated using the hydrodynamic force of the single column with footing by the singularity distribution method. Further, the linear spring constant of mooring line has been obtained by the static line tension in the initial tension condition and the drag coefficient Cd that is viscous damping term of heave motion has been assumed as 1.5.

Fig.6 shows the heave motion response function on head sea condition that is WNW wave direction with respect to the each wave height. The marks in the figure are the measured values at each regular time measurement and solid line means the theoretical calculation.

The theoretical calculation predicts measured values so well on the whole and the drag coefficient of heave motion turned out to be a reasonable value.

Fig.7 shows the response function of pitch motion on head sea condition. The calculation agrees well with the measured values on the whole although it predicts a little bit larger.

(4)Tension of the TLP: The environmental condition in the test site is favorable in summer, which allows very easy installation of the TLP. However, it becomes severe in winter. The TLP sea test was executed from July to October in 1986 and from July to August in 1987. During the test poeriod, the dynamic response characteristics of the TLP was measured and statistically analysed.

The total initial tension is 125 ton which is equal to 24% of the platform displacement. The TLP experienced 10 ton of maximal amplitude of varing tensions at the 7.3m wave height.

FUTURE VISION

The huge platforms or the gigantic man-made islands, which are to be developed for the multiple purpose use in the offshore of deep sea are still in the conceptional stage even in the foreign countries. These kinds of big projects cost enormous in the construction. However, we should consider the merits from the point of the national economics, safety and environment for the total land utilization and ocean space utilization. Offshore sea port of deep sea, marine products farm, offshore fishery base, marine leisure base and ocean energy power station are to be directed toward constructing in the ocean. Further, floating airport, power generating plant, oil refinery factory, ocean oil storage base, marine tele-port (Fig.8) are keenly expected to be constructed in the ocean due to the difficulty of the construction on land. The target is to carry out the plans which will most likely come true toward the 21st century.

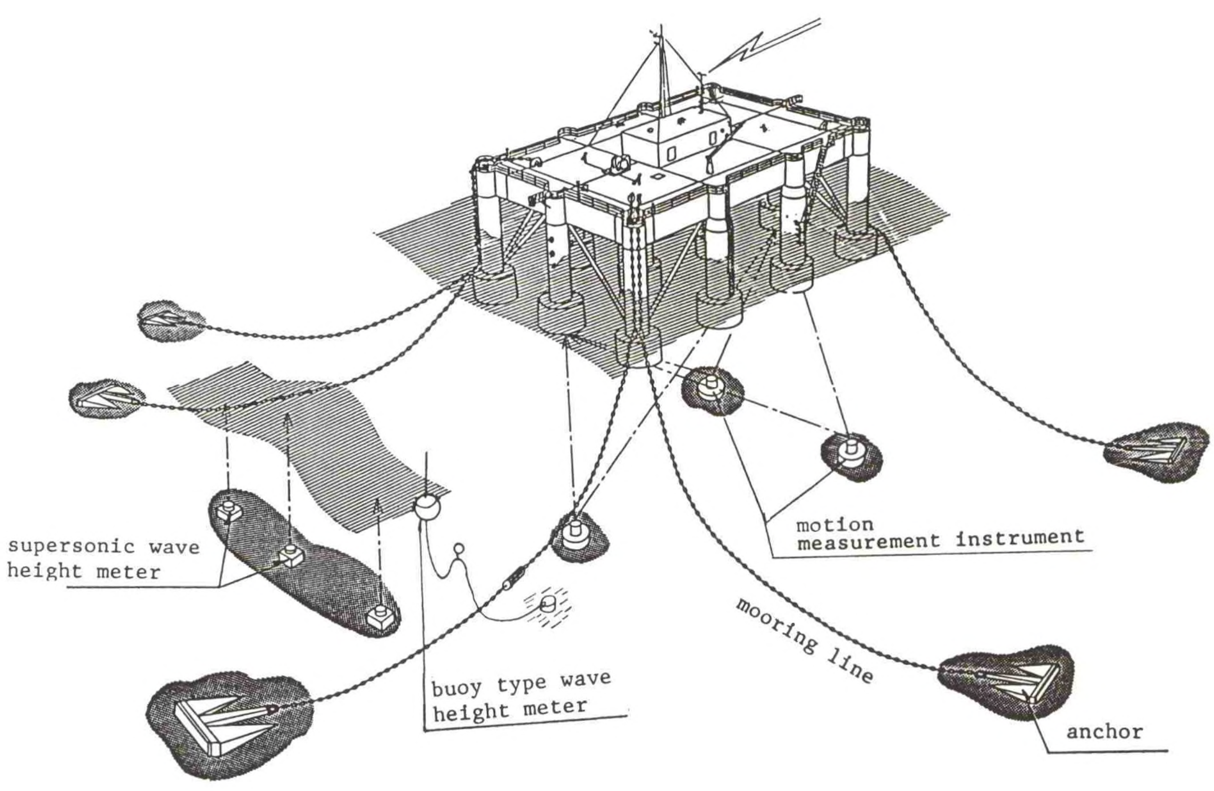

Fig.1 Concept of the test structure

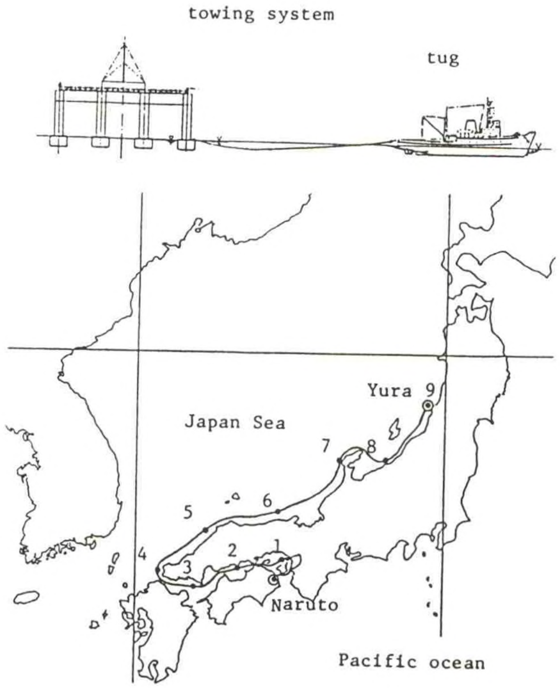

Fig.2 Towing course of the structure to the test area

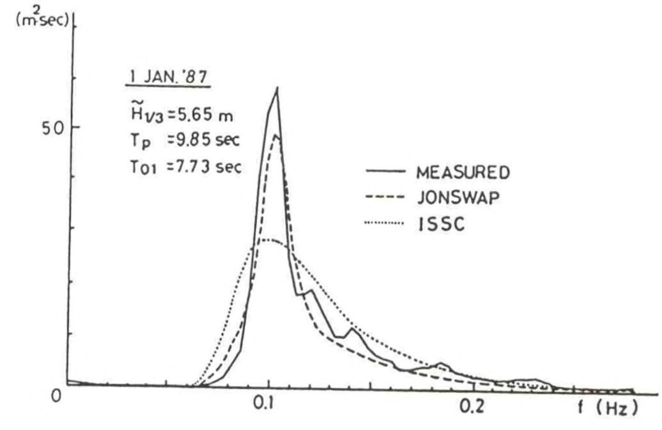

Fig.4 Measured wave spectrum compared with ISSC and JONSWAP wave spectrum

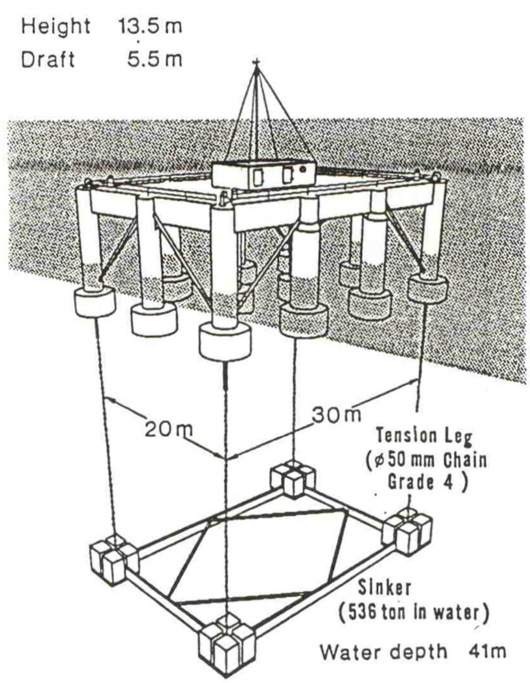

Fig.3 General view of the TLP

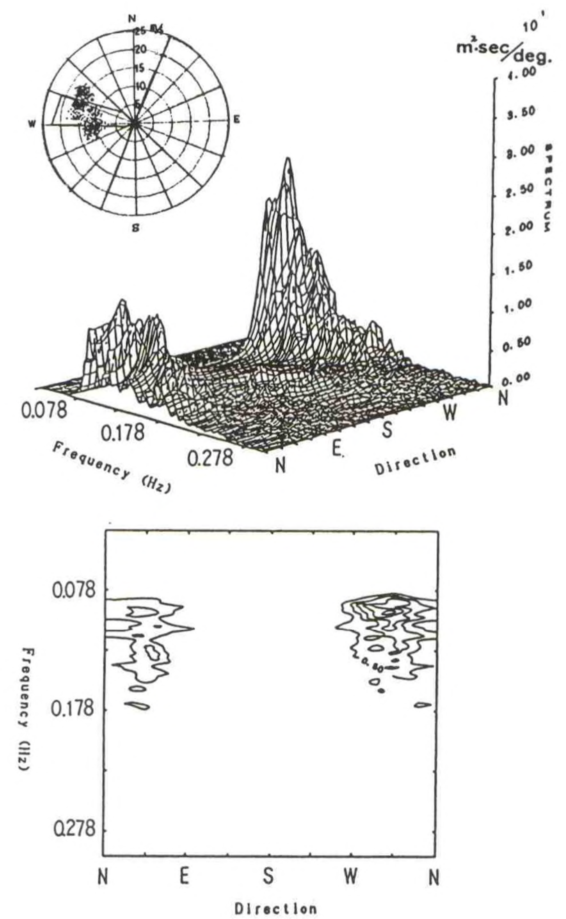

Fig.5 Estimation of the wave directional spectrum

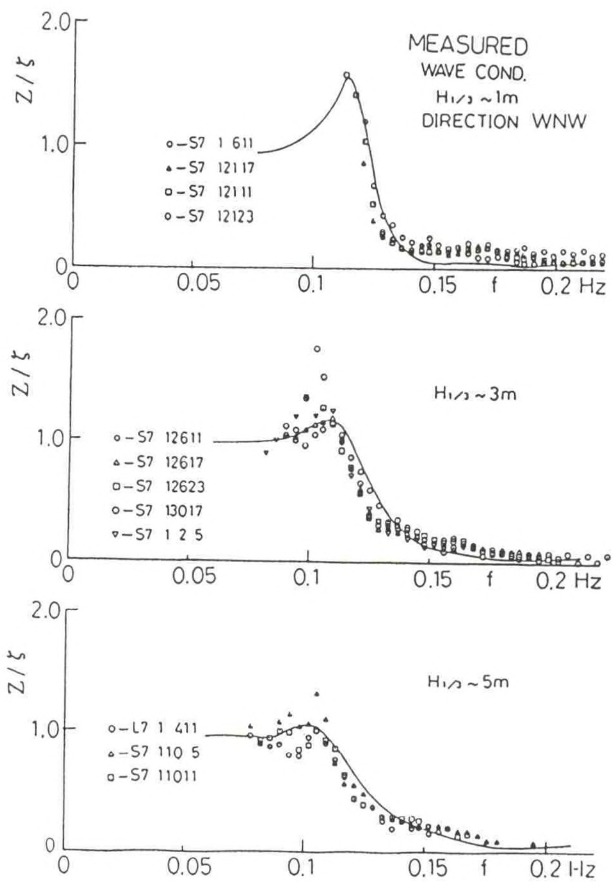

Fig.6 Effect of the wave height on the amplitude response of heave

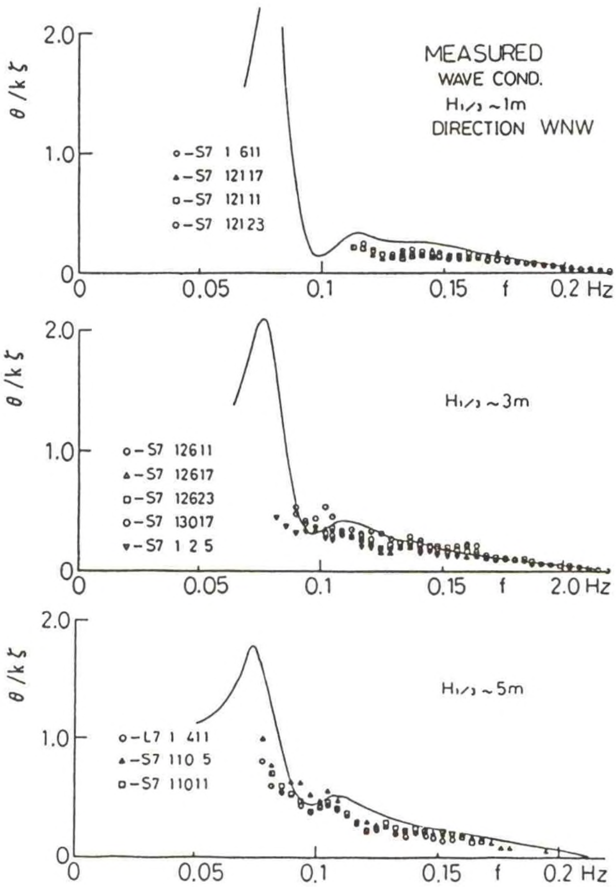

Fig.7 Effect of the wave height on the amplitude response of pitch

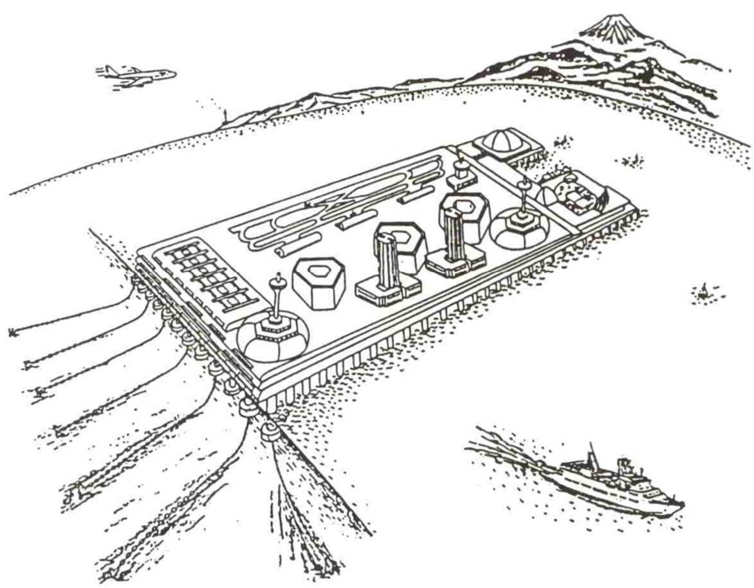

Fig.8 Concept of the marine tele-port

DEVELOPMENT OF WAVE ENERGY UTILIZATION SYSTEMS
WITH WAVE POWER EXTRACTING CAISSON BREAKWATERS

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1. Introduction

Ministry of Transport has been developing a fixed-OWC wave power converter called a wave power extracting caisson. This device can be used as caissons for composite-type breakwaters and sea walls, thus functioning as a breakwater and a wave power device at the same time.

Fig.1 shows a conceptual view of a wave power extracting caisson breakwater. A wave power extracting caisson consists of a hollow case called an air chamber and an ordinary caisson supporting it. The front wall of an air chamber is a curtain wall with an opening so as to let waves enter inside. The wave action makes the water level in the air chamber fluctuate up and down, the air in the chamber is compressed and expanded generating air current within a nozzle and thus wave power can be converted into air power. By converting this air current into revolving power through a turbine and then revolving a power generator, electric power can be generated. A Wells turbine is to be adopted for wave power extracting caissons. This turbine is a specially designed turbine which enables one to obtain revolving power in the same direction even with reciprocating air current.

The basic study on developing this device has been conducted for five years since 1982 at Port and Harbour Research Institute, Ministry of Transport, and, as a result, designing of such a device now becomes possible.

At Coastal Development Institute of Technology, by request of Ministry of Transport, Comprehensive Research Committee on Utilization of Wave Power was organized and studies including a feasibility study of the system utilizing wave power were conducted in 1985 and 1986.

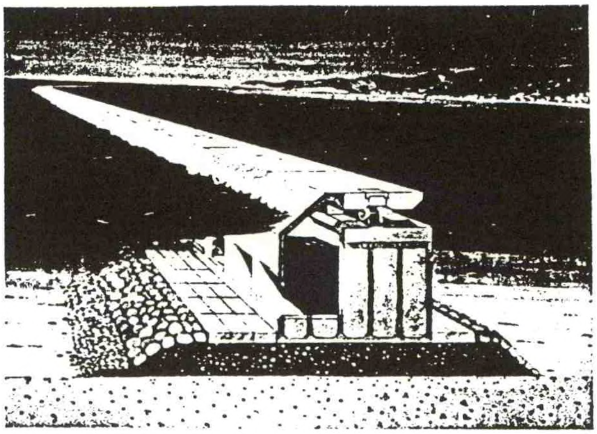

Fig.1 Conceptual Drawing of Wave Power Extracting Caisson Breakwater

With these studies as a basis, the 1st District Port Construction Bureau has started a field verification study for wave power extracting caisson breakwater since 1987.

This paper reports the outline of the research conducted so far and its future plan.

2. Basic Study in a Laborarory

Studies conducted at Port and Harbour Research Institute can be roughly divided as follows:

(1) Study on air output

Wave power is converted into air power in the air chamber. The theory describing this process,"thermodynamics and wave kinematics method" was proposed and verified experimentally. This theory was also expanded to be applicable for ocean waves with irregularity and directional spreading.

The optimum dimension of an air chamber can be decided according to this theory. The width of an air chamber is to be approximately 10-20%

of a wavelength and an opening ratio of a nozzle to be approximately 1/100-1/250. Under such conditions the converting efficiency into air power would be over 70%.

(2) Study on Wells turbine

Air power is converted into turbine power with a turbine. A Wells turbine is also included in the thermodynamics and wave kinematics method which is verified experimentally, thus enabling one to estimate turbine output and design a turbine.

(3) Power generating experiment with a large-scale model

For a comprehensive study inclusive of a generator, a power generating experiment was conducted building a model scaled in 1/3 to the prototype with a turbine of 70cm in diameter and a generator of 1kW in rating. A design method for a wave power extracting system was verified in this experiment. Facilities for protecting the turbine and generator in case of abnormally stormy waves were also discussed.

(4) Study on a wave resisting design method for a wave power extracting caisson.

A wave power extracting caisson functions as a wave power converter as well as a breakwater. The function of a wave power extracting caisson as a breakwater and its wave resisting stability was investigated through model tests. It has been revealed that a wave power extracting caisson highly functions as a caisson for breakwater with low reflection and high stability against wave forces Based on the result of the model tests a wave resisting design method is proposed.

A part of this study conducted at Port and Harbour Research Institute has already been reported in UJNR, 1986.

3. Research on Utilizing Systems

At Coastal Development Institute of Technology, Comprehensive Research Committee on Utilization of Wave Power was set up in 1985 and 1986. The committee was composed of engineers and researchers of Port and Harbour Bureau, Ministry of Transport: Port and Harbour Research Institute, Ministry of Transport: Navigation Aids Department, Maritime Safety Agency; Universities; Japan Marine Science and Technology Center; and private corporations in the fields of electric power, electricity, steel, naval architecture, and construction. For establishing system for utilizing wave power with breakwaters of wave power extracting caisson, the committee conducted research on practical applications of design and construction method and discussed utilizing systems of generated power.

The outline of the outcome is described below.

(1) Design, construction, and the construction cost for wave power extracting caisson breakwaters

Trial designs for constructing wave power extracting caissons at the depth of 10m were made and construction methods were discussed. For a comparison, designs for ordinary composite-type breakwaters, caisson breakwaters covered with wave dissipating blocks and perforated wall caisson breakwaters were also made. Fig.2 shows an example of study outcomes with a comparison of construction costs for each design.

The abscissa represents different cases of wave conditions with the higher wave height toward the right. As shown in this figure the construction cost for wave power extracting caissons is about the same as that of perforated wall caissons and, under a certain condition, falls lower than that of caisson breakwaters covered with dissipating blocks.

(2) Standard wave power extracting system

The structure and the cost of a standard wave power extracting system were discussed. The wave power extracting system is composed of a wave power extracting caisson breakwater, a turbine, a generator, control and protection devices, and power transmission devices. Depending on the user's system, devices for smoothing and storing power are necessary.

Fig.3 shows an example of a standard wave power extracting system. The incidence of an average 7.5kW/m wave power into a wave power extracting caisson results in the incidence of 150kW wave power per a 20m-caisson. However, this is the average value and it should be noted that wave power in the field varies every moment to moment. Considering such fluctuating property, a rating of an electric generator, i.e. the maximum generating power, should be decided. It is decided here for the rating to be 50kW and the average generating power to be 25kW with the rate of operation for generators of 0.5. A single generator is installed on each caisson.

Under a simplified assumption, a trial calculation of the cost was carried out for a general estimation. The resulting construction cost is 1,048,000yen/kW while power generating cost 19.3yen/kW. In this calculation a turbine is estimated as 25,000,000yen/unit, a generator 12,000,000yen/unit, control and protection devices 12,000,000yen/unit, the interest rate 6%, durability 35 years and residual cost 10%. The cost of breakwater caissons was not included. As the power generating cost is very much affected by that of a turbine, lowering the cost of a turbine directly affects decreasing cost.

(3) Utilizing systems

Power generated through the wave power extracting system using wave power extracting caissons can be utilized in various usage. Among them nine cases were studied by considering whether the utilization of wave power has any merits such as user's easier access to the supply and also technological advancement. Table 1 is a brief description of wave power utilizing systems corresponding to the conceptual design.

(4) Case Studies

Presuming the utilization of wave power at actual sites, a trial design for wave power extracting caisson breakwater and the utilizing system was made and the construction cost of the systems, power generating cost and other technical and legal matters were summarized. The trial designs were made for the following utilizing systems at the presumed sites.

a) Power generating systems for remote island (Port W, Okinoerabu Island, Kagoshima Prefecture)
b) Power supply for lighthouses on breakwaters (Port S, Fukushima Prefecture)
c) Snow melting system (road heating) (Port S, Yamagata Prefecture)
d) Sea water exchange system (Port M, Miyazaki Prefecture)

Fig.4 shows a conceptual design of power generating systems of wave power extracting caisson breakwaters for a remote island. Wave power extracting caisson breakwaters with the total length of approximately 300m is installed at the depth of 10m along with 1000kW-electric generators, and then electric power is connected to the supplying system of the island. The present electric power on the island is generated with diesel power generators supplying total capacity of 9600kW. Wave power is to complement the diesel power supply with estimated power generating cost of 23.3yen/kWh. It is revealed that feasibility of utilizing wave power as complementary power supply is high in a remote island where power generating cost runs to a high side.

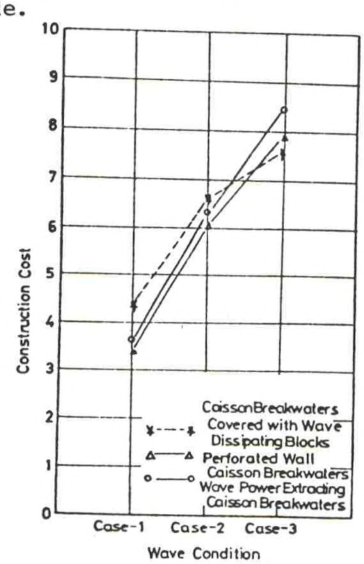

Fig.2 Comparison of Breakwater Construction Cost

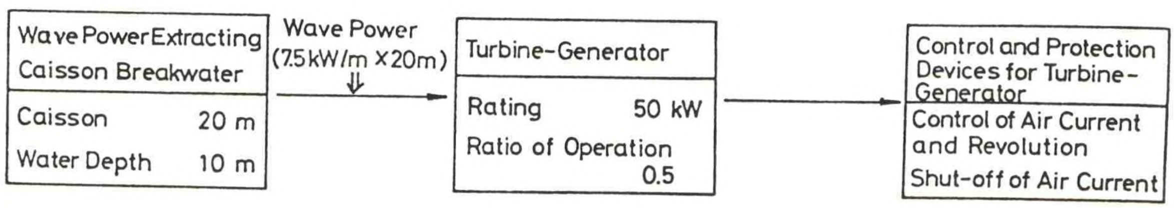

Fig.3 Standard Wave Power Extracting System

Table 1 Wave Power Utilization Systems

Utilization	System Example	Basis
Power generation for remote islands	(1) A wave power extracting facility with the rating of 500kW is installed to complement a power generator of 500kW already installed on a remote island with 4000 inhabitants. (2) A wave power extracting facility with the rating of 500kW is installed to complement a power generator of 300kW already installed on a remote island with 200 inhabitants.	Power being generated on an island 0.9-1.5kW/person
Power generation for a lighthouse	A wave power extracting facility with the rating of 1kW is installed as power supply for a lighthouses at breakwaters	Power generation necessary for a lighthouse approximately 100 W
Power Generation for electrodeposition	A wave power extracting facility with the average power output of 80kW creates rock mounds for fish habitat where fish tend to gather in the sea area of 5-6 ha.	Consumed power for electrodeposition foundation area $80kW/4000m^2$
Road Heating	A wave power extracting facility with the rating of 400kW melts the $2000m^2$-snow.	Power consumption for melting snow $170-300/m^2$
Heated water supply for sea culture	A wave facility with the average power output of 200kW convert $5^{\circ}C$ water to $25^{\circ}C$-warm water $100m^3/day$	
Hot water, heating, warm water supply system	A wave power extracting facility with the average power output of 280kW supplies hot water and heating to 50 houses and simultaneously melts snow on the $200m^2$-roads	Hot water supply 1.5kW/unit heating 2kW/unit melting snow $0.25kW/m^2$
Air breakwaters	A wave power extracting facility with the rating of 200kW dissipates 50% of waves with the period of 2.7 second and the height of 50cm on the reach of 35m	necessary amount of air $84m^3/min$, necessary air pressure $2kg/cm^2$
Sea water exchange (water-conveyance)	A wave power extracting facility with the average output of 60kW exchange sea water in the bay lowering present COD of 30ppm to 3ppm, where outside sea water is 2ppm, and input load the bay is 100ppm with inflow of $700m^3/day$	Inflow by a 50kW-pump is $60m^3/min$
Desalination of sea water	A water power extracting facility with the rating of 40kW desalinates sea water through the inverted infiltration method producing $1000m^3/day$ (5000person/day)	Capacity for a main pump of $1000m^3/day$-water production facility is 250kW. Water consumption per head is 200 l/day

Fig.5 shows a conceptual view of a power supply system for a lighthouse with a wave power extracting caisson breakwater. Lighthouses at breakwaters do not require large power supply. In this study fairly large supply, which is mere 200W, is assumed. To supply this amount of power a part of a caisson (4m) is to be an air chamber. The rating of the generator is 375W and the air output from the air chamber is large compared with the rating of generators. Therefore, power can be generated mostly by this rating of generators with small capacities of storage batteries to be needed. This type of the system is effective for an offshore breakwater such as breakwater of Port S where the cost for power transmission cables is high.

Fig.6 shows a conceptual view of a road heating system utilizing wave power extracting caisson breakwaters. A wave power extracting caisson breakwater is to be constructed in the section of 1000m at the second North breakwater of Port S and 50 electric power generators (total capacity of 10000kW) of 200kW rating are to be installed. The generated power is to be transmitted to the center of S city for heating 50,000m^2-pedestrian-roads to melt snow with required heat capacity of 200W/m^2 through underground heating cables. Simulation of snow melting based on actual snowfall data reveals that snow can be melted proprely through the system owing to a relatively high correlation ratio between snowfall and high waves. The cost of generating power of this system is at the high side of 30yen/kWh, for the working ratio of the system is less than 1/2 since this area has strong waves only in winter and almost none in summer.

Fig.7 shows a conceptual view of a sea water exchange system with a wave power extracting caisson. A wave power extracting system is used for a part of seawall. At reclaimed land of Port M, sea water is pumped up with wave power to far inside the port to improve the quality of the sea water within the port. The total length of the wave power extracting seawall is 120m and the average 4m^3/s sea water is exchanged for 1500m. It is assumed that the water flow of 4m^3/s can improve sea water quality from 5ppm into 3ppm within the port. The water flows in an open channel which is also expected to be utilized as a river park within the reclaimed land. In this system wave power is not converted into electric power but directly used to revolve pumps through revolving power of turbines. Therefore, the cost is less than 1/2 of the sea water converting system through usual buying of electricity.

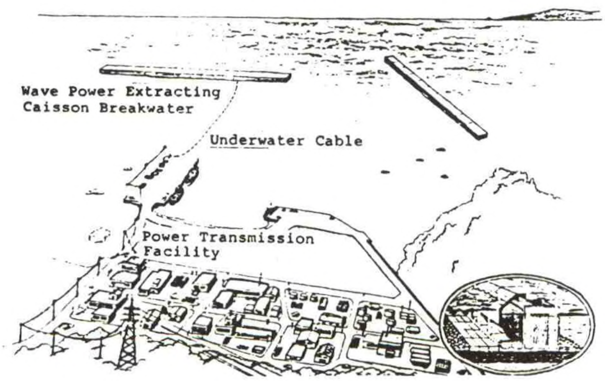

Fig.4 Power Generating System for a Remote Island

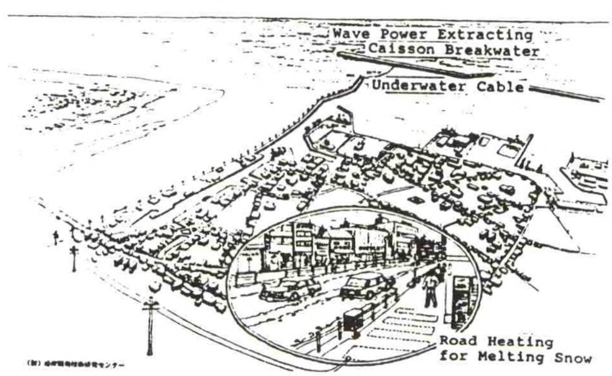

Fig.6 Road Heating System for Melting Snow

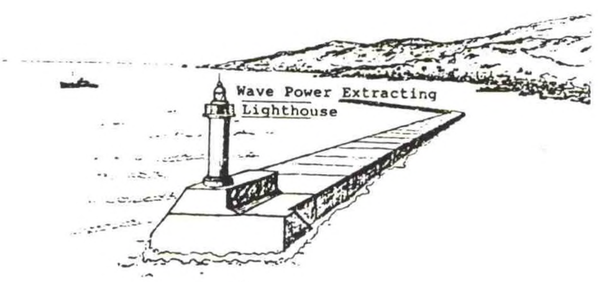

Fig.5 Power Supply System for a Lighthouse on a Breakwater

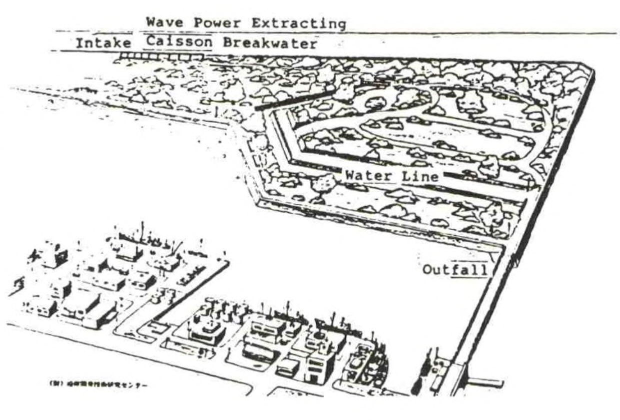

Fig.7 Sea Water Exchange System

4. Field Verification Experiment

(1) The outline

The 1st District Port Construction Bureau, Ministry of Transport, has been conducting field verification experiments in the scheduled period from 1987 through 1991. As shown in Fig.8 the experiments are carried out at Port Sakata. Facing the Japan Sea Port Sakata is a large port consisting of two parts, the Main Port Area and North Port Area. Between these two areas the second North breakwater is under construction. Setting one of the caissons at this breakwater as a wave power extracting caisson, a turbine and electric generator are installed for electric power generating as well as for conducting various measurements. As the water near the second north breakwater is 20m deep, a large caisson should be installed. This is also the point where wave power reaches approximately 20kW/m in average during the winter time. The design significant wave height at the breakwater is 10.2m while the significant wave period 14.5s.

(2) The experimental procedure

The experiments are to be conducted in the period of 5 years and the procedure for each year are as follows:

1987 The overall planning for the experiments, in addition to the basic design of the breakwater, design in detailed parts, and discussion on construction methods

1988 building the lower parts of caissons, building rubble-mound foundation, manufacturing turbine generators, and installation of measuring instruments

1989 building the upper part of a caisson, installation of caissons, building a machine room, installing turbine generators, power generating experiment, and measurement

1990 power generating experiment, measurement, and data analysis

1991 data analysis, and making a report

(3) The purpose of the experiments

The purpose of the field verification experiments is outlined as follows:

a) Verification of the design against waves as a breakwater
b) Verification of the design method for an air chamber as a wave power extracting facility.
c) Verification of a design method for an air turbine and generator.
d) Investigation on operation and control methods against fluctuation of incident wave power
e) Verification of behavior of protection devices
f) Investigation on building methods of the breakwater
g) Investigation on utilization of power supply

(4) Breakwaters and power generating facilities

Fig.9 show a sectional drawing of the experimental breakwater with the width of the caisson 24.5m, the width of the air chamber 7m and the elevation of the caisson top 12.5m. The width of the air chamber corresponds to 13% of the wavelength of wave with period of 6s. The elevation of the caisson top almost corresponds to the design significant wave height. The air chamber with the width of 4m is divided into five rooms and three of them are used for generating power.

Fig.10 shows a plan view in vicinity of a machine room in which a turbine generator is installed. A turbine generator is installed in the center and an air control valve to control the air stream as well as pressure relief valve to lower the air pressure is installed. Two Wells turbines of 1.3m in diameter are used in a tandem type. A generator of approximately 50kW is considered.

(5) Construction method

The wave power extracting caisson differs from general breakwater caissons in its special shape. As the front wall of an air chamber forms a slope, construction is to some degrees difficult. It is considered that great wave force applies the inclined wall and high accuracy of construction is called for.

At Port Sakata caissons are manufactured on a floating dock. As the water at the manufacturing spot is not deep enough the lower parts of larger caissons are manufactured on a floating dock and the upper parts are joined on the calm sea within the port. As the upper inclined wall of wave power extracting caisson is manufactured by joining on the sea, it is necessary to effect a proper construction control.

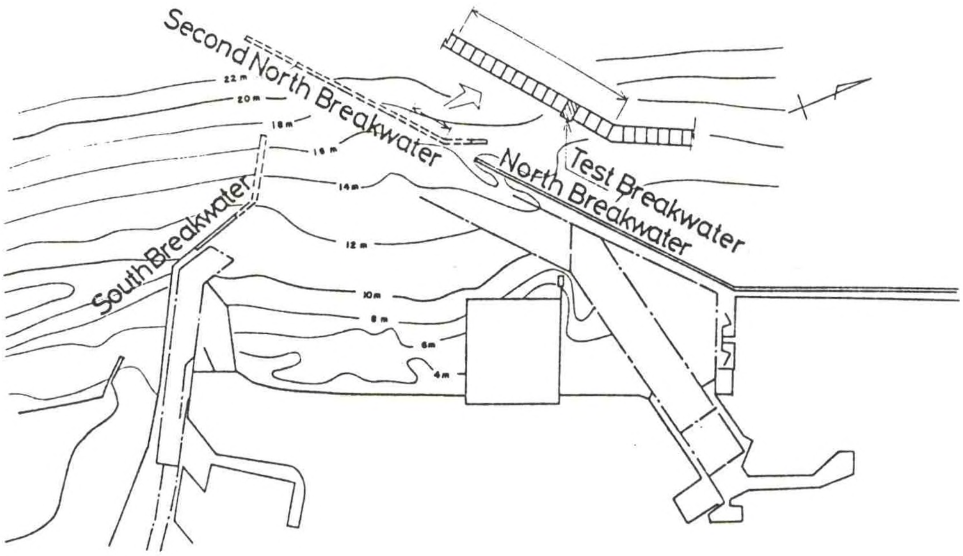

Fig. 8 Plain View of Port Sakata

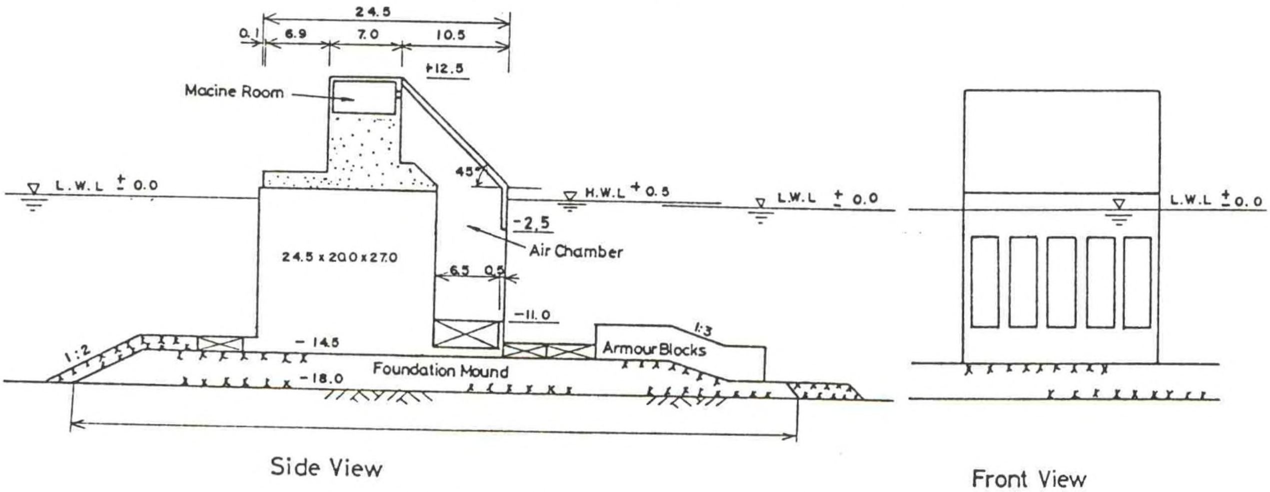

Fig.9 Sectional View of Breakwater for Experiment

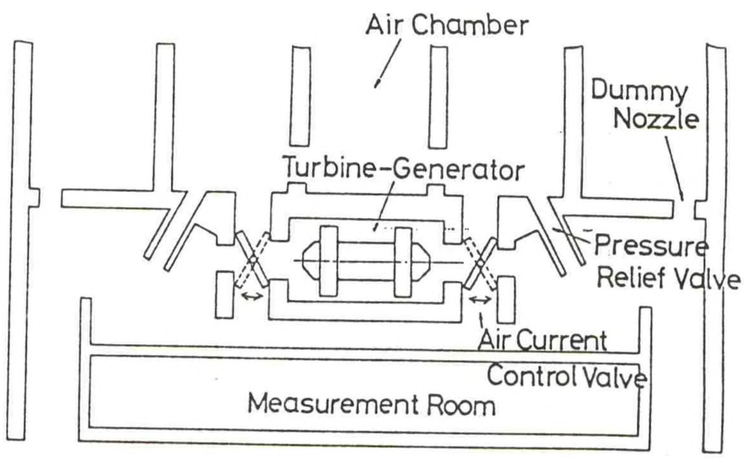

Fig. 10 Plain View of Machine Room

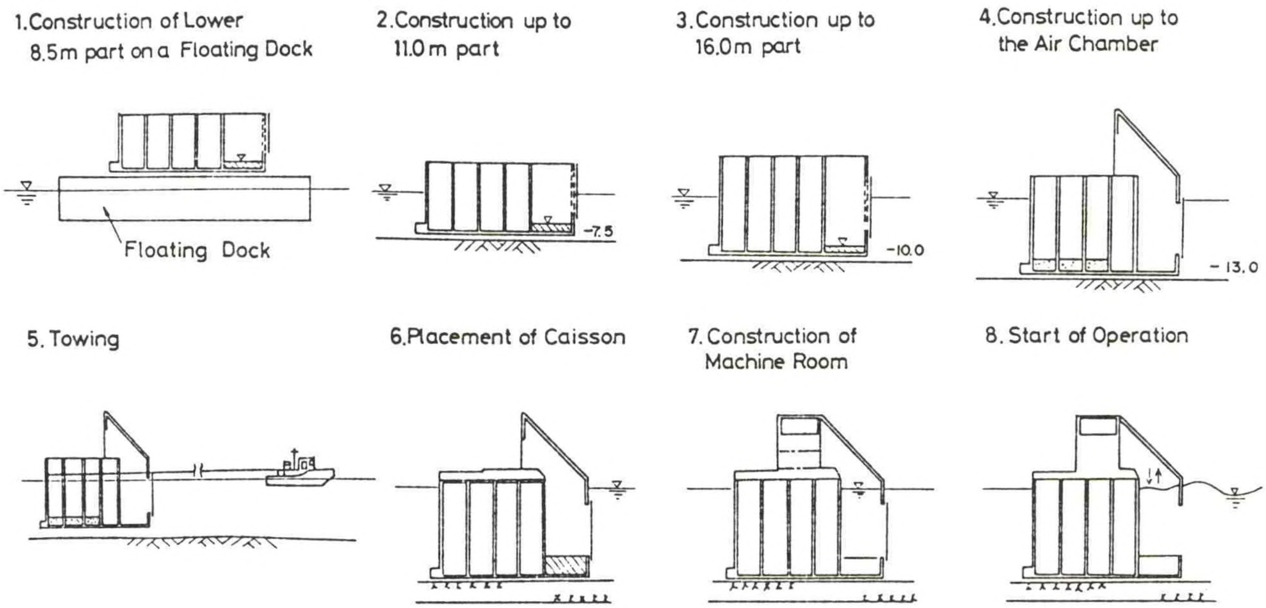

Fig.11 Caisson Construction Procedure

The caissons manufactured up to the inclined part is towed in the sea and installed on a foundation mound. The machine room for a turbine and a generator is constructed after the installation. Fig.11 shows the procedure of the construction of the wave power extracting caisson.

(6) Measurements

In the experiments various types of sensors are installed on caissons and generating facilities. The data obtained are amplified in the machine room at the caisson, converted into light signals and sent to the observation room on the land through optical fiber cable.

The preliminary analysis of the data is conducted in the observation room and, at the same time, data is recorded into data recorders. In the experiments the following items are measured.

a) Incidence waves
The height, period, and direction of incident waves at breakwaters are measured.

b) Air pressure and wave pressure on caissons
Pressure forces exerted at walls of caissons are measured with wave pressure gauges, and strains of the walls are also measured with strain gauges attached to reinforcing steel bars. The movement of caissons is also measured with accelerometers.

c) Air output
Air output can be measured through the air pressure and variations of water level in the air chamber. The air velocity inside the nozzle is also measured.

(7) Organization

The breakwater is to be designed by Niigata Survey and Design Office, the 1st District Port Construction Bureau and is to be constructed by Sakata Port Construction Office. A study group including private corporations is to be organized for experiments on generating power. To conduct harmonious and effective experiments at the field an advisory committee is set.

5. Conclusion

For utilization of wave power through wave power extracting caisson breakwaters, basic studies were made and experiments on field are to be conducted. Through these systematic studies the day to put this system for practical use will be in the near future.

References

1) Takahashi,S,, and Goda, Y.,: Development of wave power extracting system with vertical breakwaters, Proc. 13th Meeting US-Japan Marine Facility Panel, UNJR, 1985, pp.42-47.
2) Coastal Development Institute of Technology, Comprehensive studies on wave power utilization, CDIT, 1987.

OCEAN MEASUREMENT SYSTEMS

PROJECT FOR NEW TECHNOLOGIES ON OCEAN SURVEY SYSTEM

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New ocean survey technologies, which have high reliabilities, accuracy and more intelligent functions, are required for ocean development in future. The Science and Technology Agency of Japan (STA) has promoted a project to develop the technology for the precise investigation of coastal area from fyscal 1983 to 1987, using the Special Coordination Funds for Promoting Science and Technology. In the first 3 years, the following ocean survey systems were designed and manufactured in labolatory, and in the last 2 years they have been examined in the actual test fields.

The results of examinations have shown the success of this projects as follows.

(1) DEVELOPMENT OF EFFECTIVE AND ADVANCED SENSING TECHNOLOGY FOR OCEAN MONITORING

(a) Composite Optical Sensor System for measurement of sea water property.

(i) Temperature and pressure sensor which utilize the acrylic fiber's refraction change caused by temperature and pressure.

(ii) Salinity sensor which detects the difference of refaraction index between sample sea water and the standard.

(iii) Turbidity sensor which measures the turbidity by comparing the intensity of scattered lights and transmitted lights.

The sensitibities and measuring ranges of sensors are shown in Table. The values in brackets were examined in the field test.

	Accuracy		Range	
i) TEMPERATURE	± 0.05 °C	(±0.05)	0～50 °C	(11～17)
i) PRESSURE	± 0.01 kgf/cm^2	(±0.01)	0～10 kgf/cm^2	(0～0.9)
ii) SALINITY	± 0.2 °/₀₀	(±0.2)	0～40 °/₀₀	(31～33)
iii) TURBIDITY	± 0.2 °/₀FS	(±0.2)	0～150 ppm	(0.1～3.)

(b) Ship—mounted Advanced Acoustic Doppler Current Profiler (AADCP)

Current in the deeper layer has been able to measure by AADCP which was improved by the phased array type transducer and the advanced signal processing with auto correlation method.

Specification of AADCP

maximum depth of detectable water current	400 — 500 m
maximum depth of detectable sea floor	1000 m
velocity resolution	1 cm/s
beam angle	±30 °
acoustic frequency	70 kHz

(c) Ocean Acoustic Tomography System (OATS)

As for the results of the field test in the Kuroshio region, OATS has succeeded in distinguishing two sonic waves travelling through the different sound passes from transmitter which was located about 100 km apart.

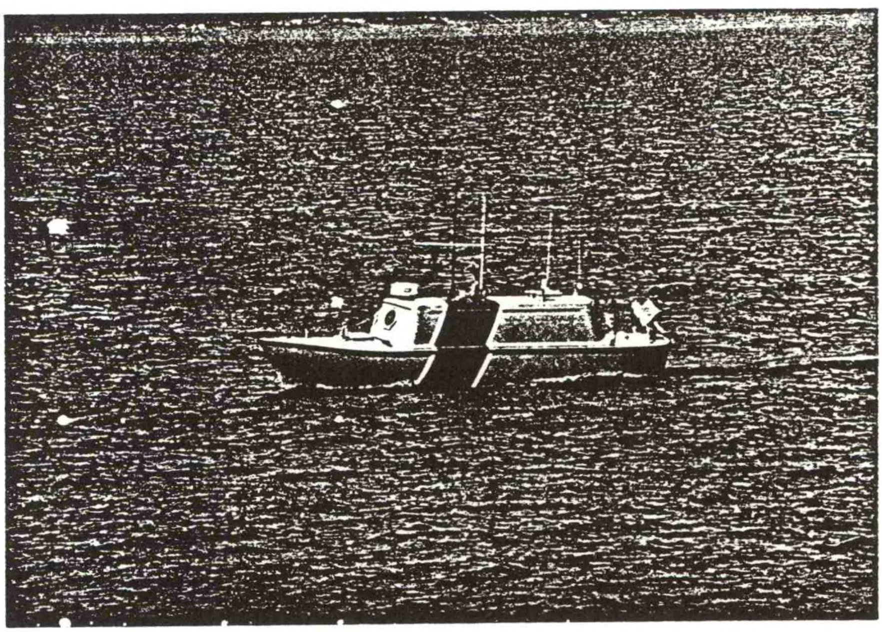
(d) Intelligent Sonar System for Measurement of Oceanic population of Fish and Plankton (ISSMOFP)

ISSMOFP is made of composites of the horizontal and the vertical sonars and ISSMOFP has been successfully examined to obtain oceanic population quantitatively with the double integration technique on the signal processing.

(2) DEVELOPMENT OF THE INTELLIGENT DATA COLLECTING SYSTEM IN BUOYS.

(a) Self-propelled and Self-navigated Buoy System (SSBS)

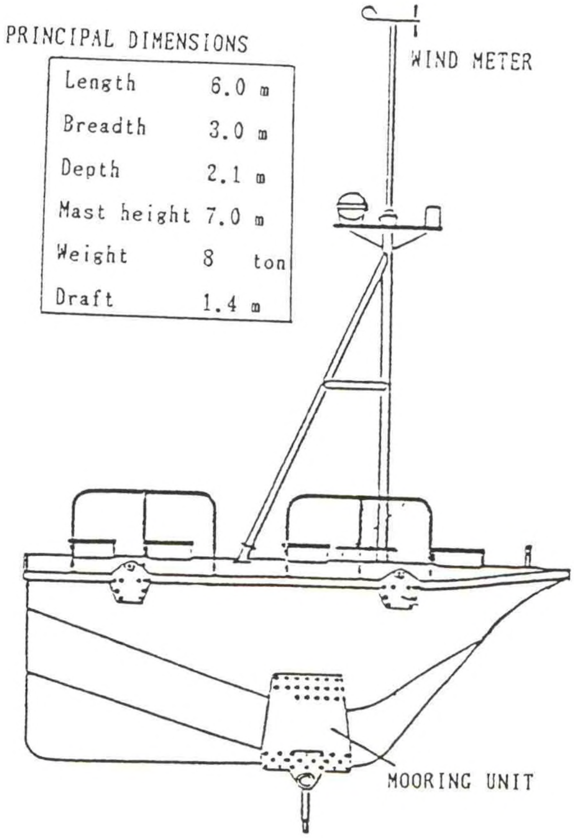
SSBS in the field examination.



SSBS, which is controlled by the pre-memorized program and by the remote manual handling, has been successfully operated in the field. It gathers informations about the fields such as water depth, temperature, and etc., supposing a dangerous condition like a eruption of sub-sea volano.

(b) Ship-shaped Mooring Buoy System (SMBS)

SMBS, which is used for monitoring the wave, wind, and other sea conditions, has been successfully examined to work continuously during 3 months at the site about 400m depth.



Ship-shaped Mooring Buoy

(3) DEVELOPMENT OF SEA BOTTOM SURVEY SYSTEM FOR PRECISE AND EFFICIENT OBSERVATION ON THE SEA FLOOR AND SUB BOTTOM STRUCTURE.

(a) Narrow Multi Beam Sounder System,

which scan the sea floor widely and efficiently by cross fan beam, has been successfully examined to survey the sea floor topography and sedimentary condition in the field about 100—500m depth area.

(b) Deep-Towed Seismic Profiling System,

which is used for surveying precisely the detailed sub bottom structure in the deep sea, has been successfully examined in the sea area about 4000m depth. And it is planned to examine in a further deep sea about 6000—7000m.

ADVANCES IN OCEAN DATA COLLECTION SYSTEMS

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ABSTRACT

As the 21st century approaches, global use of the oceans and coasts will dramatically increase for commerce, industry, and leisure purposes. Corresponding demands will be placed on marine environmental analysis and forecast services, including oceanography, weather, and climate, to ensure the efficiency and safety of ocean and coastal activities. Data must be supplied in order to achieve accurate analyses and forecasts. This paper explains the need, briefly describes the present state of the art, and predicts the future trends in ocean data collection, using the programs of the National Data Buoy Center as examples.

1.0 INTRODUCTION — THE NEED FOR OCEAN OBSERVATIONS

Traditionally, observations of the marine environment have been made with an aim toward improving the safety and efficiency of human enterprise on the sea and at the sea-land boundary. Certainly, there is an impressive history of.scientific data collection efforts for which the pursuit of knowledge has been the sole reason for existence; nevertheless, the bulk of environmental data gathered from the oceans has been for more immediately pragmatic, though no less noble, purposes. As we proceed into the 21st century, the need for ocean observations, in both quantity and variety, will increase in response to the practical demands levied by human endeavors in a world of shrinking resources and increasing population growth. Use of the sea for military, commercial, and leisure purposes will multiply. At the same time, pressure on the ocean environment will intensify as the demand for resources from the sea expands and as pollution and waste disposal concerns are heightened.

The United States and Japan are examples of this dramatic growth in oceanic and coastal utilization. Both countries, but especially Japan, rely heavily on international trade, a vast quantity of which is most efficiently transported in ocean-going ships. A host of marine-related activities provide the infrastructure for the shipping industry, including port facilities, shipyards, naval architecture and marine engineering firms, ocean navigation and communication networks, and other secondary businesses and institutions, such as steel manufacturing, harbor dredging and navigation, and marine licensing and regulatory agencies. Offshore oil and gas exploration and production, although currently in a slump, will almost certainly rebound and expand into the next century. Fishing will multiply, and the technology to support the fishing industry will undergo continued modernization, enabling more efficient harvesting of both nearshore and pelagic fish stocks. All these activities will result in an increasingly important human interest in the sea, both in terms of capital investment and commercial potential, and in terms of human lives.

In both Japan and the United States, the coasts and adjacent waters have become prominent areas of national attention. Approximately 50 percent of America's population lives within 100 km of the coastline, and this percentage is growing. Residential and leisure usage of the coastal regions is evident in the massive growth in coastal construction of shoreside condominiums and yachting facilities. In the summer, Americans practically "live" on the beaches. All this coastal growth places an enhanced emphasis on land-sea environmental processes. In addition, pressure is being directed to restoring and preserving coastal features, such as marshes and river deltas, and to arresting such phenomena as beach drift and erosion.

A final significant area of oceanic use of major importance to the free world is defense. Naval exercises and patrols occur continuously, both on the ocean surface and below, in order to ensure the safety and security of the free nations of the world.

Knowledge of the ocean and coastal environment is essential to deep-water activities, such as shipping, to coastal concerns, and to defense. To the extent possible, forecasts of the marine environment constitute an increasingly important segment of that knowledge. For shipping and offshore industries, marine weather and ocean wave observations and the forecasts they support are essential to safety of life at sea, routing and navigation, and deep-water operations. Climatological records, based on long-term observation series, are invaluable to engineers and designers for determining the required strength and stability of ships and other marine structures. Fishermen rely on local forecasts of marine weather in the conduct of their operations, especially in areas such as the North Pacific, where icing and violent waves can and do result in capsizing and loss of life. Tropical cyclone forecasts, and warnings of other storms and severe events, such as tsunamis and unusually high tides, annually save countless lives and help to lessen property damage along the coasts.

Global climate fluctuation is the other side of the ocean data collection requirement. The oceans, which serve as massive heat sinks and advect thermal energy, interact with the atmosphere to affect major weather patterns and to influence climate throughout the world. With adequate data, the relationships behind such climate phenomena as El Nino/Southern Oscillation can be studied and their impact predicted. The effects of climate changes on society and industry can be substantial, as exemplified by the El Nino-related drought in Australia and the simultaneous disastrous fishing season off western South America in 1982-83. Climate forecasting and the integrated understanding of the global effects of ocean dynamics and ocean-atmosphere interactions can be expected to grow in both scientific and commercial significance in the decades ahead.

Marine forecasts and climate studies both require reliable and accurate observations: in the case of weather, the reports must be available in real time. Accuracy entails systematic means to ensure sensor calibration, to provide data quality assurance, and to perform maintenance and repair of observational systems as required. Automation of measurements is also essential for accuracy and is necessary for cost-effective operation as well. Data telemetry techniques must be reliable, must allow for the incorporation of data quality assurance, and must provide for timely and appropriate dissemination to forecasters and other users. Reliability demands a comprehensive and in-depth effort in network design, equipment engineering, logistics planning, operational support, quality control, and configuration management. Beyond these aspects, observing systems and networks must satisfy critical data requirements in consort with complementary observing techniques. Consequently, as we proceed into the last decade of the 20th century, we can expect the need for ocean data to increase — high quality observations that are reported reliably, accurately, and cost effectively.

2.0 THE STATE OF THE ART IN OCEAN DATA COLLECTION IN 1988 — AN OVERVIEW

Ocean data collection is almost as broad and varied a subject as the oceans themselves. To describe sufficiently the scope and multiplicity of present ocean observing systems is well beyond the limitations of this paper. The scientific and academic community, defense agencies, offshore oil industry, shipping concerns, and fisheries and other biological interests all operate programs to measure physical phenomena in the oceans. At the U.S. National Data Buoy Center, our primary focus is on marine and coastal meteorological observations and, on a more limited scale, with oceanographic measurements (i.e., predominantly surface phenomena, such as waves, ocean temperature, and surface current patterns). Even in the area of marine meteorology and oceanography, a large spectrum of observing technologies exists. These will be covered briefly from a "philosophical" point of view, and then will be followed by a short description of the state of the art as exemplified by NDBC.

In the last twenty years, the single most significant advance in ocean data collection has been the introduction of environmental observation and data relay satellite technology. Satellites and satellite-communicating systems have enabled the collection of a vast spectrum of data from the world's oceans with an efficiency never before envisioned. This is not to say that *in situ* observations have become passe; rather, *in situ* observations have been demonstrated to be essential complements to satellite measurements. However, most automated *in situ* observations rely on satellite telemetry for data relay, particularly for real-time data from remote locations. It is satellite telemetry that allows the NDBC moored buoy and coastal station networks to provide real-time data (i.e., via the Geostationary Operational Environmental Satellite (GOES)), and also enables near-real-time receipt of messages from more remotely deployed drifting buoy systems (via the Argos system on NOAA polar-orbiting satellites).

Modern environmental satellites are equipped with a host of sensor systems for making remote measurements of the oceans. Capabilities include: imagery (both visible spectrum for cloud patterns and derived upper winds and for ocean color, and infrared for ocean fronts and eddies); microwave radiometry (for sea surface and sea ice temperature); radar altimetry (to determine sea surface topography, ice edge, significant wave height, and nadir wind speed); radar scatterometer measurements (sea surface wind); and microwave synthetic aperture radar (for directional wave spectra). Also, soundings of vertical profiles of atmospheric temperature and moisture are made by satellites using microwave radiometric techniques.

Despite this impressive list of capabilities, satellite remote sensing systems do have practical limitations. Most important is that they do not provide continuous measurements from the same location as do marine surface stations. Available satellite-borne sensors are incapable of "seeing" below the sea surface, and are, therefore, of little use for subsurface oceanography. The utility of satellite meteorological capabilities, while a substantial benefit to forecasters and other users, is also somewhat limited. Visible imagery is restricted to daytime observations, and both infrared and visible imagery systems are unable to penetrate cloud cover. Satellite observations of surface winds and ocean waves, in general, are indirect quantities requiring the application of sophisticated numerical algorithms to yield useful results. They also are not directly comparable to surface measurements since they are typically asynoptic areal averages. Wind and wave measurements, as well as other satellite remote observations, are "vulnerable to systematic biases that can be compensated for only by frequent reference to the conventional *in situ* observations" [1]. (For example, NDBC coastal stations and moored buoys, in response to this need for "ground truth," are being converted to measure winds continuously on behalf of a NESDIS-sponsored program for satellite verification [2].) Alternatively, "satellites are doing a good job of measuring... cloud cover and cloud temperature, atmospheric temperature and moisture profiles, sea surface temperature, and ice cover" [3]. Satellite-sensed atmospheric profiles are more accurate in the upper portion of the atmosphere.

It should be noted that recent advances in the state of the art of ground-based meteorological observing systems also hold significant promise for marine weather monitoring. These include horizontal scanning Doppler radar systems (the National Weather Service's (NWS) NEXRAD), and vertical profiling Doppler radars (the Environmental Research Laboratories (ERL) Upper-Air Wind Profiler), which will enable dramatically improved detection of mesoscale atmospheric phenomena for use in analysis and forecasting. Surface-based radiometric temperature and moisture profilers have also been developed and tested. The wind profiler radar and radiometric profiler enable continuous monitoring of vertical atmospheric profiles, in contrast with radiosonde launchings that typically occur twice daily. NDBC has and continues to play a significant role in the development of the wind profiler. On behalf of ERL, NDBC system-engineered and is acquiring 31 upper-air, wind profiling, Doppler radar units for installation in the Profiler Demonstration Network in the central United States (Figure 1). NDBC, in consort with NASA, also sponsored the development of a compact microwave temperature and moisture profiling radiometer (Figure 2). This unit is being evaluated by ERL against other radiometers and radiosondes, with promising results. To the extent these systems are installed in coastal areas or on islands or deep-ocean platforms, the data they will provide will significantly contribute to the knowledge of the oceans and coastal environment.

NDBC operates one of the most extensive *in situ* marine environmental real-time observing networks in the free world, with its fleet of over 50 moored buoys and over 40 coastal stations (Figures 3 and 4). In addition, NDBC maintains a continuous network of about 50 drifting buoys in the Southern Ocean for the Tropical Ocean and Global Atmosphere (TOGA) program (Figure 5), along with other smaller drifting buoy networks throughout the world's oceans. The next section is a description of some of the more important facets of the NDBC operation. It is important to note that successfully running a network of automated data collection systems in a marine environment is not a trivial task. The ocean is a harsh, unforgiving, and, to a certain extent, unpredictable environment. Success demands the highest quality engineering, careful attention to data quality assurance, and thorough end-to-end systems planning. This is especially the case where increasing requirements for ocean data are being levied in light of fixed or declining human and monetary resources.

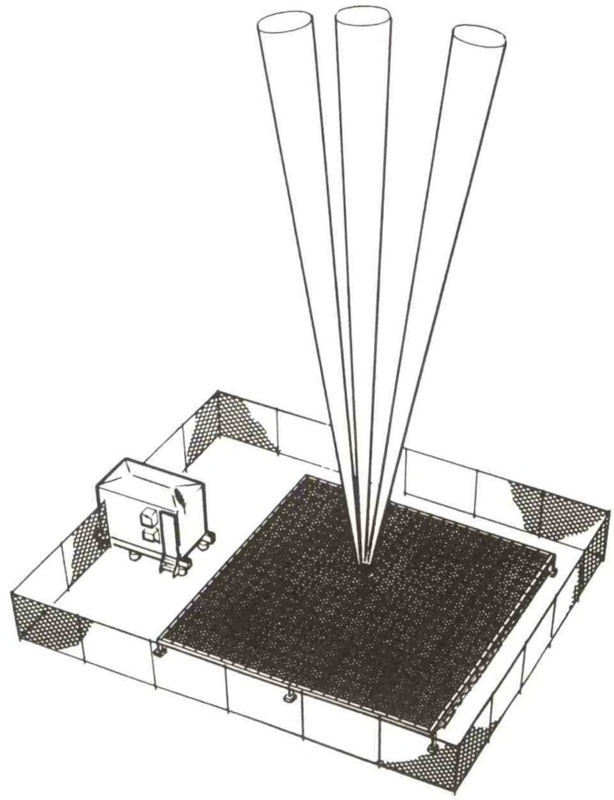

Figure 1. *Upper Air Wind Profiler*

3.0 THE STATE OF THE ART IN OCEAN DATA COLLECTION IN 1988 — AT NDBC

3.1 MOORED BUOY SYSTEMS

The moored buoy network is operated, maintained, and upgraded to collect *in situ* environmental data from data-sparse marine areas, to relay these data to the National Weather Service and other users, and to monitor the quality of the data measurements on an ongoing basis.

From the initial 6-buoy network deployed in 1976 and 1977 in the eastern Pacific and Gulf of Alaska, the moored buoy network has grown to over 40 buoys located in the Atlantic and Pacific Oceans, the Gulf of Mexico, the Great Lakes, and the Bering Sea. Synoptic data are collected hourly and transmitted via the Geostationary Operational Environmental Satellite (GOES) system to the U.S. National Meteorological Center near Washington, DC, where the data are monitored and disseminated.

The buoys are equipped with electronic payloads to perform the measurements listed in Table 1. The payloads are low-power systems that are able to operate up to several years with batteries

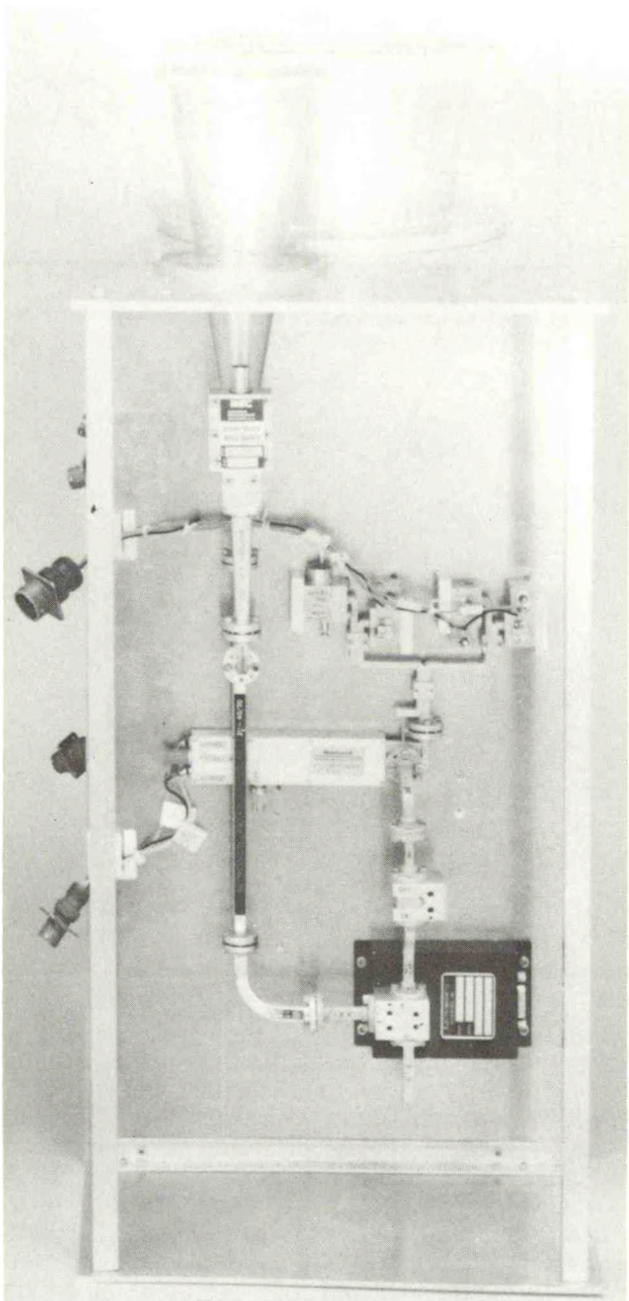

Figure 2. *Upper Air Temperature and Moisture Profiler*

alone on large hulls and for indeterminant periods on almost any sized hulls with solar power (photovaltaic cells). Hull types are shown in Figure 6. With the exception of the inexpensive 3-meter discus, NDBC buoys can be serviced at sea while moored. The 3-meter must be brought aboard ship or retrieved to port. On a networkwide basis, NDBC achieves a data performance, buoys to shore, of greater than 85 percent annually.

Several new moored buoy programs are under way, or are planned to occur in the next several years, that will be expanding the traditional scope of the NDBC network. These include an array of two to three buoys off Cape Canaveral to provide critical offshore observations for space shuttle launch and recovery; a network of directional, wave-measuring, 3-meter moored buoys in the Atlantic (some equipped with specialized sensors) for the Surface Wave Dynamics Experiment (SWADE) sponsored by the Office of Naval Research; and planned participation in the Global Ocean Flux Study Ocean Chemical Buoy deployment, which would involve surface and subsurface biological and chemical sensors on a host NDBC buoy. Other ongoing and new initiatives and sensor enhancements are described in [4].

3.2 DRIFTING BUOYS

The NDBC drifting buoy program is an ongoing effort with a significant domestic and international role. Drifting buoys (Figure 7) are relatively small, self-contained, expendable data collection platforms capable of being deployed from aircraft or ships throughout the world and able to operate unattended in excess of one year. They offer a uniquely flexible and inexpensive means to obtain critical observations from remote ocean locations or from specific data-void regions with short notice.

TOGA continues to be the most significant NDBC drifting buoy program. Since TOGA's beginning in January 1985, NDBC has maintained a continuous network of about 50 operational drifting buoys throughout the oceans of the Southern Hemisphere. These buoys provide reliable meteorological and oceanographic data (barometric pressure, air temperature, sea surface temperature, and ocean current/drift track) while experiencing a mean time to failure of over 400 days. To deploy the drifters in the desired locations, NDBC developed an extensive logistics program that involves the participation of several countries and other U.S. agencies. They all have made significant contributions to the success of the logistics program for TOGA. The United States plans to provide some 40 to 50 drifters to TOGA each year through 1995. As of October 1987, 150 buoys had been deployed with 51 still operational.

In another important initiative, six TOGA-type typhoon drifters were deployed by the U.S. Navy during May 1987 in the Pacific Ocean southwest of Guam. These buoys, procured by NDBC, provided excellent meteorological data, especially during several typhoons. An NDBC-developed Local User Terminal (LUT) satellite receive station on Guam provided real-time meteorological and position data. As a result, the Navy plans to continue the use of this system in support of operations with 10 to 20 new drifters each year.

Smaller-scale drifting buoy projects have been conducted for the U.S. Navy and NATO with buoys equipped with both meteorological sensor suites and subsurface thermistor (Tz) lines to a depth of 600 meters. Associated drifting buoy developmental efforts are under way demonstrating capabilities for

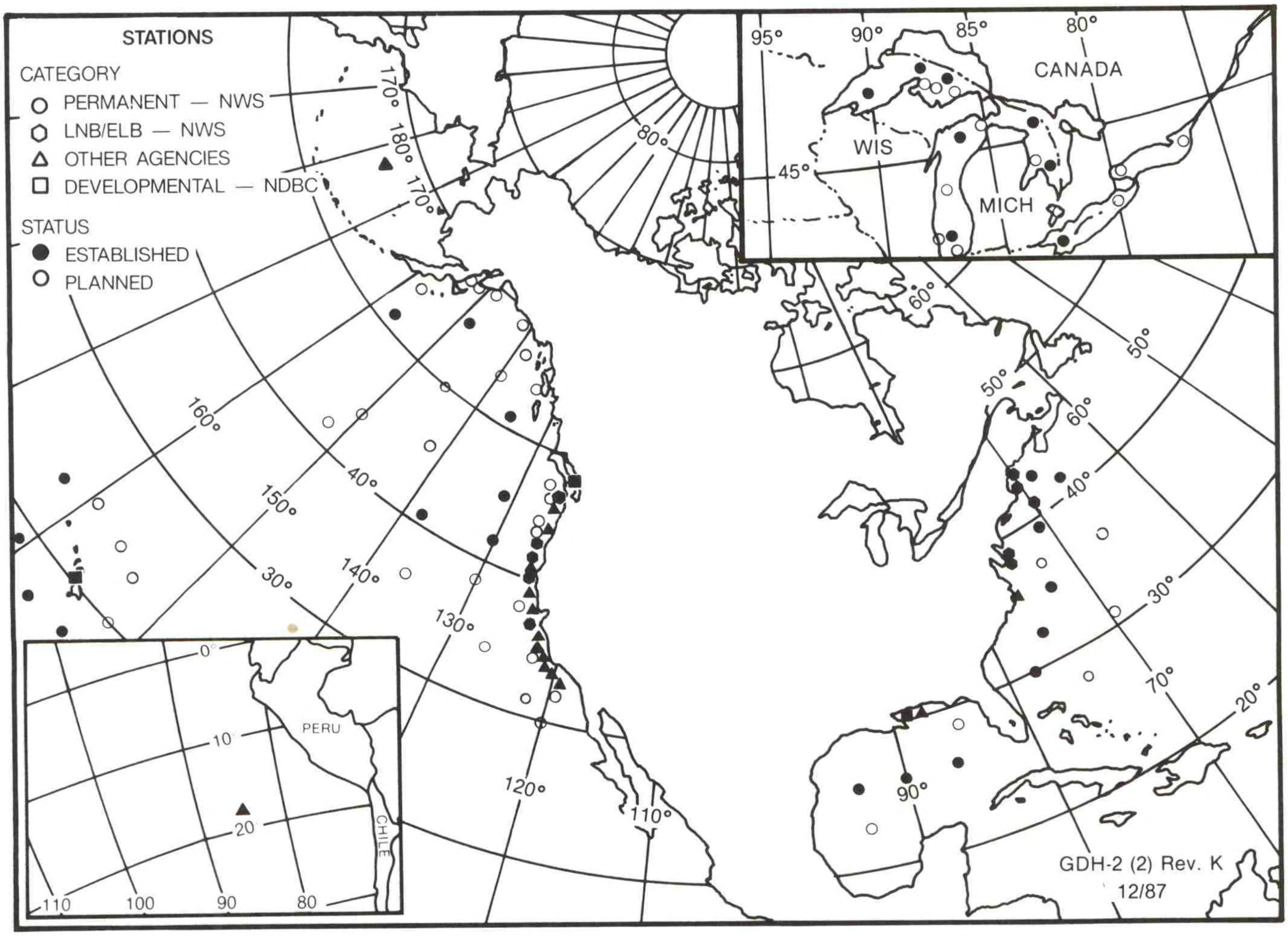

Figure 3. *NDBC Buoy Locations*

remote control turn-on/turn-off, wind direction measurement, and nondirectional wave spectra measurement. An effort to develop a minibuoy (a sonobuoy-sized drifting buoy) capable of deployment through standard aircraft launch tubes) is also in process. All drifting buoys report data through the Argos system carried on board the NOAA polar-orbiting satellites (which also provides buoy position).

3.3 COASTAL-MARINE AUTOMATED NETWORK

Forecasts, watches, and warnings issued for the marine and coastal areas of the United States depend, for the most part, on observatons. However, observations in these areas have been decreasing over the last few years as manual observations at U.S. Coast Guard (USCG) light stations are lost due to lighthouse automation that is scheduled for completion in 1989. In response to the need for more coastal and offshore observations, the Coastal-Marine Automated Network (C-MAN) was established in 1981 to increase NWS marine meteorological observations. The network currently consists of 41 fixed sites and 11 buoy stations. The fixed sites are located on 8 USCG and 1 commercial offshore platforms; 19 USCG lighthouses; 7 beach areas; and 6 exposed fishing piers. The buoy stations are located on eight USCG Large Navigational Buoys (LNBs) and three Exposed Location Buoys (ELBs). A typical land station is shown in Figure 8.

C-MAN-measured parameters are similar to those measured by NDBC moored buoys. They are transmitted hourly via GOES, but are also updated every 15 minutes so that they can be obtained via local telephone line, where available. In addition to the standard measurements, selected C-MAN systems have been equipped with tide/water level gauges, dewpoint sensors, precipitation gauges, visibility sensors, and laser wave height sensors (for use on offshore platforms).

3.4 WAVE MEASUREMENT

The NDBC Waves program includes (1) the development, testing, and demonstration of systems that operationally acquire and report high-quality ocean surface wave data from buoys and other marine platforms, and (2) the provision of support for operational systems, particularly in areas of troubleshooting and data quality evaluation for the

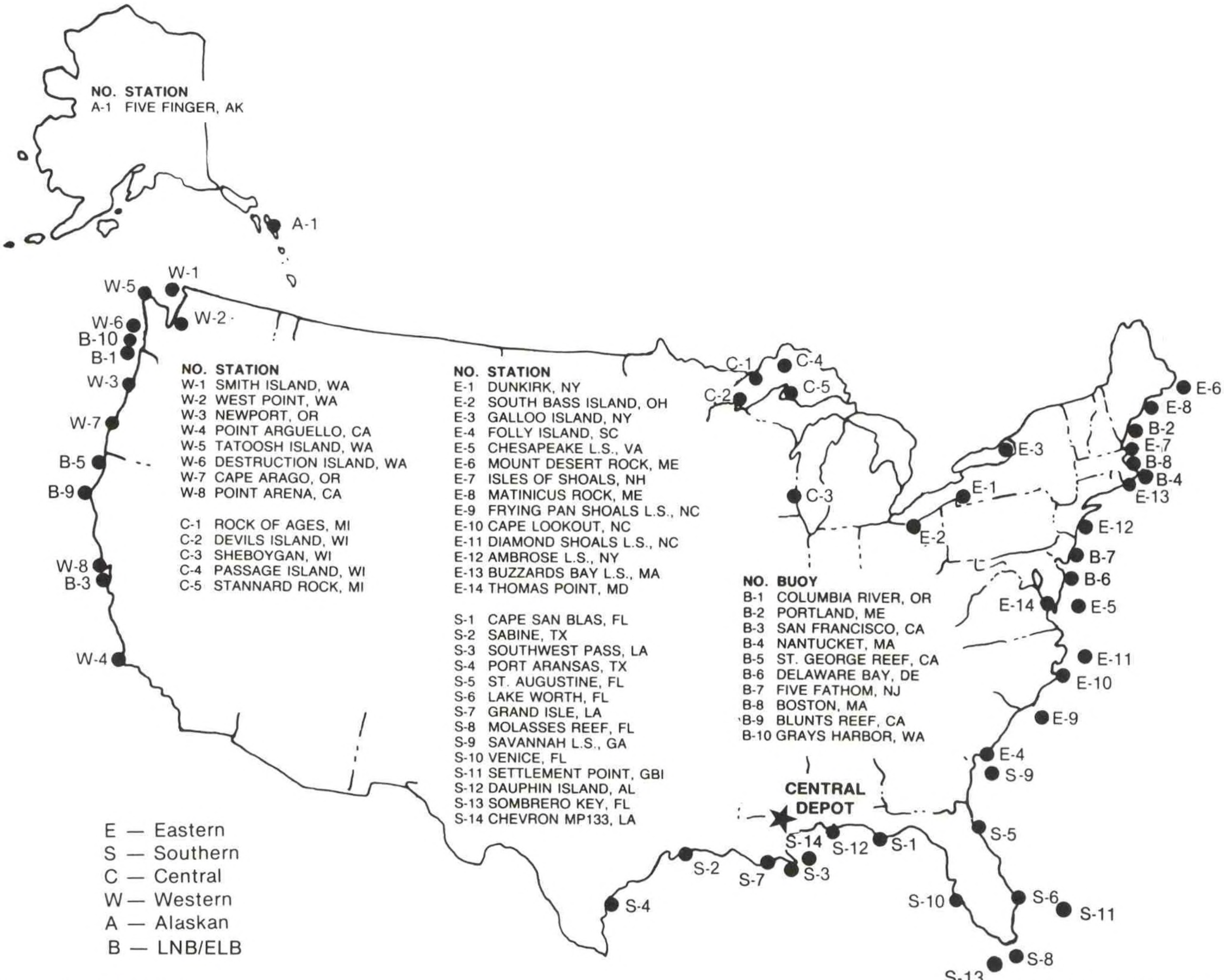

Figure 4. *C-MAN Sites*

more technically advanced systems. These operational systems are a part of the overall payloads.

Nondirectional wave systems are operational on all current moored buoy, LNB, and ELB hulls. Nondirectional wave systems are very near to being operational for fixed sites and are under development for drifting buoys. A line-of-sight (LOS) system is under development to provide nondirectional wave data from nearshore areas to C-MAN fixed platform stations and to local shoreside receive sites for real-time use. The shoreside receive sites would use a personal computer for data processing and local display.

NDBC, on behalf of the Naval Civil Engineering Laboratory and the U.S. Army Corps of Engineers, has deployed a number of directional wave measurement buoys at locations off the East and West Coasts of the United States and in the Gulf of Mexico. This capability is fully demonstrated for 10- and 12-meter discus buoys and for the 3-meter discus, which has become the directional wave "workhorse" due to its size, convenience of transport and deployment, and cost. NDBC 3-meter buoys with directional wave measurement systems will be deployed in the Atlantic over the 1988-1991 time frame for SWADE.

4.0 THE FUTURE IN OCEAN DATA COLLECTION

As the 21st century approaches, the requirements for ocean data collection will increase, as outlined in Section 1.0. A number of factors will affect the way in which these requirements are met. For the next decade, the key factors appear to be the following:

- **An Emphasis on Integrated Monitoring Systems.** Three issues are apparent: (1) a trend to large-scope and long-term national and global observing programs to more comprehensively serve analysis and forecasting needs (e.g., planning is now under way for projects related to global ocean monitoring and national wave measurement); (2) developing integrated observing and predictive systems for mesoscale concerns (i.e., coastal regions and harbors), based on multiple data collection systems feeding into a central computer-enhanced data display and forecast center such as the planned Interactive Marine Analysis and Forecast System (IMAFS)[5]; and (3) the creation of synergistic joint programs, where several programs are acting in consort to support common

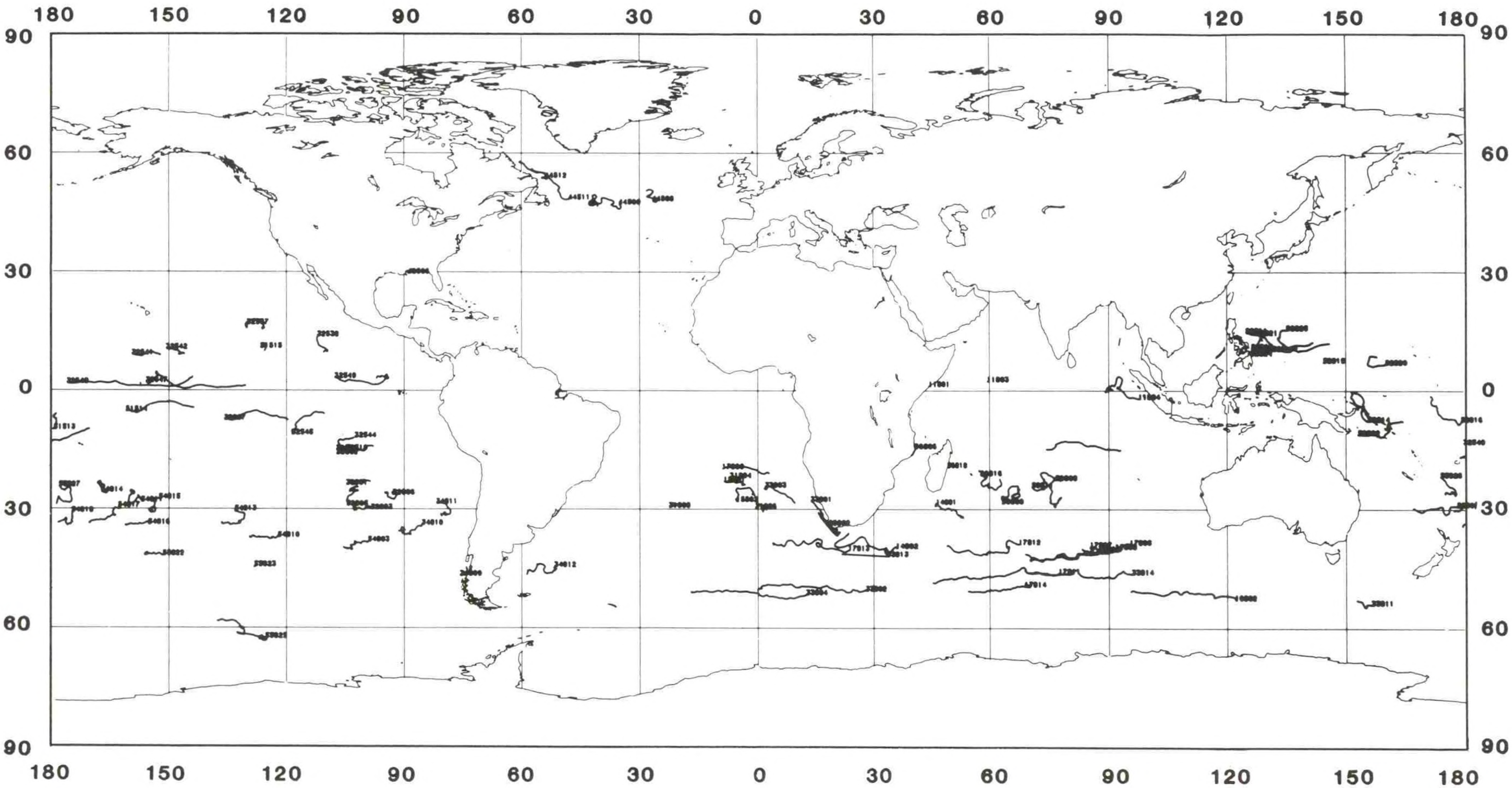

Figure 5. *TOGA Drifting Buoys — October/November 1987*

Table 1. *Typical Moored Buoy Payload Data*

Parameter	Reporting Range	Reporting Resolution	Sample Interval	Sample Period	Total System Accuracy
Wind Speed	0 to 80 m/s	1 m/s	1 sec	8.5 min	±1 m/s or 10%
Wind Direction	0 to 360°	10°	1 sec	8.5 min	±10°
Wind Gust*	0 to 80 m/s	1 m/s	1 sec	8.5 min	±1 m/s or 10%
Air Temperature	-40° to 50° C	0.1° C	90 sec	90 sec	±1° C
Barometric Pressure	900 to 1100 hPa	0.1 hPa	4 sec	8.5 min	±1 hPa
Significant Wave Height	0 to 20 m	0.1 m	0.78 sec	20 min	±0.2 m or 5%
Wave Period	2 to 33 sec	1 sec	0.78 sec	20 min	±1 sec
Wave Spectra	0.03 to 0.5 Hz	0.01 Hz	0.78 sec	20 min	—
Surface Water Temperature	-15° to 50° C	0.1° C	90 sec	90 sec	±1° C

* Highest 8-second window average retained.

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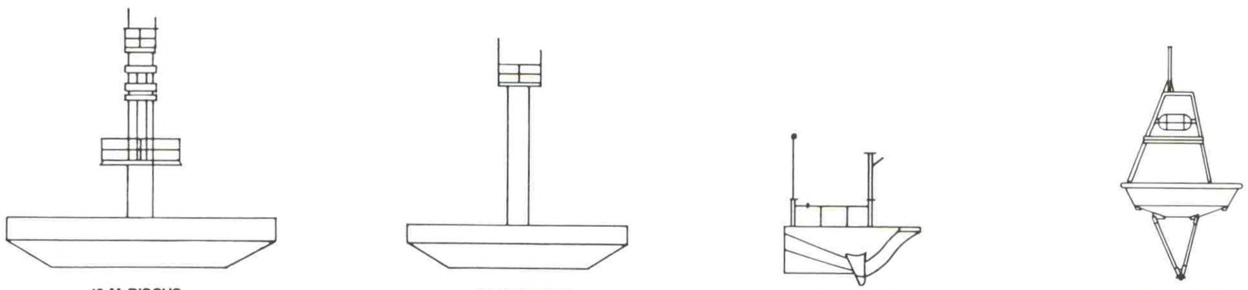

12-M DISCUS

1. EEP (12D03 - 12D08)
   a. HULL WEIGHT 104,000 LB
   b. POWER SYSTEM 4,000 LB
   c. PAYLOAD 400 LB
   d. BALLAST 81,600 LB
   e. DEPLOYED 190,000 LB
   f. VCG 4.3 FT
2. ONR (12D01, 12D02, 12D09)

10-M DISCUS

1. PEB (10D01 - 10D06)
   a. HULL WEIGHT 60,000 LB
   b. POWER SYSTEM 4,000 LB
   c. PAYLOAD 400 LB
   d. BALLAST 49,600 LB
   e. DEPLOYED 114,000 LB
   f. VCG 3.6 FT
2. VE (10D07 - 10D11)
   a. HULL WEIGHT 57,000 LB
   b. POWER SYSTEM 4,000 LB
   c. PAYLOAD 400 LB
   d. BALLAST 52,600 LB
   e. DEPLOYED 114,000 LB
   f. VCG 3.8 FT

6-M NOMAD

1. USN (6N01 - 6N15)
   a. HULL WEIGHT 10,000 LB
   b. POWER SYSTEM 3,000 LB
   c. PAYLOAD 350 LB
   d. BALLAST 5,900 LB
   e. DEPLOYED 19,250 LB
   f. VCG 4.74 FT
2. VE (6N16 - 6N30)
   a. HULL WEIGHT 9,400 LB
   b. POWER SYSTEM 3,000 LB
   c. PAYLOAD 350 LB
   d. BALLAST 6,500 LB
   e. DEPLOYED 19,250 LB
   f. VCG 4.24 FT

3-M DISCUS

1. (3D01)
   a. HULL WEIGHT 1,887 LB
   b. POWER SYSTEM 610 LB
   c. PAYLOAD 100 LB
   d. BALLAST 500 LB
   e. DEPLOYED 3,300 LB
   f. VCG 2.5 FT
2. (3D02 - 3D19)
   a. HULL WEIGHT 2,600 LB
   b. POWER SYSTEM 660 LB
   c. PAYLOAD 210 LB
   d. BALLAST 0 LB
   e. DEPLOYED 3,470 LB
   f. VCG 2.4 FT

Figure 6. *Moored Buoy Hull Characteristics*

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observing systems. The technology also exists to determine the optimum network array in terms of sensor system composition and density.

- **Enhancement and Advancement of Data Collection Technology.** Here, there are three aspects. 1) Satellite capabilities will become more powerful, for remote observations, for data relay, and for position/location determination, and costs, at least per datum, will decrease. In the United States, advisory planning for future satellite capabilities is accomplished via the Satellite Telemetry Interagency Working Group (STIWG), of which NDBC is an alternate member. 2) *In situ* sensor systems will become more reliable, less expensive, and have greater capability (e.g., the installation on buoys of radiometric upper-air temperature and moisture profilers may well become a reality). 3) The capability of electronic systems will continue to increase, enabling field payload systems to perform substantially more sophisticated data processing, including some level of quality assurance, while at the same time the cost of such systems will decrease. Consequently, it is conceivable to envision future ocean data collection networks composed of more reliable systems making a larger variety of observations with greater data processing on board, all working in consort with increasingly advancing satellite systems to provide much expanded and more useful data to the marine user.
- **Constrained Resources.** Fiscal efficiency, if not austerity, will be the byword of the 1990s. This leads to at least two concomitant predictions: (1) new efforts should and will be built as expansions of programs with proven performance

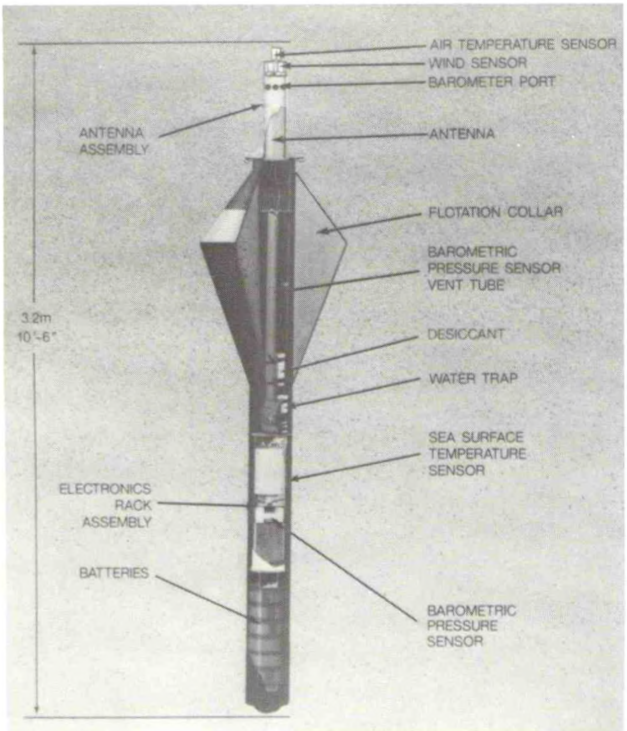

Figure 7. *Meteorological Drifting Buoy*

records and demonstrated cost-effectiveness, particularly insofar as the marine environment is concerned; and (2) success will demand a greater degree of technical and programmatic synergism between industry, science, and government, and within government, between agencies with the various pieces of the ocean environmental monitoring charter. NDBC, with nearly two decades experience in the ocean data collection business, with an organizational setup in which appropriate activities are efficiently performed in the commercial sector rather than by government employees, and with a history of effectively conducting joint international, interagency, and government-industry projects, will play a lead role in ensuring that constrained resources produce optimum results for the United States and for the world community at large.

5.0 REFERENCES

1. Wolff, Paul M. "Ocean Data Collection Systems," paper presented at the Radio Technical Commission for Maritime Meeting, San Francisco, April 1987.
2. Letter from James K. Sharp, NDBC, to John Wilkerson, NESDIS, Subject: Continuous Wind Measurements, October 21, 1987.
3. Wolff, Paul M. "Ocean Observations in Support of Interactive Models," paper presented at the Workshop on Meteorological Operational Systems, at the European Centre of Medium-Range Weather Forecasts, United Kingdom, December 1987.
4. McCall, Jerry C., "Current Status of U.S. Data Buoy Program," scheduled for presentation at PACON 88, Honolulu, Hawaii, May 1988.
5. Interactive Marine Analysis and Forecast System (IMAFS) Draft Program Development Plan for the National Ocean Service, by Program for Regional, August 25, 1987.

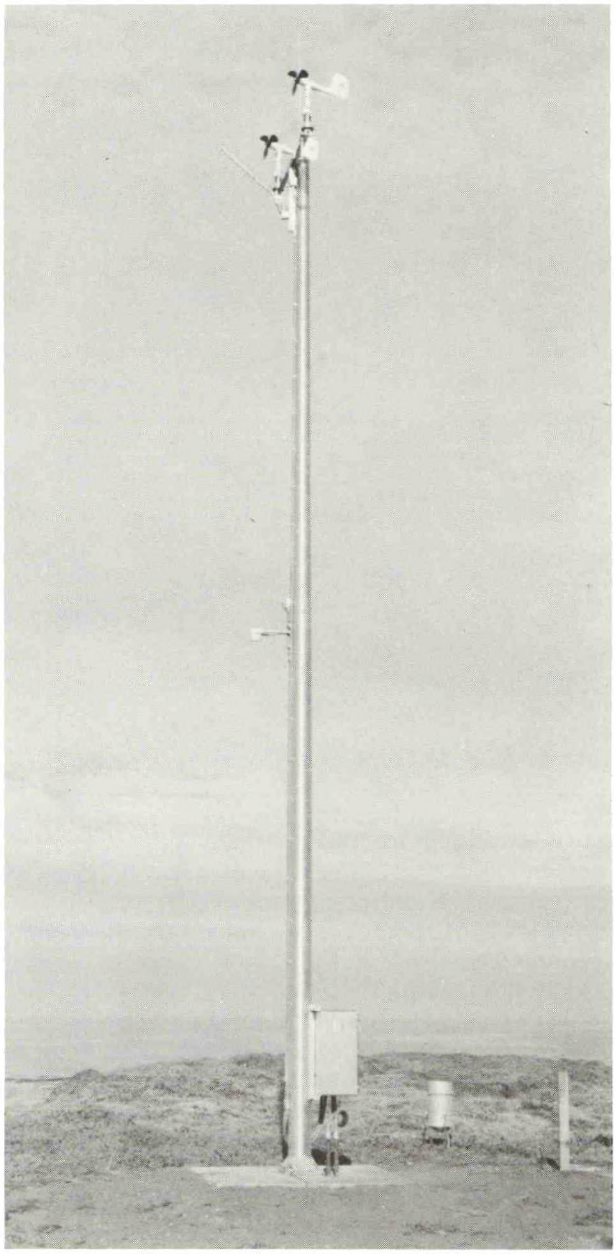

Figure 8. *Point Arena, CA, C-MAN Station*

SHORT- AND LONG-TERM WATER QUALITY MONITORING SYSTEMS ON THE CONSTRUCTION OF AN OFFSHORE AIRPORT

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ABSTRACT

Kansai International Airport is under construction, by the reclamation of offshore area of Izumisano city in Osaka Bay. On the construction works, a huge volume of material as much as 150 million cubic meters, is to be dumped into the construction site of 15-19 meters in depth. The related construction works, such as, South Osaka Coastal Development Project and Hannan Hills Development Project, are also carried out by reclaiming the parts of the coastal area or by excavating hills and distributing materials to reclamation sites. These works are scheduled to be completed in a comparatively short period of six years. The most careful attention is payed on their effects to surrounding environments. This paper describes the general introduction of the airport and its related construction works and the environmental monitoring system.

INTRODUCTION

Kansai International Airport is the first example of a man-made offshore airport in the world, and only one airport of 24-hour operation in Japan. After investigations and preparation for about twenty years, the construction started in January 1987 aiming at the completion by 1993. The new airport is expected to be free from noise unlike in the existing Osaka Airport coping with the increasing demand of airtransportation. The airport is located at 5km offshore from Izumisano city, and the southeast in Osaka Bay as shown in Figure 1. The area of the airport is 511ha and the runway is 3500m in length. The airtransportation capacity is annually 160,000 times of landing and taking-off.

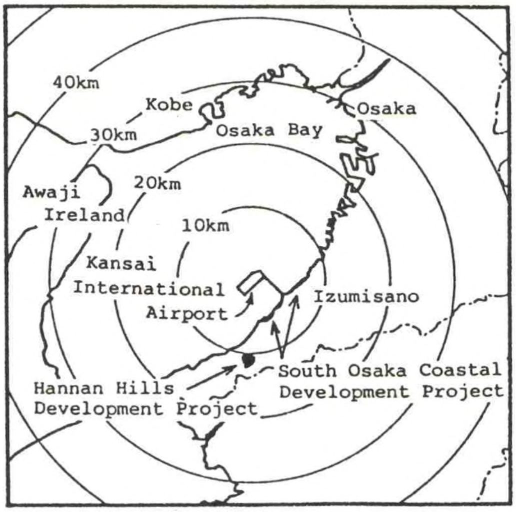

Fig.1 Location of construction works

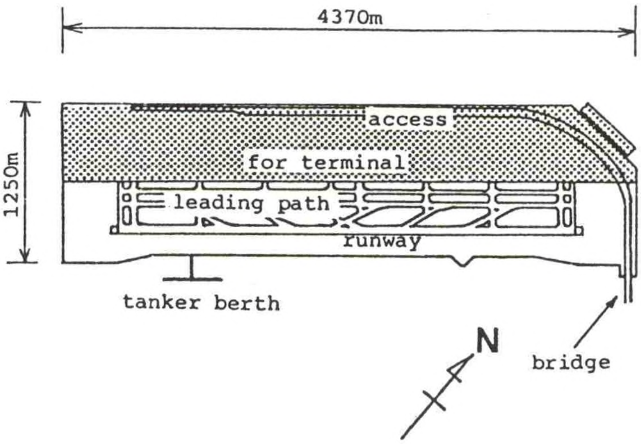

Fig.2 Layout of airport facilities

Table 1 Time-schedule of work

		1987	1988	1989	1990	1991	1992	1993
wall	Soil improvement	—	—					
	Wall	—	—	—		—	—	
reclamation	Soil improvement	—	—	—				
	reclamation			—	—	—	—	
bridge	Substructure work	—	—	—	—			
	Superstructure work	—	—	—	—	—	—	—
airport facilities					—	—	—	—
railways		—	—	—	—	—	—	—

Figure 2 shows the layout of airport facilities. The runway and the leading path are laid out in the southern side of the island, and a terminal in the northern side. The available access to the airport is the transportation by road, railway and boat. In South Osaka Coastal Development Project, 318ha in area is to be reclaimed for the related space with the airport. And in Hannan Hills Development Project, 130ha in area is to be excavated and about 50 million m^3 of the excavated material is to be distributed to the airport and about 15 million m^3 to the coastal area as the reclamation material.

The construction schedule is shown in Table 1. The reclamation will be completed in about five years. It takes about six years before service commencement of the airport.

The airport construction work is characterized by the deep water, soft soil, massive and short-term construction works, and the following problems are pointed out;

(1)Owing to the deep water and the thick soft soil layer under the sea-bed, material of about 30m in thickness must be dumped for reclamation. For this reason, design, construction and management should be carried out with the sufficient technical support on the land subsidence and the circular failure.

(2)To save the construction period, the reclamation of the airport is carried out in the same period with the the construction of the bridge connecting the airport with the main land. Therefore, burges and other boats, and materials for the construction should be well prepared, and be protected against navigation accidents.

(3)The efficiency and the security to the construction should be considered with great deal, because the most construction works are carried out 5km away from the main land.

(4)The environmental monitoring regarding the effect of the airport construction on the surroundings is being carried out in parallel with various works such as the improvement of soft soil, the management of land subsidence and its stability, progress control, work-completed control, navigation control, and environmental monitoring.

This paper relates especially the environmental management together with the general system.

WATER QUALITY MANAGEMENT

To understand the effects of the airport construction and the related works on the environmental conditions such as water quality, noise, air quality, and to perform the suitable treatments if necessary, the following environmental managements are carried out:

(1)Items selected for the environmental estimation and assessment as shown in Table 2 are measured and environmental background are obtained.

(2)Data obtained by the observation are analyzed by a certain data-processing system.

(3)The environmental effect of the construction is analyzed based on the processed data.

(4)The suitable countermeasure is performed, if necessary, based on the analysis and the assessment.

The monitoring points of water quality and sedimentation only for the airport construction are shown in Figure 3.

Table 2 Environmental monitoring items and frequencies

		Monitoring Items	Frequency		
			KIA	SOCD	HHD
Air		SO_2,NO_x,CO,SS,Hydrocarbon,Wind direction, Wind velocity	c	c	c
		Falling dust	-	M1	M1
Water quality	River Pond	Turbidity	-	-	F
		pH,DO,COD,BOD,SS,Coliforms,T-N,T-P,n-hexane	-	-	1)
	Sea	Water temperature, Turbidity,Salinity,pH,DO		c	-
		Red tide,Spill oil,Transparency,Salinity,Turbidity,pH,DO	2)	3)	M1
		SS,VSS,Grain size distribution,Current COD,n-hexane,T-N,T-P		M1	4)
Seabed sediment	River Pond	Grain size distribution,Water content,Ignition loss,pH Sulfide	-	-	5)
	Sea	Grain size distribution,Water content,Ignition loss,pH COD,Sulfate,T-N,T-P	Y4	Y4	Y4
Noise		Construction machine,Blasting	-	-	c
		Construction noise	M1	c	-
		Conveyance vehicles	-	M1	Y4
Vibration		Construction machine,Blasting	-	-	Y4
		Construction noise	-	M1	-
		Conveyance vehicles	-	M1	Y4
Phenomena on inland and in water		Ground water level	-	c	-
		Ground elevation	-	Y1	Y1
		River water elevation,River discharge,Precipitation	-	-	c
		Tidal current	6)	Y1	-
		Topography and geometory of inlets	Y2	Y2	-
Inland animals		Mammals	-	-	Y2
		Birds	-	Y4	Y4
		Amphibia,Reptiles,Insects,Arachnid	-	-	Y3
Inland plants		Vegitation,Biota	-	-	Y1
Aquatic organism	River,Pond	Fishes,Benthos,Periphyton,Zoo- and Phyto-plankton	-	-	Y4
	Sea	Fishes,Benthos,Periphyton,Zoo- and Phyto-plankton Fish eggs,Juveniles,Seaweed beds	Y4	Y4	Y4

(Note) KIA:the construction site of Kansai International Airport,SOCD:the construction site of South Osaka Coastal Development Project, HHD:Hannan Hills Development Project, c:continuous,D1:once a day,W1:once a week,M1:once a month, Y1:once a year,Y2:twice a year,Y3:three times a year,Y4:four times a year,1):M1 for daily-life environmental items and Y4 for others,2):D1 for turbidity,pH,DO,red tide, spill oil,current,W1 for SS and VSS,and M1 for others,3):W1 for floating points and M1 for fixed points,4):Y4 for river and Y1 for pond, 6):each once before and afterthe airport construction,F: after flood.

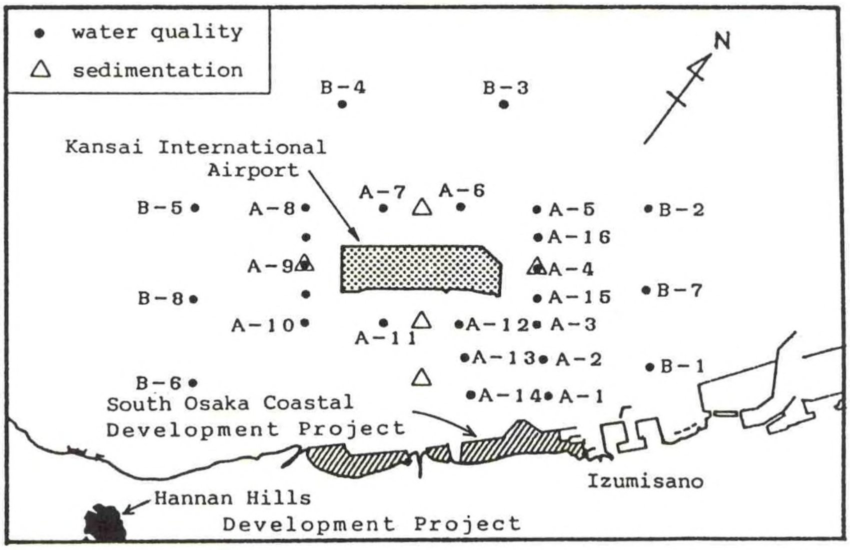

Fig.3 Water quality and sedimentation monitoring points (only for the airport construction)

The points of series A are arranged on the monitoring lines of 1km away from the construction site. The lines are determined based on the simulation results.

The points of series B are arranged for the measurement of the background value of water quality, and located 4km away from the construction site. The measuring layers are all three, i.e., 1m below the water surface, 2m above the sea-bed and inbetween them.

Usually, the monitoring is daily performed by two boats of 40 ton in weight, which cruise around 26 points next by next. The monitoring points are promptly known by using an radio wave compass (TRISPONDER) made in USA. Turbidity, water temperature, salinity, etc. are measured by a multi-water quality meter.

The data obtained on the boat are processed by a personal computer equiped in the boat and tabulated in the list on the paper, and temporally stored in the floppy disc. After landing from the boat, those data stored in the floppy disc are processed by the computer in the airport office, and produced the map of the water quality distribution. These results are used for the comparison with those of the background values, and the evaluation of the effect.

The SS(suspended solid) converted from observed turbidity is monitored. In case that the mean of the SS stays at higher value than 2mg/l for abnormally long hours, and is regarded as the effect of the construction, then the construction schedule are partially modified or stopped until the SS value decreases to the allowable value.

Additionally, to know the possible long-term- effect of the airport construction on benthos, the sedimentation is being measured every season at five points arround the airport as shown by the mark( ) in figure 3.

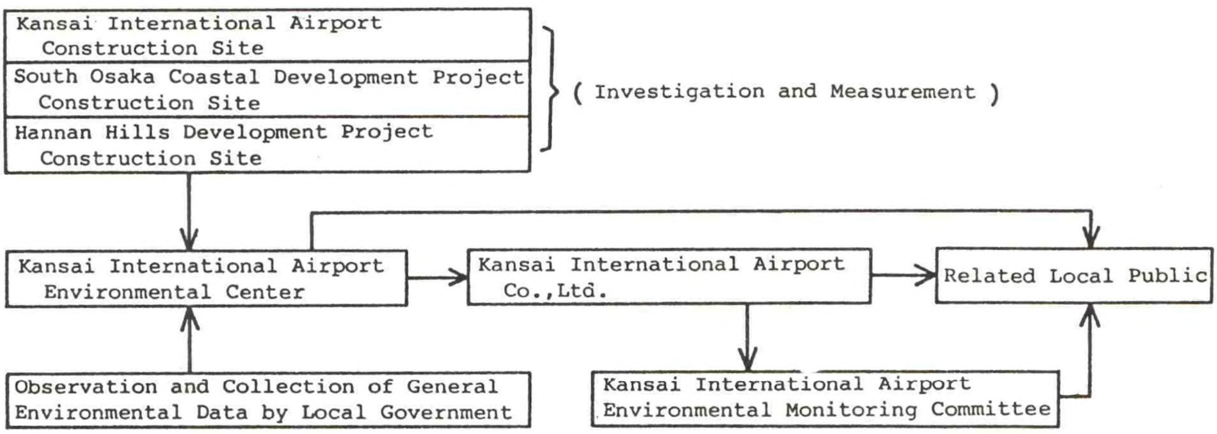

Fig.4 Flow chart of the monitoring data

An environmental monitoring committee is organized by Osaka Prefecture and the surrounding local governments consisted of 13 cities. The committee investigates the effect of the airport construction and the related works on the surrounding environment, based on the presented data, and gives some advice if necessary. Figure 4 shows the flow chart of environmental data.

CONCLUDING REMARKS

The construction of KIA is carried out on schedule owing to the successful management of construction and environmental monitor. The continuous success is expected until all seawalls around the island are completed in 1989.

REFERENCE

1)Kansai International Airport Co.,Ltd.:On the construction of seawalls for Kansai International Airport <First Report>, Oct. 1987.

2)Furudoi,T.:The generation of turbidity and its monitoring system, The 23rd Summer Seminar on Hydraulics, 1987, Course A, June 1987.

3)Horie,T.:Mathematical modeling on the fate of suspended particles by marine works and application of the models to environmental monitoring, Report of the Port and Harbour Research Institute, Vol.26, No.2, June 1987.

REFERENCE PAPERS

FUNDAMENTAL STUDY ON THE FLOATING TERMINATOR TYPE WAVE POWER DEVICE

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1. Introduction

As the ocean is very wide and it has large quantity of several natural energy resources, especialy wave energy. Fortunately, if we can utilize this wave energy effectively, it will be very useful at the isolated island or in the ocean. And this device can decrease the wave height also because of absorption of wave energy, so it will contribute to the utilization of the space of coastal zone.

JAMSTEC has been developping the floating wave power device, but the attenuator type device from 1975 and many effective results and experiences was obtained. By the way, JAMSTEC started to study on the floating terminator type wave power device, but fundamental study from 1986. Until now, we can obtaine some principal results of this type device. These are, ①high efficiency of wave energy absorption, ②wide frequency range of high efficiency region, ③ faculty of decrease of transmitted wave height, ④comparative low mooring force. This paper is described on the outline and discussion of this study.

2. The Floating Terminator

The device which is moored at the condition of coincidence of the longitudinal center line and wave crest line is called the terminator type device, as shown in Fig.1. So, it can work as the wave power device and as the floating breakwater.

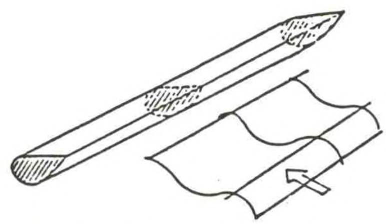

Fig. 1 Terminator type device

The principle mechanism of wave energy absorption is the oscillating water column type, so the device has several air chambers as shown in Fig.2. Each chamber has a bottom-plate, two projecting walls and an orifice at the top. When the air turbine and the generator will be setted at the orifice, the electrical generated power will be obtained. By the way, mooring lines are connected to the device. Mooring is very important problem for such terminator type device because it cannot escape from rough sea and it must protect the seashore.

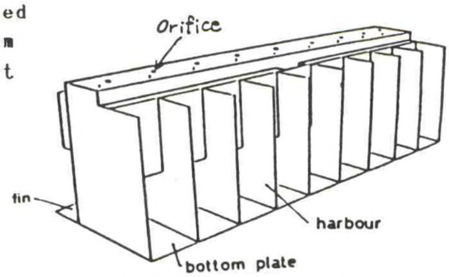

Fig. 2 Floating air chambers with harbour and fin

3. Performance of Wave Energy Absorption

Efficiency of energy conversion, motion of device and mooring force in waves were measured by model tests in the wave tank. Model tests were carried out under following three conditions. These are conditions of ①without bottom plate, ②with bottom plate and ③with harbour (and bottom plate). The device under such conditions has 9 air chambers with an orifice for each chamber as shown in Fig.3.

And, we investigated on the effect of the distance between the air chambers which are absorbing energy by the load equipment that is the orifice. By the way, the mooring force acting on each mooring lines were measured and analyzed.

The dimensions of the model of this device were 3.96 m in length in the same direction as wave crest and 0.45 m in breadth. So, the length of an air chamber was 0.44 m. Every air chamber had an orifice of 19.8

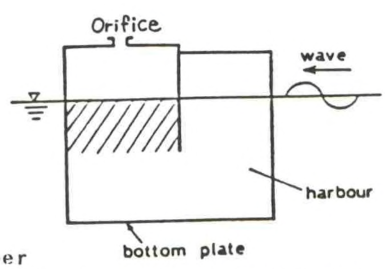

Fig. 3 Air chamber with harbour

cm^2 in flow area. And, 9 orifices were opened or closed as shown in Table 1.

The principle results are shown in Fig.4, 5 and 6. In these figures, absorption width ratio is the efficiency of conversion from wave power which exists in the length of an air chamber. According to these Figures, the bottom plate is effective for the absorption and "harbour" is further more. Especialy, when the condition is C(see Table 1) with harbour, the absorption width ratio is over 100 % because of 3 dimentional effect. But total power of absorption by the device under the condition of A with harbour is the highest, and that is 3 or 4 times as high comparing with that value by the attenuator type device.

4.Performance of Wave Absorption and Mooring Force

The ratio which is transmitted wave height devided by incident wave height under the condition of A and with harbour is shown in Fig.7. The performance of almost floating breakwater is almost same. By the way, the maximum mooring force devided by wave exciting force against to wave period is shown in Fig.8. According to such results, this device has effective behavior as the floating breakwater.

Table 1 Condition of orifice

condition \ No. of air chamber	1	2	3	4	5	6	7	8	9
A	O	O	O	O	O	O	O	O	O
B	X	O	X	X	O	X	X	O	X
C	X	X	X	X	O	X	X	X	X

(O; open, X; close)

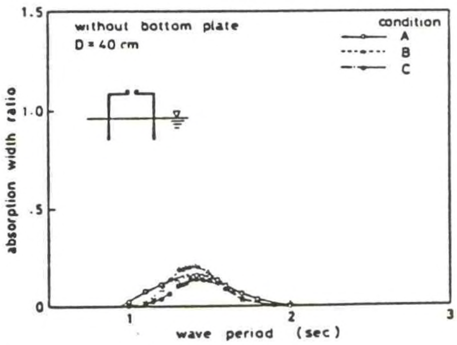

Fig.4 Wave Energy Absorption (1)

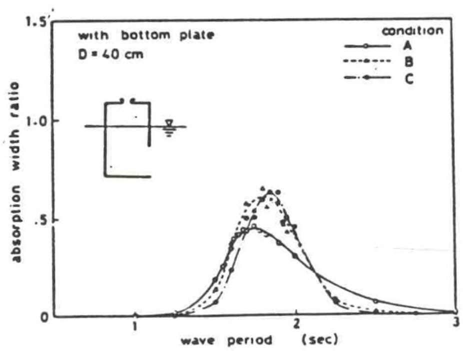

Fig.5 Wave Energy Absorption (2)

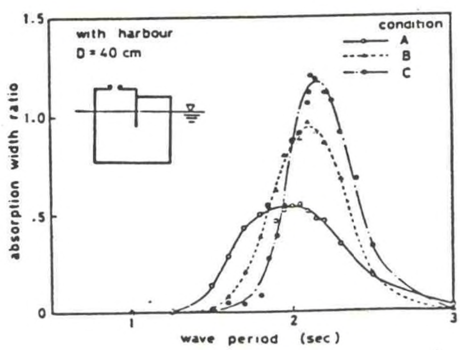

Fig.6 Wave Energy Absorption (3)

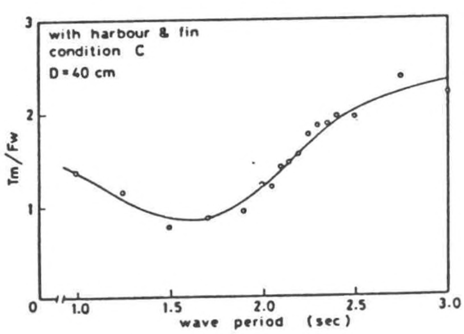

Fig.7 Maximum mooring force

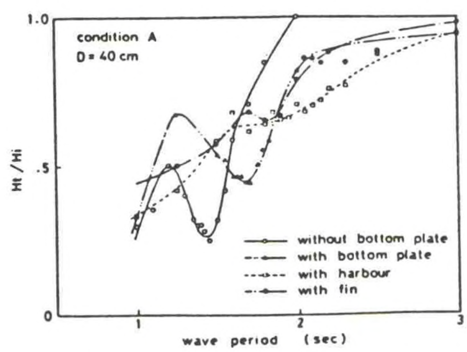

Fig. 8 Transmitted wave hight ratio

How the U.S. Coast Guard Improved Its Surface Effect Ship Fleet

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Abstract. This paper discusses the problems experienced with the Surface Effect Ships (SES's), including engine overloading, vibration, ride quality, seal wear, poor lift system performance, and metal cracking, along with the corrective actions taken to solve them. The cooperation between government and private industry, which made possible this significant turnaround in performance, is also explored. Lessons learned about SES technology are viewed in relation to the general experience of the USCG with other types of high-performance hull forms.

INTRODUCTION

By July 1983, the U.S. Coast Guard (USCG) had taken delivery of three136-ton, 110-foot, 30-knot plus aluminum hulled cutters known as Surface Effect Ships (SES's). Named Shearwater, Sea Hawk, and Petrel, these cutters were to be used primarily for drug interdiction in the southeastern United States.

A major renovation in late 1984 was done to correct problems found during the initial operations of these converted offshore crewboats. They performed well just after this renovation and then started a decline characterized by reduced speed of only about 20 knots in calm water and at light load. By mid-1985, all three vessels showed severe main engine wear, and operations were suspended to prevent catastrophic engine failures. The USCG joined with Detroit Diesel Allison and Textron Marine Systems to analyze what had gone wrong and to propose solutions.

By early 1986, after some of these solutions were implemented, Petrel and Shearwater were obtaining speeds in excess of 30 knots, with improved fuel usage and reduced maintenance requirements. Sea Hawk, however, was still slower than her sister ships, with a loaded top speed of about 20 knots in deep water. A malfunctioning lift system was suspected. After a survey, 16 changes were implemented. With the lift system modifications completed and a new set of lower pitch propellers installed, Sea Hawk hit a speed of 31.2 knots in low sea state three in deep water. As of June 1986, the entire fleet has been capable of speeds over 30 knots.

Below is a discussion of what we did to attain that high performance.

EARLY PROBLEMS

In the beginning, we found that the crew spaces were noisy, the engine rooms sooty and oily with clogging of the intercoolers on the 1600 HP Detroit Diesel main engines. There were also local cracking problems around the lift fans and aft ballast tanks. Modifications done in late 1984 were to help correct these problems.

Noise. This was reduced by eliminating port and starboard engine room accesses from the living space on the second deck and by installing additional soundproofing on the forward engine room bulkhead. New accesses to the forward machinery space were cut in the port and starboard fidley houses that were part of the exhaust stack addition.

Sooty Engine Room. The exhaust gases recirculating from the through-hull side exhaust ports back into the engine room air supply were thought to cause the sooty and oily condition in the engine room as well as the carbon fouling of the main engine intercoolers. The initial attempt to solve this problem

This paper is a shortened version of a report, appearing in the Naval Engineers Journal in May 1988 and entitled, "The History of Performance Improvements Aboard the Coast Guard's Fleet of Surface Effect Ships" by Gary Larimer, USCG R&D; CWO Joe McCollum, USCG SES Division Key West; Benton Schaub, Maritime Dynamics; CDR Donald Van Liew, USCG R&D; and Charles Whipple, Textron Marine Systems.

involved the weighty addition of exhaust stacks, however, this proved not to be the solution. Later, exhaust leaks and crankcase emissions into the engine room were found to be the actual cause of the dirt, fouling, and loss of power to the engines.

Structural Cracking. Cracking of the structural aluminum near the lift fans was due to several factors: 1) the fans were connected to the hard-mounted lift fan engines with relatively inflexible couplings; 2) failure of the lift fan pillow block bearings due to ingestion of sea water; and 3) lift fan imbalance caused by the loss of balance weights. These all created severe vibrations, and thus, cracking. The initial attempt was to shore up the structural support of the fan pillow block bearings and the plate structure under the fans, and then, mount the lift engines on springs. This reduced air flow to the fans and created excessive lift fan engine movement that caused failure of the alignment-sensitive power take-offs, the flexible couplings, and the fan bearings. Additionally, the 136-ton boats now had a displacement of 150 tons.

Engine Wear. After the yard period, the performance of the SES's improved somewhat, but soon they began a downward slide. By February 1985, trials in deep water on Sea Hawk showed a top speed of only 23 knots and that the main engines were torque-limited. By June 1985, operations with all three vessels were suspended due to rapid engine wear and the possibility of main engine failure. Although not a direct factor in the suspension of operations, cracking problems, due to misaligned or out-of-balance lift fans, still persisted.

MODIFICATIONS/RENOVATIONS

Main Engine Upgrade/Modifications. From June to December 1985, we contracted with Detroit Diesel for an upgrade of the 1600 HP 16V149TI engines to 1800 HP 16V149TIB. This meant installing blower by-pass mechanisms, new pistons that decreased the compression ratio from 16:1 to 15:1, larger injectors, and new turbochargers with greater output pressures and air flow capacities.

The net result was 200 more HP available at the engine output shaft. Of this, approximately 120 HP resulted from the elimination of parasitic blower losses at the higher rpm's (the blower is needed only at lower rpm's to help scavenge exhaust gases from the two-cycle engine). Eighty HP was gained from the increased turbocharger output pressure and air flow capacity, the decreased depression ratio, and the increased fuel flow.

During this modification, we discovered that where the exhaust pipes joined the main pipes, the pipes were not cut off at the surface of the main pipe, but extended inward until they almost touched face to face. This had been creating excessive back pressure and caused much of the accelerated engine wear.

Lift Fan Drive System. Next, we installed torsionally flexible "Vulkan" drive couplings and U-joint drive shafts. This gave smooth power transmission to the lift fans and allowed for slight misalignments, or hull flexing. Before this change, we had spent $39 K and over 1,700 man-hours annually repairing power take offs and wafer-disc couplings. After two years of use with the new installation, a total of only $3 K and 16 man-hours have been used for repairs.

Before this modification, alignment of the lift fans with the fan bellmouths was accomplished in part by shimming the bellmouths out from the volute walls. This created air gaps through which high-pressure air inside the volute could short-circuit back to the fan inlet. Improper bellmouth position also adversely affected an important running fit between the bellmouth and the center of the fan rotor, creating a large loss in fan efficiency. Proper alignment and removal of the shim spacers to close the gap saved a lot of air leakage. In-pace dynamic balancing of the lift fans prevented further fan vibration.

Automatic Bearing Lubricators. "Electro- lubes," devices that continuously feed a small amount of lubricant to the bearings, were installed. They continuously push out bearing wear material, such as chrome flakes, and lubricate the bearing seals, making them more efficient in keeping out contamination. Upon cooling, the bearings actually draw in more grease rather than sea water, giving added protection. The payoff was a repair cost to bearings over two years of only $800 and 32 man-hours, rather than the previous $15 K and 1,350 man-hours of repair of lift fan bearings and $4.5 K and over 200 man-hours of repair of main propulsion shaft bearings. The cost to maintain new lube devices for all three vessels for a year was minimal, at $6 K and 24 man-hours.

We now have a lube oil analysis program that identifies potential problem areas in the engines before significant damage occurs.

Crankcase Emission Collection. Winslow crankcase emission filter coalescers were installed above the main engines to collect vapors from the crankcase vents, condense the lube oil in these vapors, and return the oil to the crankcase. This reduced the oily film problem and has saved about $1,150 of oil per main diesel per 180 days of underway time.

Fuel Oil Coolers. Hot fuel created more power losses; we had been averaging 145-147° F after periods of full power. This caused a loss of approximately one percent per 10-degree rise in temperature that equalled a loss of 99 HP per diesel. Fuel oil coolers were installed on the main and lift fan engines that lowered fuel oil temperatures to between 95 and 100 degrees farenheit.

Engine Room Air Ducts. To cool the high (145 degree farenheit) engine room temperature, ductwork was installed to put incoming air over the main engine air inlets. We regained 0.5 HP per cylinder for each 10-degree drop in temperature for a toatl of 44 HP per engine. The weather decks were painted white to reduce heat absorption from the sun. Now, the temperature over the main diesels average 105 to 110 degrees farenheit.

Correction of Exhaust Leaks. We discovered that the exhaust pipes had been misaligned during the stack modification in 1984. The resulting force fit cased strain on the turbo-charger casing and causing casing cracks, gasket ailures, and manifold cracking. This explained, in part, the reason for the sooty, oily engine room, and the intercooler clogging.

Lift System Improvements. Originally, we thought that increased weight on the SES fleet was the reason for the low speeds. Since no instrumentation was installed to indicate cushion or stern seal pressure and the tachometers for both the main and lift engines were unreliable, our realization of lift system problems was slower to come about. After a careful survey, we identified this problem area and made a list of corrective actions.

Lift Fan Inlet Air. When the stacks were added, they blocked off about 25 percent of the existing air intakes to the lift fans. Additionally, the upgraded lift fan bearing supports further blocked the air flow. Compounding this problem, several lockers were installed that blocked the free flow of air from the main deck into the intake screen. We moved the lockers, decreased the thickness of the expanded metal screen on the lift air inlet, and cut additional openings in the plenum chamber face and top edge to regain the area of air inlet that was lost when the stacks were installed. Now the lift fans can easily pull in adequate air.

Turning Vane Performance. We found that the turning vanes that send a portion of the lift air to the aft seals had been bent and the required 10 percent higher than cushion seal pressure was not present. Our solution was to mount turning vanes on a sliding tray-like device. By varying the position in the lift fan air flow, more or less high pressureair could be diverted to the aft seal until the right position of the vanes was determined. The tray with the vanes was then secured. The result was the seal inflating to its proper geometry.

Fan-Bellmouth Alignment. To reduce the rubbing noise between the fan bellmouth and the fan, the crew had bent the edges apart and had added shims for alignment that created further air gaps between the bellmouths and the fan volute walls. Reducing these gaps also lessened the loss of high pressure cushion air.

Fan Blades. The blades on the centrifugal fans were found to have blistered paint and large tar or grease deposits. These were cleaned up.

Aft Seal Improvements. A new seal trimming procedure was needed. The old way caused an improper fit, with wrinkles and creases that caused early wear on the seals and gaps in the seal-to-hull fit, wasting cushion air. The new trimming technique took into account the sloping sidewall of the SES so that at proper inflation, the seal was tight.

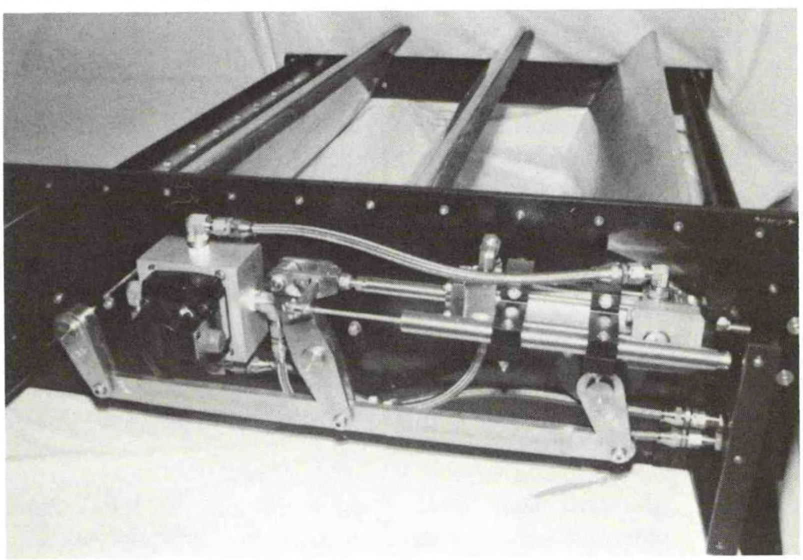
Propellers and Shafting. Prop and shafting problems are common on high performance craft. We experienced cracking near the blade roots of the original stainless steel Gawn-Burrill propellers. The were replaced with nickel-aluminum-bronze propellers with slightly reduced pitch with not further cracking problems but some blade root cavitation erosion reported. Inadequate heat treatment of some shaft welding caused failure of two shafts. Normal operations will eventually cause some shaft and propeller damage due to striking an object.We now change our propellers in the water by removing tail shafts with the propellers attached. Plugs are installed in the stuffing boxes to prevent water from entering. This change-out method eliminates the need for expensive drydocking.

Forward Seal Wear Weight Control. In 1985, seal maintenance and replacement costs were hurting us ($300K to $350 K yearly for three boats). While the aft seals were close to a service life of 2000 hours, the forward fingers were lasting only 568 hours out of a 1200-hour design life. By 1987, the figure dropped to $36 K per boat per year. The reason: weight reduction and relocation.

We moved the LCG further back aft so that the finger seals were no longer riding deep in the water instead of skimming the surface as they should. At proper ride, they should not be dragged backwards forming sharp bends in the fabric. These boats were originally designed as offshore crew/supply vessels with the deckhouse far forward leaving a large, flat cargo area aft with aft ballast tanks to control trim, based on the cargo carried. Since the Coast Guard used the boats with no cargo aft, the ballast tanks, filled to give proper trim, jsimply added more weight to the boats so that they resonated with the propellers causing cracking.

By relocating as much weight aft as possible, less ballast is needed and the boats became lighter. Some specific examples of weight reduction include storage shelves and deck gratings removed from the forward damage control area, oil bath air filters on both lift fan diesels replaced with Farr paper element filters (900-lb. reduction). The original cast bronze hayward raw water strainers on the lift engines and generator sets were replaced with GROCO strainers (800-lb. reduction). We found that many small savings in weight can quickly add up to better vessel performance.

Ride Control System. One of the solvable problems with the SES technology is that when the boat is on cushion, heave motion damping is minimal and excitation of the air cushion by passing waves causes the SES to bounce at its natural frequency of two Hertz. This bounce is also in the human fatigue range, and thus, makes it uncomfortable and tiring for the crew. We were able to correct this problem through a contract and design with Maritime Dynamics, Inc., for a



Ride control system vent valve module.

ride control system to be put on Sea Hawk. The system involves a microprocessor-based digital controller located on the bridge, two vent valve assemblies housed in two four-foot high "dog houses" located in the port and starboard engine rooms on the forward engine room bulkhead. Its hydraulic system is driven off the starboard lift engine. The controller senses cushion pressure and supplies a command signal to the hydraulic servo valves that open and close the shutters on the vent valves. The vented cushion air is dumped dirctly into the low pressure side of the lift fan compartment where it is recirculated to the cushion through the lift fans. With our new ride control system turned on, we recorded reductions in RMS measurements of heave acceleration of 70 percent (0.17 g's RMS to 0.07 g's).

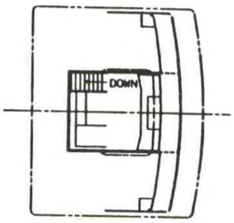
CONCLUSION

During the first five years of operation, our SES's revealed many of the "bugs" that historically plague new high-performance craft - regardless of hull type. Exhaust misalignments, propeller cavitation problems, localized metal cracking, vibration, weight increase, and maintenance plagued high performance craft long before the advent of SES's and will continue to do so for fture craft designs.

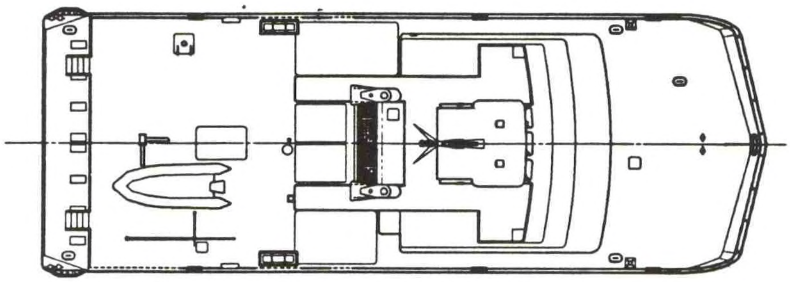
Today, all three SES's are capable of at least 30 knots in calm water with power to spare, and with RPM-limited main diesels, fuel consumption is down, speed is up, and maintenance costs are reduced. The ride control system makes the SES more comfortable to ride.

In the realm of fuel savings, the modification of lower pitch propellers, lift system improvements, cleaner engine rooms, cooler fuel and engine inlet air, and better operating trim had a marked effect on fuel consumption. We went from a top speed of 20 to 23 knots in calm water, burning 220-240 gph, to now easily running at 30 knots in calm water, burning only 180-185 gallons per hour. (Equivalent monohull designs burn 350 gph at 30 knots.) The difference in fuel costs now pays for the seals with an additional $300 K left over.

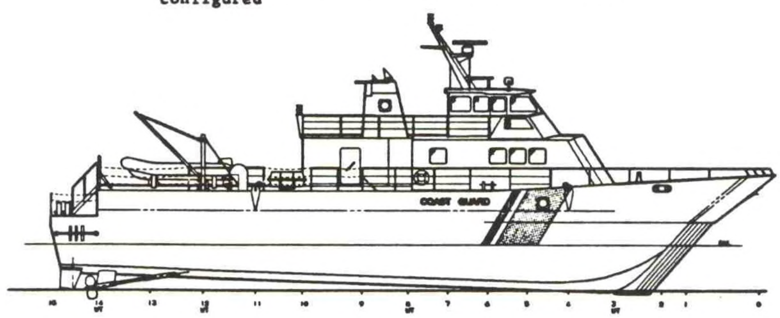
In many cases, the current SES's exceed their original design specifications. In the future, the addition of the Coast Guard's recently developed "Larimer and Van Liew Pre-Swirl Vanes and Twisted Propeller" could increase top speed by another 10 percent and further reduce fuel consumption by 15-20 percent. New modified designs built specifically for patrol boat duties could fine tune the benefits of this unique hull design even more.

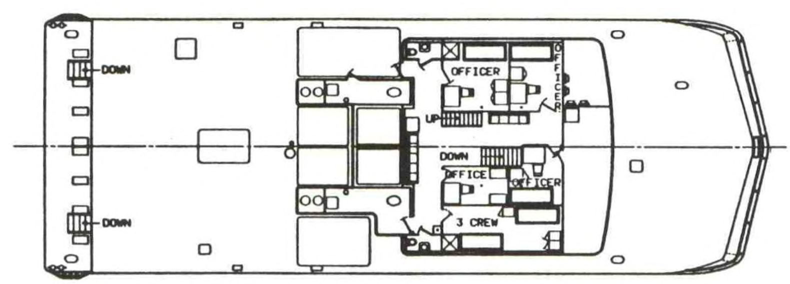


01 LEVEL - WHEELHOUSE

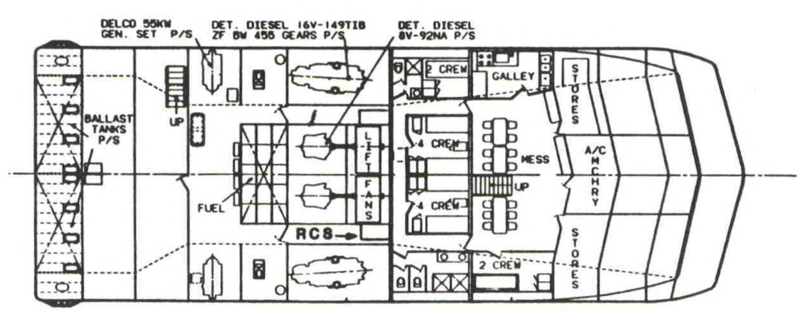


Profile and plan view of the WSES as currently configured



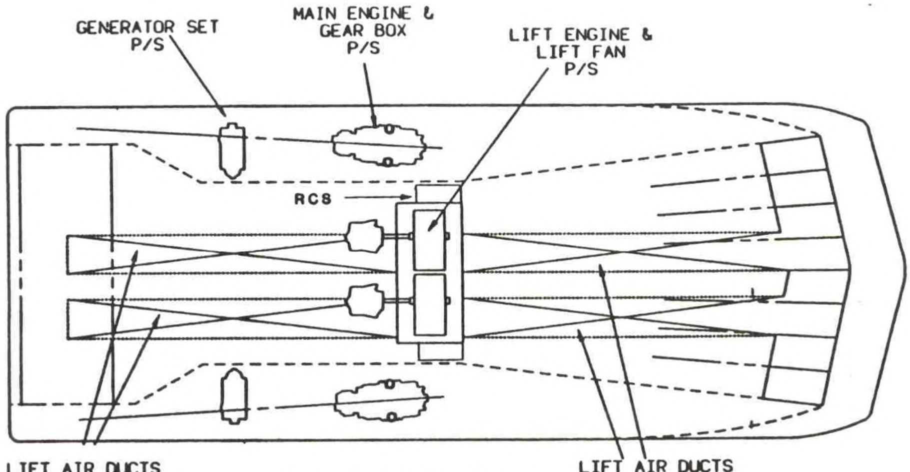


MAIN DECK LEVEL

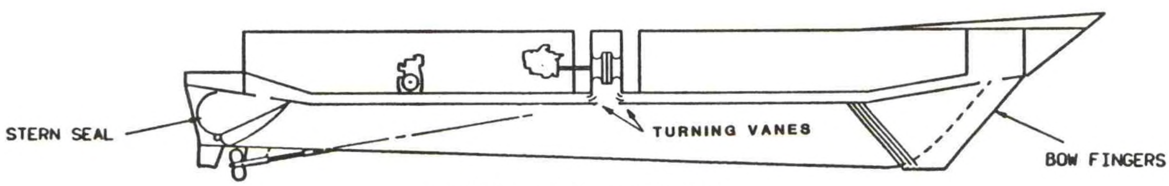


SECOND DECK LEVEL

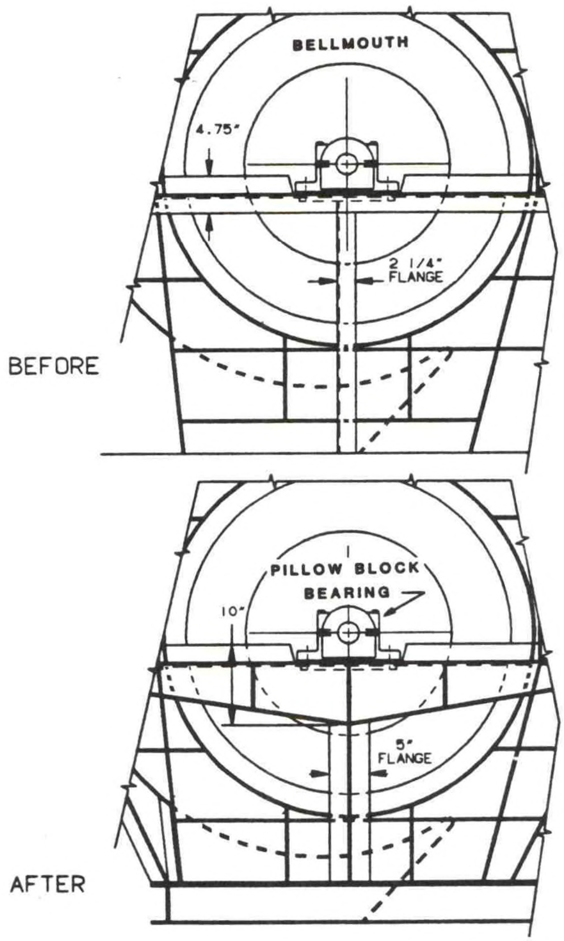
Current arrangement of the WSES



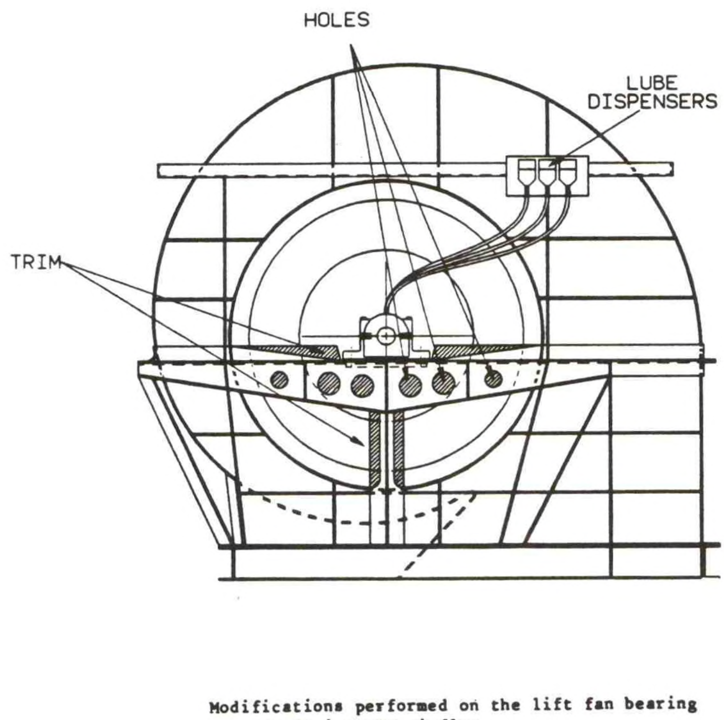
SECOND DECK PLAN



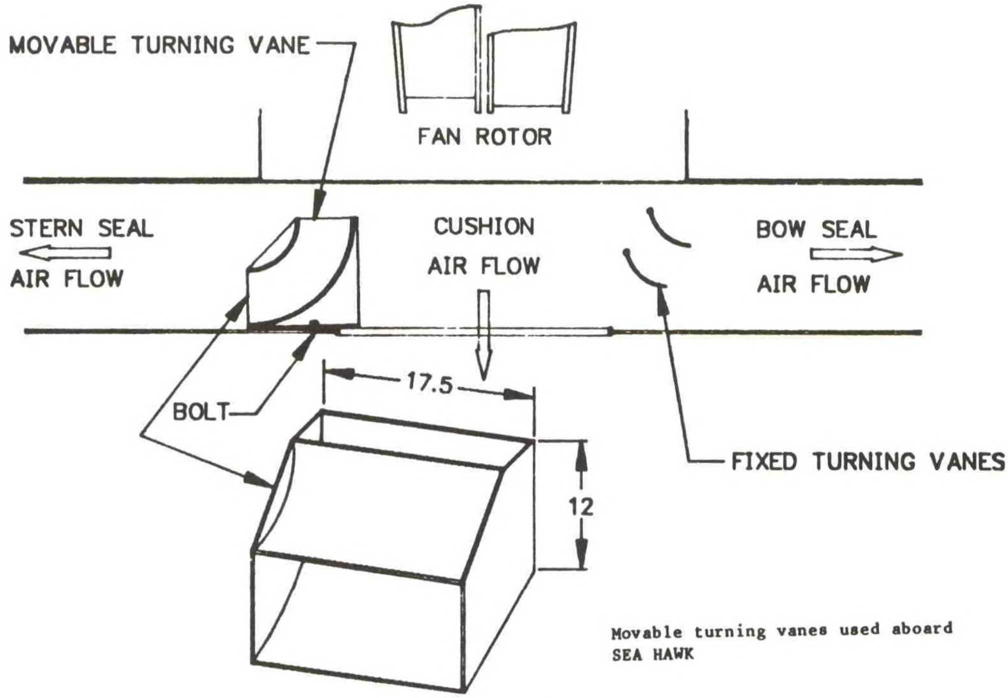
CENTERLINE PROFILE



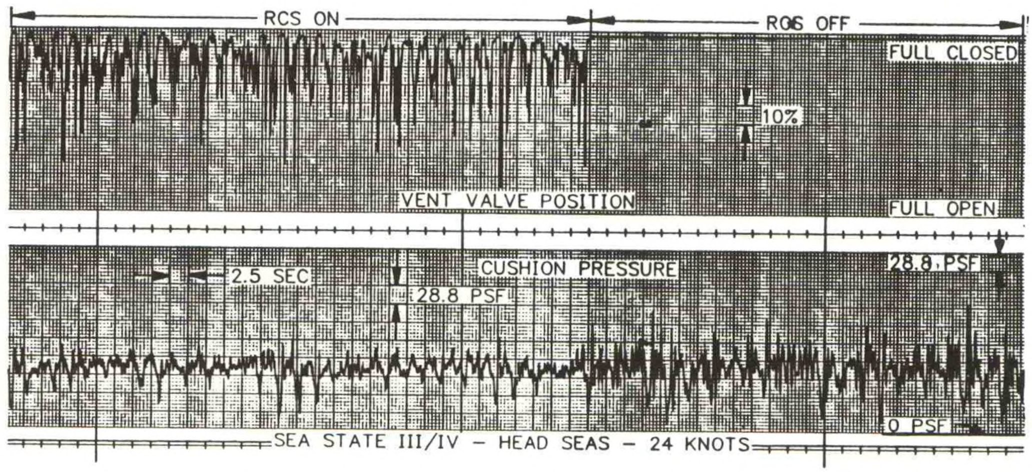
Fan bearing support structure, before and after yard period in late 1984



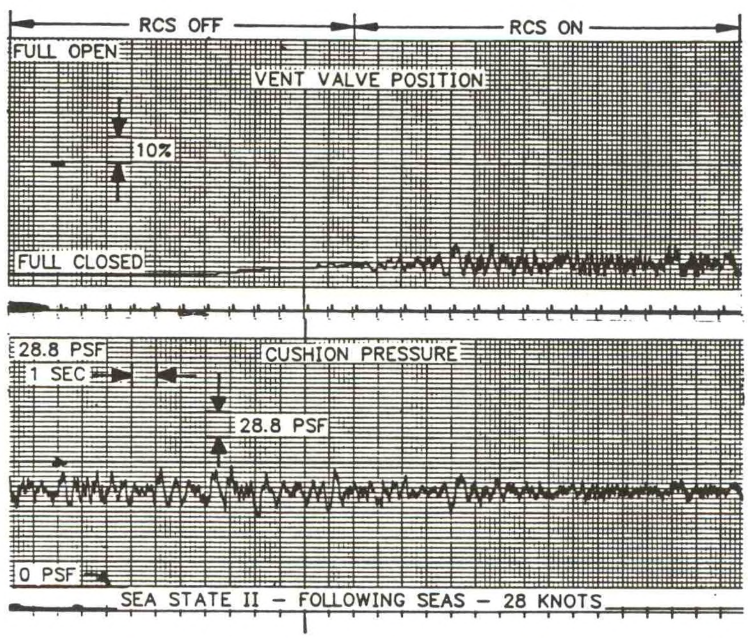
Modifications performed on the lift fan bearing support to improve airflow



Movable turning vanes used aboard SEA HAWK



RCS stripchart readings on board SEA HAWK, 4 to 6 foot head seas



RCS stripchart readings on board SEA HAWK, 1 to 2 foot chop

ADVANCES IN HANDLING VEHICLES AT SEA

Howard R. Talkington

Naval Ocean Systems Center, San Diego, California

INTRODUCTION

Handling undersea vehicles at sea has been a challenge every since we started to operate with them. A modified back hoe was used for early operations off San Clemente Island with Cousteau's Sous Coupe and the Deep Star 4000 (Figure 1). Large cranes with constant tensioning systems launched and recovered the Turtle and Sea Cliff and the RUWS vehicles. Large over the stern "A" frames have been used for a number of craft; notably the Shinkai 2000 and Alvin (Figure 2). However, these all require rather large craft to provide the necessary stability.

This paper will discuss some techniques developed to allow operations by smaller support craft and for special purpose systems. The need for handling mine countermeasure devices has required equipment that is built of low magnetic material and able to withstand high shock, but still provide rapid launch and retrieval and cable positioning.

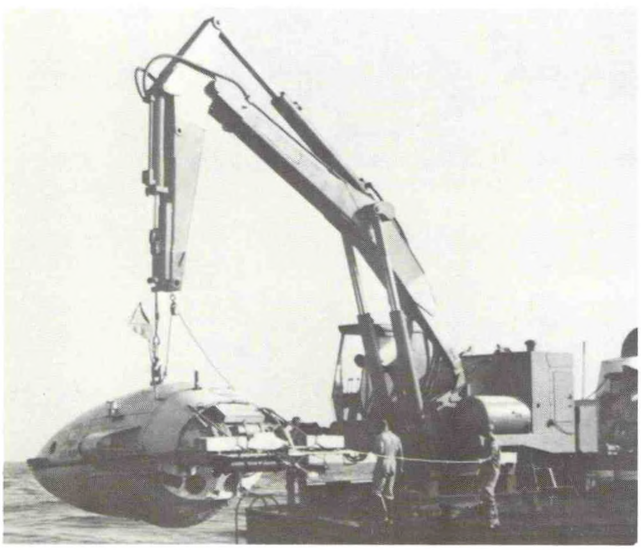


Figure 1. Deep Star 4000 on Back Hoe

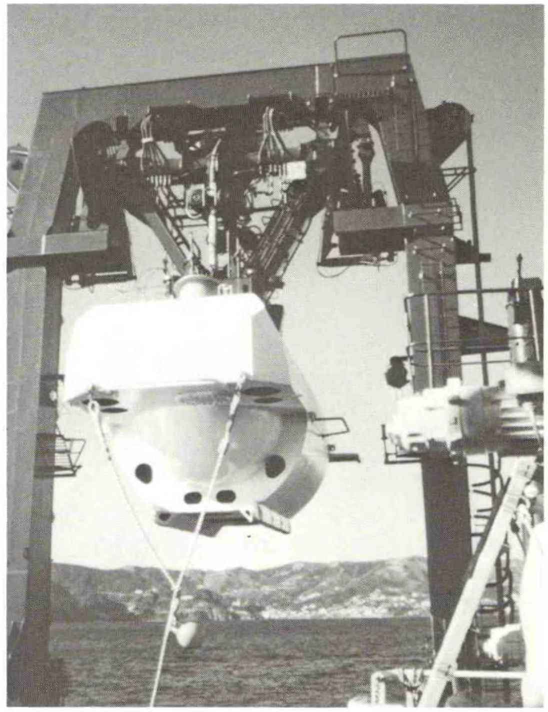


Figure 2. Shinkai 2000 on 'A' Frame

Advanced Undersea Search System

A system that could operate from small craft of opportunity was desired for the Advanced Undersea Search System (AUSS). This handling system would be used during the experimental, development, and operational phases of the program. Different craft would be used for varying periods of each phase of the program. The AUSS vehicle is an Autonomous Undersea Vehicle (AUV). Since there is no umbilical cable or other lifting eyes or slings, a special method of handling is required. AUSS launch and recovery are accomplished by means of a tiltable ramp deployed off the fantail of the support ship (Figure 3). To launch, the vehicle is rolled, from carts, into the ramp which rests horizontally on deck. As the ramp is rolled aft, by a hydraulically powered mechanism, it tilts into the water as the ramp center-of-gravity passes beyond tilt rollers. Upon release from the ramp, the vehicle slides down the ramp into the water and its propulsion is activated. Retrieval reverses the process. Upon surfacing, the vehicle automatically deploys a flashing light, radio beacon, and nose float with an attached retrieval line. The support ship steams into position and deploys the ramp. The retrieval line is grappled and the vehicle is pulled up the ramp. Restraints, in the form of air-inflated hoses on the inside walls of the ramp, are used to hold the vehicle in place. Once the vehicle is restrained, the ramp is pulled forward and allowed to tilt to the horizontal. The vehicle may then be released from the ramp and moved onto maintenance carts.

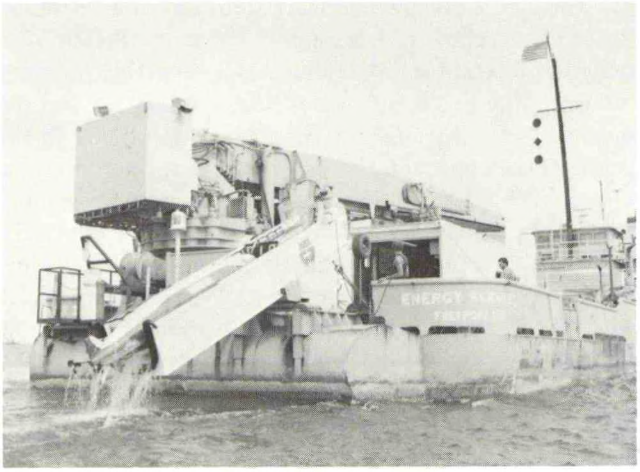


Figure 3. AUSS in Ramp

Mine Neutralization Vehicle System

The mission of the AN/SLQ-48 Mine Neutralization System (MNS) is to neutralize underwater mines through the use of a tethered submersible vehicle. It uses a somewhat unique handling system to deploy the remotely controlled mine neutralization submersible vehicle. The handling system consists of two main units, a Vehicle Handling System (VHS) for deploying the vehicle and an Umbilical Cable Handling System (UCHS) for storing the vehicle's umbilical cable. The VHS is a "burtoning" type crane (Figure 4).

The VHS consists of the shock-mounted stowage stand; the saddle which attaches to the top of the vehicle for launch and recovery; three lines to burton the saddle and vehicle overboard; and the booms and winches to operate the lines. By controlling the winches, the VHS operator can lift the vehicle from the stand, place it in the water, and release it using the pneumatically operated release mechanism.

During recovery, docking of the vehicle to the saddle takes place at a depth of 3 to 10 feet under water. Subsurface docking decreases the effects of wind and waves during the docking maneuver. The control console operator flies the vehicle into the saddle. Then, the VHS operator latches the vehicle and operates the winches to haul the vehicle on board. At no time are divers required to deploy or to recover the vehicle.

The VHS consists of outrigger booms, winches, boom stays, boom rests, boom rest stays, and hoisting lines. There are two outriggers: one forward and one aft of the vehicle storage area. The center boom feeds the unbilical cable from the Umbilical Cable Handling System (UCHS), over the overboarding sheave, and through the saddle to the vehicle. The saddle is an aluminum frame surmounted by a cast aluminum fairlead for the unbilical cable, and four pneumatically operated latches that lock the vehicle to the saddle.

The Umbilical Cable Handling System (UCHS) stores 3,500 feet of umbilical cable on an electro-hydraulically driven drum. Because of the constant tension feature, there is essentially no possibility of dragging the cable on the bottom, or of knotting it. The cable when stowed on its drum is cooled with a salt water spray.

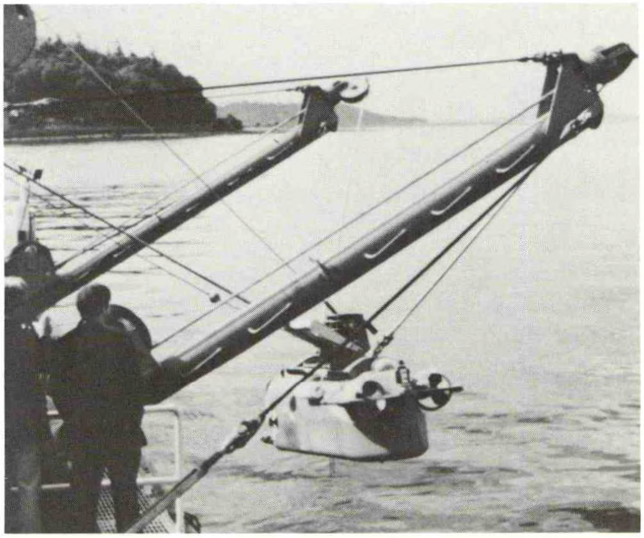


Figure 4. MNS & Burtening System

Multipurpose Crane (MPC)

The Mine Neutralization System (MNS) was originally developed for the Navy's new Mine Countermeasurers (MCM) Ship. To handle the other mine neutralization and sweeping equipment on the ship, two stern cranes are used. With the development of the Navy's new Mine Hunter Craft (MHC) which is smaller and designed for harbor and coastal MCM missions, the number of equipment handling systems had to be reduced due to size and weight considerations. The Naval Ocean Systems Center (NAVOCEANSYSCEN) proposed that a single Multi-purpose Crane (MPC) be used on the MHC which could handle the MNS vehicle and any of the other equipment. The MPC must meet all military specifications including shock, vibration, electro-magnetic interference and also be non-magnetic.

To solve the complexity of launch and recovery of the vehicle with this Single boom non-magnetic hydraulic crane, a special handling system had to be developed (Figure 5). The system included a saddle which interfaced with the vehicle and would lift it out of the water, a snubber which would mate with the saddle at the tip of the crane, a high response winch and the associated electronic control system. The winch has the capability to follow the motion of the vehicle in the synchronous mode and it can also enter a constant tension mode when attached to the vehicle to reduce the effect of high cable tensions or "snap-loading" on the system. Results of the at-sea testing have shown that the MPC has met its design goals.

Figure 5. MNS & MPC

Launch and Recovery Platform (LARP)

Launch and retrieval operations can be made significantly simpler and less hazardous if the relative motion between the submersible and the launch platform can be reduced or eliminated. One way this can be accomplished is by devising means for placing the launch and retrieval platform under water so that the submersible can be launched or retrieved beneath the turbulent water-air interface. There 20 to 100 feet below the sea surface, both the submersible and platform are subject to the same steadying forces and are away from the surface waves, making the launch or retrieval operations much less hazardous.

The Launch and Retrieval Platform (LARP) is a 35-by 18-foot towed catamaran designed to provide a stabilized platform for underwater launching and retrieval of submersibles. This system is based on the original work proven by demonstrations with the LRT at the Makai Range (Figure 6).

The platform can be submerged to its normal operating depth of 65 feet by surface support divers or remotely via a tethered power cable. LARP can be positioned in a hovering mode, at any depth between the surface and 200 feet, by means of buoyancy-ballast compartments located in the center of each pontoon. Other sections of the pontoons are utilized as ballast or buoyancy tanks during lowering and raising operations. Buoyancy blocks, mounted above the pontoons, provide added stability during the active penetration of the air-sea interface and while the vehicle is under tow. Twelve high-pressure air flasks are mounted below the buoyancy blocks and supply the necessary air for deballasting.

The vehicle can be disassembled in one day for fly-away operations and reassembled on site in 48 hours. It was initially designed to handle Makakai and other submersibles providing their displacement does not exceed 10 tons. With a hull displacement of 50,000 pounds, a design depth of 200 feet, and a deck area of 420 square feet, the LARP is useful for a wide variety of research and development tasks.

Figure 6. LARP

Helicopter Transport

An interesting technique was innovated in the early 1970's. For operations near shore, a helicopter was used to transport a submersible from the shore support area to the dive site (Figure 7). The operators were transported separately, due to the safety aspects of helicopter carried loads.

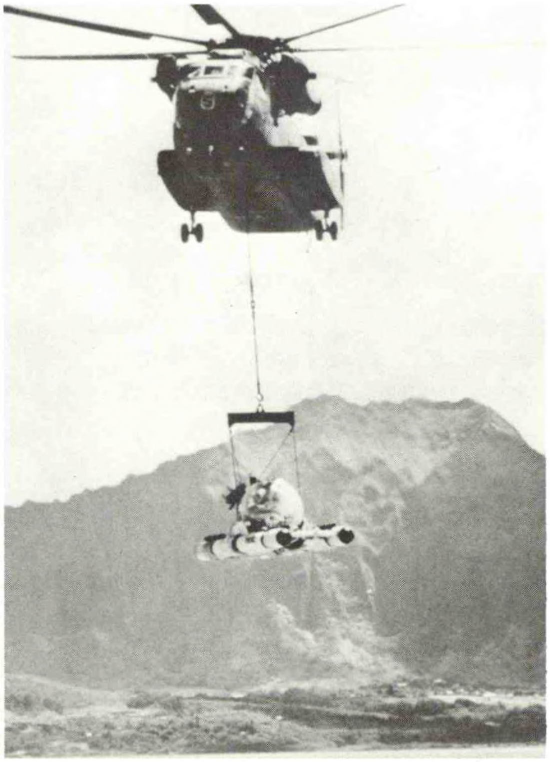


Figure 7. Makakai with Helicopter

DUMAND Detector Array

A particularly difficult problem has been the deployment to 4000m depths of the 200m long Vertical Detector Array for Project DUMAND (Deep Underwater Muon and Neutrino Detector). The array consists of two tension cables about one meter apart supporting seven very large (38cm dia.) photomultiplier tubes, electronic controllers and processing equipment, calibration light sources, and environmental measuring instruments; all connected by fiber optic data transmission cables. The array has been developed into a robust assembly that protects the many fragile components. Since the system is designed to detect the very faint light from cosmic neutrino and muon induced cherenkov emissions, the string must be stabilized in the water column to deter stimulation of bio-luminescent background. The triple task for the handling system was (1) deep depth, (2) fragile equipment, (3) critical stability.

The solution for handling the DUMAND array for sea experiments was to use the SWATH Ship, SSP Kaimalino (Figure 8), to provide maximum surface stability, along with a "ram tensioner," and a double block 'A' frame over the well at the center of minimum motion. This combination provided a reliable means to deploy the array a multitude of times to various depths including four times to 4000m. The system worked well and very good scientific data was obtained that has proven valuable to the DUMAND Program. A video tape showing the operation is available, and will be shown at the meeting of the panel.

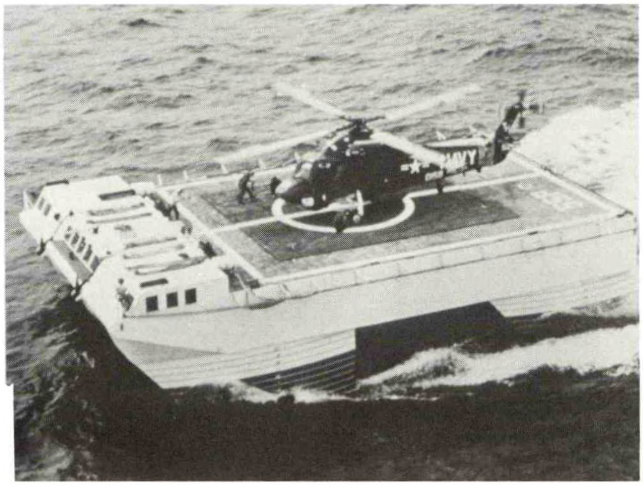


Figure 8. SSP KAIMALINO

Submersible Underwater Docking Concept

Ships or floating platforms with center wells allow handling through their center of motion and thereby greatly reduce the forces due to pitch and roll; but the heave characteristic prevails. An idea for the future is a concept that would defeat the heave forces and provide a platform lowered to reasonably shallow depths to effectively stay at rest with the water column. The vehicle may then swim up to the platform and dock without fearing the support ship induced high relative motions of the docking apparatus. The keys to holding the platform constant relative to the water column are a set of horizontal louvers that, when open, give little vertical drag, and couple the underwater platform to the support craft; and when closed, provide high drag, and couple the underwater platform to the water column (Figure 9). A set of four hydraulic cylinders, one on each corner attached to the four supporting cables, provide constant tensioning of the lift lines in both modes of operation. The patent provides the following description:

A launch and recovery system for submersible vehicles operating from a surface support station includes a platform configured to pass through a well in the support station and descend below the surface of the water and is supported by four cables attached to the corners thereof. Provision is made for docking and launching the submersible vehicle on the upper or lower surface of the platform. Hydraulic tensioning devices couple each of the supporting lines to the platform and, together with controllable louvers, isolate the launch and recovery platform from movements induced by the sea state acting upon the surface support station. The platform is carried by the surface vessel and is lowered through the center well to a point beneath the surface of the water. The platform has docking and mooring provisions on an upper or lower surface thereof for the submersible vehicle and a trapeze structure carried so as to cooperate with the submersible vehicle in launch and recovery operations to assist in its successful docking on the platform. The platform is stabilized in its underwater position by means of controllable louvers which alter the effective flat plate area thereof and hydraulic line attachment means which prevent variations in line tension caused by sea state action on the surface vessel from being transferred to the platform.

While this concept has only been demonstrated in model tests, it is presented in the hopes that it will provide some stimulus for non-classical solutions to the problems associated with handling undersea vehicles at sea.

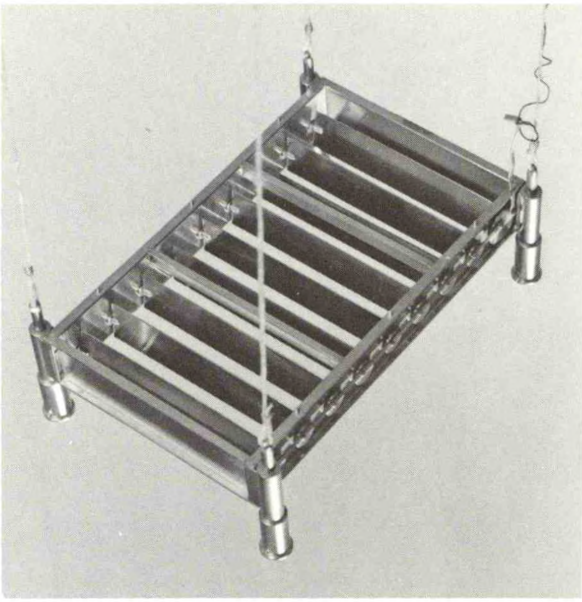


Figure 9. Submersible Underwater Docking Concept (Modes)

Underwater Navigation Supporting System
for 6500m Deep Research Submersible

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Abstract

The manufacturing of an Underwater Navigation Supporting System for a 6500m Deep Research Submersible for JAMSTEC is now proceeding.

This system will be installed on board the Surface Support Ship.

The system is provided with two functions, one is a preliminary geographic investigation of a sea which is carried out from sea surface prior to a research by the manned submersible. The other is a navigation supporting for the submersible during its submergence through which monitoring its position, guiding its underwater activity, providing mutual communication are performed.

This system consists of a Surface Hibrid Navigation System, Automatic Radar Plotting Aid, Underwater Acoustic Navigation System, Underwater Telephone System, Multi-narrow Beam Echo Sounding System, XBT and Total Control and Display System etc. The latest acoustic/electronic technologies have been applied to each equipment so as to meet the requirements of increased service range in proportion to the diving depth of the submersible.

Especially, an advanced SSBL/LBL navigation with a planar array hydrophone, an advanced underwater telephone equipped with beam steering have been adopted.

To perform capability of this system fully, extreme cares to be paid to the installation of the system on board the support ship. For example, each Transducer can be protruded below the ship's keel to avoid acoustic interference by the ship's hull.

In addition, special measures have been taken so as to reduce underwater noises radiated from the surface support ship.

This system is scheduled to be completed in 1988, and installed on board the surface support ship which will be delivered in 1990.

Introduction

Kawasaki Heavy Industries, Ltd. (KHI) received an order from JAMSTEC the manufacturing of one set of the Underwater Navigation Supporting System for the 6500m deep research submersible (named as "SHINKAI 6500") followed by new building of the Research Vessel (named as "YOKOSUKA") which will be also used as a surface support ship for the "SHINKAI 6500" They are now manufacturing at KHI facilities.

In 1981, KHI delivered a real Surface Support Ship "NATSUSHIMA" for submersible for JAMSTEC first in Japan.

It is expected that the "YOKOSUKA" will be the latest high-performance Research Vessel ever built in the world, provided with advanced and improved equipments based upon KHI's abundant experience and accumulated precious knowhows.

The R/V "YOKOSUKA" is to be equipped with the following submergence supporting subsystems which are useful for the support of activities of the submergence of "SHINKAI 6500".

(1) Launch and retrieval system

(2) Underwater Navigation Supporting System.

(3) Replenishment (re-charging batteries, etc.) and maintenance system

In this paper, the outline of the Underwater Navigation Supporting System in item (2) above, as well as the performances and features of the major equipments together with the installation on board R/V "YOKOSUKA" are described.

DESCRIPTION OF THE SYSTEM

The Underwater Navigation Supporting System has two outstanding features.

One is a preliminary environmental and topographical investigation of a sea which is carried out from sea surface prior to a submergence research by a manned submersible.

The other is a navigation supporting for the submersible which is performed during its submergence research activities.

By that preliminary investigation, various data of interested sea area such as water depth, bottom topography, and vertical profile of water temperature are to be obtained on board.

From those data, following items (1) - (4) are find out and are utilized not only for the planning of support ship's coming navigation but also for the planning of safe and effective submergence research activity by the submersible.

(1) The sea bottom target with its position which is the object of the submergence research activity by the submersible.

(2) Characteristics and position of particular research targets which can be a guide for the underwater behavior and activities of the submersible.

(3) Position of the obstacles and/or dangerous topography which may interfere with the research activities by the submersible in the near or above of the sea bottom.

(4) Predicted acoustic ray propagation chart to get optimum position relationship between the support ship and the submersible, for realizing the best condition of available performance of the acoustic equipment.

The function of supporting the submergence of the submersible has been so designed that they can provide the useful information as listed below, by obtaining most of the informations throughout the period of submergence.

(1) The accurate absolution position of the surface support ship (LONG, LAT), as well as the relative position of the submersible with the surface support ship can be obtained.
By combining these information, the absolute position of the submersible can be determined, through which adequate information including proper instructions (for example; bottoming position of the submersible) can be given from the surface support ship to the submersible in accordance with the predetermined submergence research plan.

(2) Acoustic positional reference points are to be set up on the sea bottom, thereby the correct position of the surface support ship and of the submersible in relation with the reference points can be measured accurately on board.
Then the surface support ship can provide proper guidance for the submersible with highly reproducible position information to the reference points.

These reference points can be also utilized for LBL navigation equipment on board the submersible.

(3) The motions of other ships located adjacent to the surface support ship (such as position course speed) can be analyzed simultaneously the surface support ship can continuously track the location of the submersible.

By super-imposing these surface information on underwater one, the surface support ship can issue anti-collision supporting information to the submersible to ensure safety during the surfacing of the submersible.

(4) Mutual communication means between the surface support ship and the submersible can be provided.

(5) The surface support ship can continuously record and store navigation tracing of the submersible during the underwater research activity.

Then the stored record can be provided as repeatable information as required from time to time.

Furthermore, to utilize this system efficiently, the system can integrate and centralize information obtained from component equipment.

To materialize these functions, the system configuration has been constructed as shown in Fig-1.

The system is composed of an Underwater tracking and locating group, Surface/Underwater communication group, Bottom topographic research group, Ocean environment research group, Surface positioning group, and Surface ship motion analyzer group.
This system has the following improvements in comparison with that on the support ship "NATSUSHIMA":

(1) To enlarge the service range drastically with the increase of the diving depth of the submersible, the following measures have been newly introduced.
  ° Adoption of low frequency range (relatively low absorption loss) for acoustic equipments.
  ° Adoption of planar array transducer for sonars to secure high S/N ratio at the receiving point.

(2) The development and installation of the Multi-narrow Beam Echo Sounder in lieu of conventional PDR and side scan sonar to ensure underwater research efficiency and accuracy in the ocean topographical investigation.

(3) To enhance accuracy in surface positioning, the Hybrid Navigation System has been upgraded by newly applying advanced-type sensors and advanced data processing technique such as GPS/NAVSTAR, Loran-C ρ-ρ processing.

DESCRIPTION OF MAJOR SYSTEM COMPONENTS

1. Acoustic Navigation System

This system can provide underwater position locating functions combined with transponders which are preinstalled on the ocean floor.

The system can locate the positions of the surface support ship, submersible, transponders and towing objects (optional equipment in the future) on an earth fixed co-ordinate or a co-ordinate based on said transponders array.

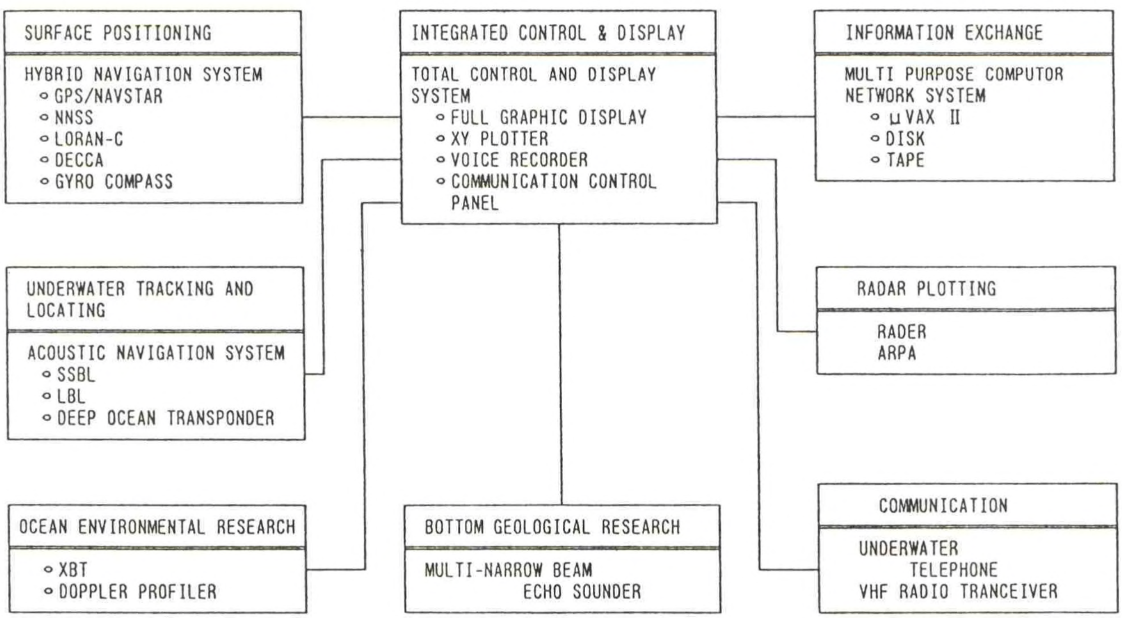

FIG.1 UNDERWATER NAVIGATION SUPPORTING SYSTEM FOR 6500m DEEP RESEARCH SUBMERSIBLE

The system also locates the relative position of the submersible, the transponders and towing object to the support ship.

Outstanding features of this system are as follows:
Principal particulars are shown in Table-1.

(1) Advanced SSBL has been used together with advanced LBL for underwater position location. Advanced SSBL system using 16-element planar hydrophone array has been applied in lieu of conventional type to detect various acoustic reply signals with high S/N ratio.
This advanced SSBL has been developed by KHI and applied to "NATSUSHIMA" successfully. Subsequently such systems have been installed several ships with favorable reputation.

Low frequency version SSBL receiver has been newly developed for "YOKOSUKA".
(In this connection, the size of the hydrophone array has been increased to 900 mm in diameter)

In LBL measurement, the S/N ratio has been drastically enhanced by using the slant range information obtained from the Multi-channel SSBL receivers without using the conventional-type single transducer receiver.

(2) Firstly in Japan, a synchronous pinger has been introduced to the submersible which is used for position locating by the support ship.
(Suitable type has been developed by KHI)

Sonic pulse signal, which precisely synchronized with the high-accurate time standard in Underwater Navigation System on the surface support ship, is issued from the pinger.
Then the above sonic pulse signals are received by the SSBL receiver installedon the surface support ship through which the submersible position relative to the support ship can be determined.
This means that the positional measurement can be conducted accurately and successfully regardless of any noise radiated from the submersible.

Transmitting signal frequency of the pinger is set to be able to interrogate the transponders on the ocean floor, therefore LBL navigation on board the submersible is possible.

(3) KHI has also developed a recoverable-type intelligent deep sea Transponder which is used at max. 11000m in depth. That is, the transponder is applicable to any ocean world.
In developing the Transponder, to compensate the decrease of data rate caused by the increase of range, improvements have been made by introducing multi-frequency reply function.
Furthermore, the Transponder has been increased in capability by adding the Depth telemetering, and base-line measuring modes to the conventional active, inactive and release modes.

(4) The receiving channel has been specified as 8 CH + 2 CH (option).
All channels are processed out from the SSBL receiver, which will be able to meet the requirement for tracking of a very deep version ROV in the future.

(5) Three types of transponder array calibration method have been provided, first is newly developed direct calibration with base-line measuring mode of transponders.

Second is a quick calibration method using range and bearing data of SSBL receiver.

Third is a conventional LBL calibration method.

MODE	: SSBL, LBL
OBJECT TO LOCATE	: SUPPORT SHIP, SUBMESIBLE, TRANSPONDER, ROV (OPTION)
FREQUENCY	: SEE FIG.2
RECEIVER CHANNEL	: 6 CH +2 CH (OPTION)
HYDROPHONE	: 16 ELEMENT PLANAR ARRY

TABLE 1 PRINCIPAL PARTICULARS OF ACOUSTIC NAVIGATION SYSTEM

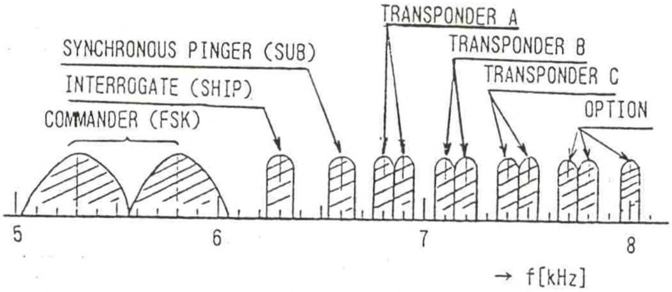

FIG. 2 FREQUENCY ALLOCATION FOR ANS

2. Underwater Telephone System

This system is useful for mutual communication between underwater telephones installed on the submersible and the surface support ship.

The communication is made either through vocal or keying signals.

The frequency and modulation type are fully compatible with UQC system (upper side band SSB modulation) which is used worldwide.

Outstanding features of the system are as shown below.
Principal particulars of the system are given in Table-2.

(1) To improve the S/N ratio, with the expansion of the service range, the beam steering system for both transmitting and receiving have been adopted first in Japan.
3 x 3 elements planar array transducer has been developed through which two kinds of directivity patterns (Wide/Narrow) have been prepared. Wide beam and one narrow beam are set in downward direction, another eight narrow beams are set in circumferential direction.

Suitable beams are selectable toward the relative direction of the submersible, and thus, efficient communication can be achieved.

in operation, the beam direction is selectable automatically or manually based on the submersible location information sent from the Acoustic Navigation System.

To facilitate the manual selection, a receiving signal level indicator of each beam is provided for operator's reference. (See Fig-3)

(2) Two sets of Transducer, Transmitter/Receiver and Controller are provided which are connected crosswisely, thereby optional combination is freely selectable.
This improves the reliability of the system.

(3) All the contents of mutual communication will be recorded on the magnetic tape cassette by the voice recorder provided in the Total Control and Display System.

CARRIER FREQ.	:	8.0875 kHz
AUDIO FREQ.	:	0.5~3 kHz
SIDE TONE FREQ.	:	712 Hz
BEAM WIDTH	:	WIDE:46°, NARROW:32°
SOURCE LEVEL	:	108 dB re μbar at 1 m

TABLE 2 PRINCIPAL PARTICULARS OF UNDER WATER TELEPHONE

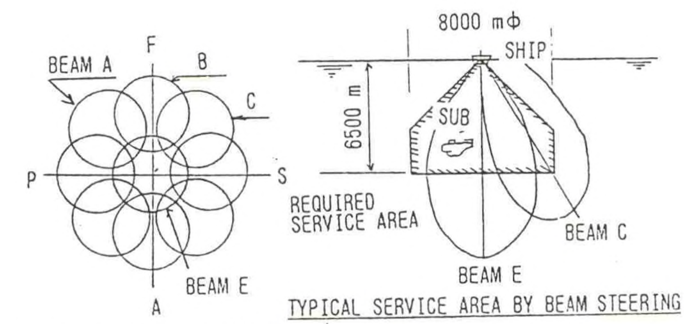

FIG. 3 PREFORMED NARROW BEAM PLAN VIEW

3. Multi-Narrow Beam Echo Sounder

This is a cross fan beam type sonar which can detect and survey the sea bottom topography and the water depth from the ocean surface.
This extremely deep sea type has been newly developed first in Japan.

Outstanding features of the sonar are as shown below.
Principal particular of the sonar are given in Table-3.

(1) To enhance the searching capability, the search beam width has been set to 2° and 45 pieces of preformed beams have been adopted, by which only through one time transmission, 45 pieces of depth data are obtainable within the range of ± 45° downward. (See Fig-4)

(2) To enhance the efficiency of topographical surveillance operation, the following figures are prepared and selectively displayed on the color display monitor:

1 True/relative motion contour map

2 3-dimensional view of bottom topography

3 Longitudinal section view of water depth (any one of 45 directions)

4 Athwart section view of water depth

5 Raw sonar video, etc.

(3) The depth data thus obtained are plotted as a real time contour chart on the X-Y plotter.
Further, the data are logged on the magnetic tape together with other data such as position and sonar parameter.

(4) To utilize the material and equipment fully, the X-Y plotter and the vertical reference unit are used common with the Acoustic Navigation System.
The contour plotting and data logging are performed by general-purpose computer system.

FREQ.	:	12 kHz
DEPTH RANGE	:	50 m~11000 m
DEPTH RESOLUTION	:	1 m
SOURCE LEVEL	:	≥130 dB re μbar at 1 m
RECEIVE BEAM WIDTH	:	2° × 20°
TRANSDUCER	:	HYDROPHONE 64 ELEMENTS PROJECTOR 32 ELEMENTS

TABLE 3 PRINCIPAL PARTICULARS OF MNBES

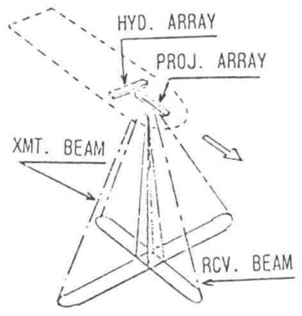

FIG. 4 PRINCIPLE OF CROSS FAN BEAM

4. Surface information equipments

4.1 Hybrid navigation system

The latest version of navigation sensor GPS/NAVSTAR, NNSS, Loran-Cs, DECCA, gyro compass, and Doppler Profiler are adopted and each data obtained is automatically processed by a general-purpose computer system by which, the present location of the ship can be determined accurately and continuously.

As a second function of this hybrid navigation system, a Route Tracking capability combined with the Steering system is provided.

4.2 ARPA - Automatic Radar Plotting Aid

Based on the information obtained from two sets of radar, the movement of ships adjacent to the surface support ship (range, bearing, course, velocity, CPA, TCPA, etc.) can be analyzed by the ARPA.

The data obtained from ARPA are transmitted to the Total Control and Display System, where the movement of ships together with the under water information is displayed on the color display system.

5. Total Control and Display System

This is a digital processing full graphic CRT display system.

In this system, various kinds of surface/underwater information are integrated and centrally displayed on the CRT screen 7 segment displays, lamps thereby the surface support ship and submersible are conducted successfully.

Major displaying items:

Graphic support ship/submersible position display pattern
° Earth fixed plan view
° Support ship centered plan view
° Submersible centered plan view
° Submersible centered plan view (with superimposed surface information)
° Vertical section view
Calculated underwater sound ray path display pattern

Various status information
° Equipment status (power on/off, ready etc.)
° Transducer (protruding/retracting position, etc.)

Major controlling items

VHF radio/Underwater telephone remote operation and voice recording

Acoustic Navigation System remote operation with character display and keyboard

Multi-purpose graphic display operation

Fitting on R/V "YOKOSUKA"

Principal particulars of the "YOKOSUKA" are shown in Table-4.

The Acoustic Transducers of this system should be installed at locations which are separated from other equipments and are low in underwater radiation noise from the support ship. (refer to Fig-5)

Projector and hydrophone array provided in the Acoustic Navigation System are to be mounted at the end of the hydraulic powered retracting device. During the service, the array is to be protrude up to 2 m below the keel of the surface support ship. The array is so designed as to be retracted in the ship's hull when it is not in use.

Two transducers of the underwater telephone system are to be installed in the acoustic dome which is mounted on the hydraulic powered retracting device.

During the service, the dome is to be protrude up to ab. 1 m below the keel pf the support ship.
The dome is so designed as to be retracted in the ship's hull when it is not in use.

The transducers of the multi-narrow beam echo sounding system are installed in a recessed location of the bottom where acoustically harmful air-bubbles are seldom observed. This recessed location is filled with fresh water.

Various electronic components for the transmitter/receiver, signal processor and other devices are provided in the air-conditioned central control room and/or electronics equipment room adjacent to the steering house.

Major patterns displayed on the CRT screen in the Total Control and Display System is transmitted to the remote display monitors provided in the fore wheel house, aft wheel house and laboratory for operator's convenience.

The Central Control Room is designed as a commanding center of the underwater navigation investigation.

LENGTH (LPP)	: 95 m
BREADTH (MLD)	: 16 m
DEPTH (MLD)	: 7.3 m
DRAUGHT	: 4.5 m
GROSS TONNAGE	: APPROX. 4500 tons
CRUISING SPEED	: APPROX. 16 kt

TABLE 4 PRINCIPAL PARTICULARS OF R/V "YOKOSUKA"

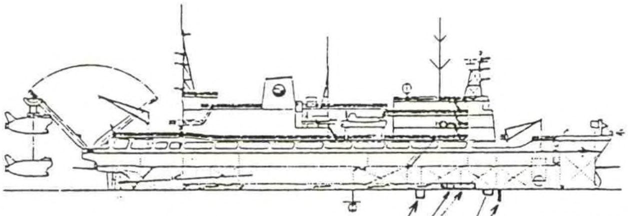

FIG. 5 TRANSDUCER ARRANGEMENT

Underwater Radiation Noise Reducing Measures

To exert the performance of the Underwater Acoustic System fully, it is necessary not only to improve the equipments as mentioned above, but also to reduce the underwater radiation noise from the surface support ship.

In the past, a thorough noise reduction measure was taken on the surface support ship "NATUSHIMA" which materialize a "Quiet" ship.

This time, however, the decrease of underwater radiation noise level is aimed by the factors of 10 dB below the target noise level of "NATSUSHIMA". (See Fig-6)

Generally various types of noises are radiated from a ship.
Typical examples are shown in Fig-7.

Among them, structure-borne noise caused by the vibration of the main engine and auxiliary machinery, as well as directly radiated noise from the propellers should be treated with extreme care. For this purpose, a new underwater noise prediction method using S.E.A method for the processing the structure-borne noise has been established so as to take various noise suppression measures.

For example, main generators are supported by double vibration-isolation devices, and low noise main engines with vibration isolators are adopted, as well as the engine room is provided with air-borne noise insulation wall and bulkhead.

As for propeller concerned noise, generally propeller radiated noise is strongly connected with the occurrence of the propeller cavitation.
To reduce possibly the occurrence of the propeller cavitation at relatively slow speed operation of the support ship, new propeller has been designed in consideration of following items.

(1) Improvement of wake distribution at the propeller

(2) Adoption of improved propeller geometry with high skew, tip-unloaded pitch distribution and etc.

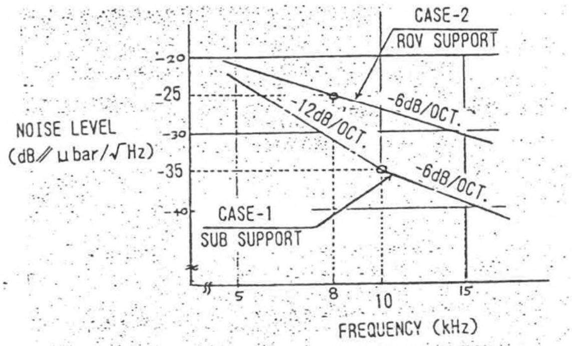

FIG. 6 ALLOWABLE UPPER LIMIT OF RADIATED NOISE

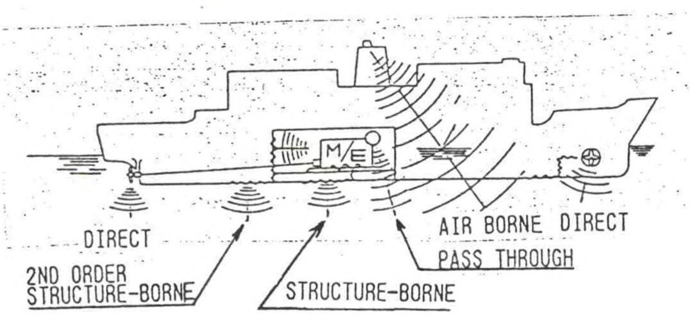

FIG. 7 VARIOUS NOISE RADIATION ROUTES

(3) Adoption of optimum combination of the propeller pitch angle and the number of revolution.

Cavitation test using scaled model propellers have been conducted at the cavitation tunnel of Tokyo University and full scale propeller radiated noise of the support ship has been predicted.

Conclusion

We have described for the Underwater Navigation Supporting System of "SHINKAI 6500" and its installation on board "YOKOSUKA".

At present, each component system is being manufactured at Vendors facility. The installation stage at our facility is scheduled for around the middle of this year (in 1988) after conducting the overall preinstallation system performance test at KHI factory.

Upon completion of the installation at the beginning of 1989 extremely careful tests will be repeated until October, 1989, including the authorized combined overall test with "SHINKAI 6500".

Then in the beginning of 1990, the system is scheduled to be delivered to JAMSTEC.

We hope that this system will exert its performances fully and can make a great contribution to the ocean investigation and ocean development domestically and worldwidely.

We will make every possible effort to complete the system successfully.

DEEP SEA ROV " MARCAS-2500 " FOR CABLE MAINTENANCE AND REPAIR WORKS

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Meguro R& D Center
Kokusai Denshin Denwa Co., Ltd.
Meguro, Tokyo

Sango Tokunaga
Ship& Ocean Engineering Division
Mitsubishi Heavy Industries, Ltd.
Chiyoda, Tokyo

MARCAS-2500 is a newly developed tethered ROV, which assists construction, maintenance and repair works of submarine telecommunication cables in the depth of up to 2500 meters, and has been used in the construction project of a new international optical fiber submarine cable system.

SYSTEM DESIGN REQUIREMENT

System requirements for the design of MARCAS-2500 have been considered as follows.

(1) Maximum operating depth : 2500m
The statistics of cable troubles and the future techniques for construction and maintenance were taken into account.

(2) Maximum operational sea state : 5

(3) Current condition : 4 kn at surface
Current profile is assumed on the basis of past data at the regions where submarine cables were installed.

(4) Tasks :
- a) Inspection of installed submarine cables
- b) Measurement of the burial depth of cables
- c) Burial and reburial of cables
- d) Removal of obstacles such as fishing gears and anchors
- e) Determination of faulty point of buried cables
- f) Cutting of cables
- g) Assistance in cable recovery work
- h) Investigation of the seabottom

(5) Mobilization:
Land transportation of all equipment is possible without special permit or method. The system can be installed and operated on a small boat (like a work or tug boat) which is temporarily employed.

CONFIGURATION OF THE SYSTEM

MARCAS-2500 system consists of following major eguipments shown in Figurel
(1) Vehicle
(2) Operation hut and power hut
(3) Tether cable
(4) Tether cable handling system
(5) Launch and recovery system

Figure 2 is a picture of the vehicle and Figure 3 shows the configuration of the vehicle and its optional equipments. Table 1 is the specification of MARCAS-2500 vehicle.

The tether cable for MARCAS-2500 is optical fiber and power line composite type cable, which includes three optical fibers and two kinds of electric power lines as shown in Figure 4. Table 2 shows the specification of the tether cable.

Tether cable handling system consists of an overboard sheave, a traction winch, a cable storage drum, an accumulation sheave, and a hydraulic power package.

In MARCAS-2500 system, the vehicle has an acoustic transmitter, which acts as a responder in SSBL mode, and two acoustic recievers that are acoustic marker locators. On the basis of SBL technique, measurement of time difference between the two recievers presents the transponder position from the vehicle.

The PID control technique is employed in the automatic control of altitude, heading and depth of the vehicle.

Sensor data, that is, altitude, heading, depth, angular acceleration are sent to the surface computer that calculates proper voltages for controlling servo valves of thrusters.

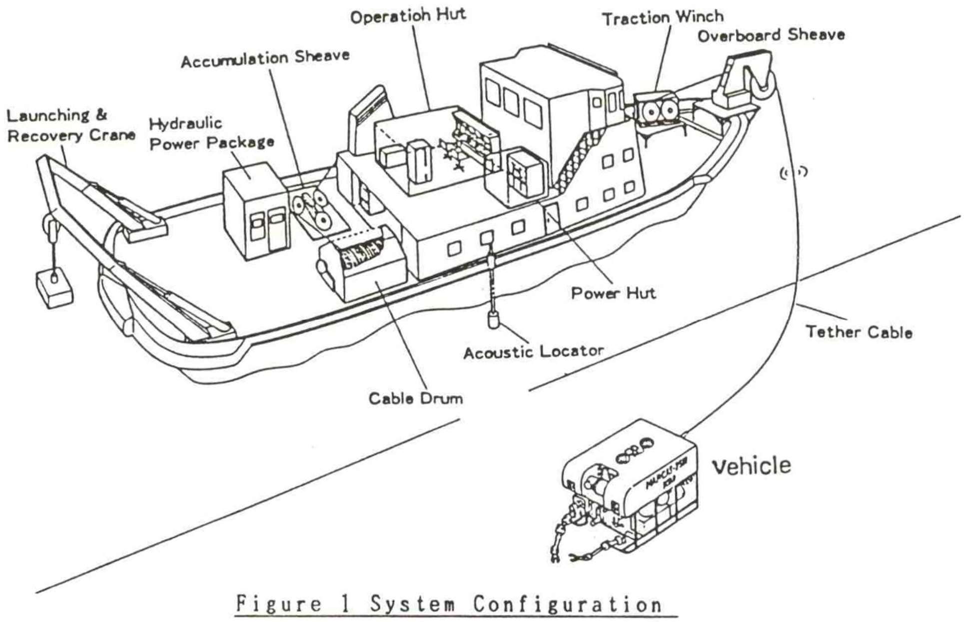


Figure 1 System Configuration

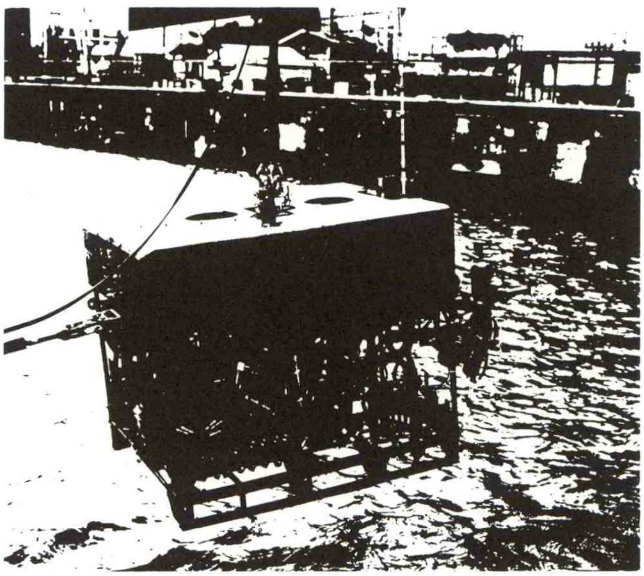


Figure 2 Photo of MARCAS 2500

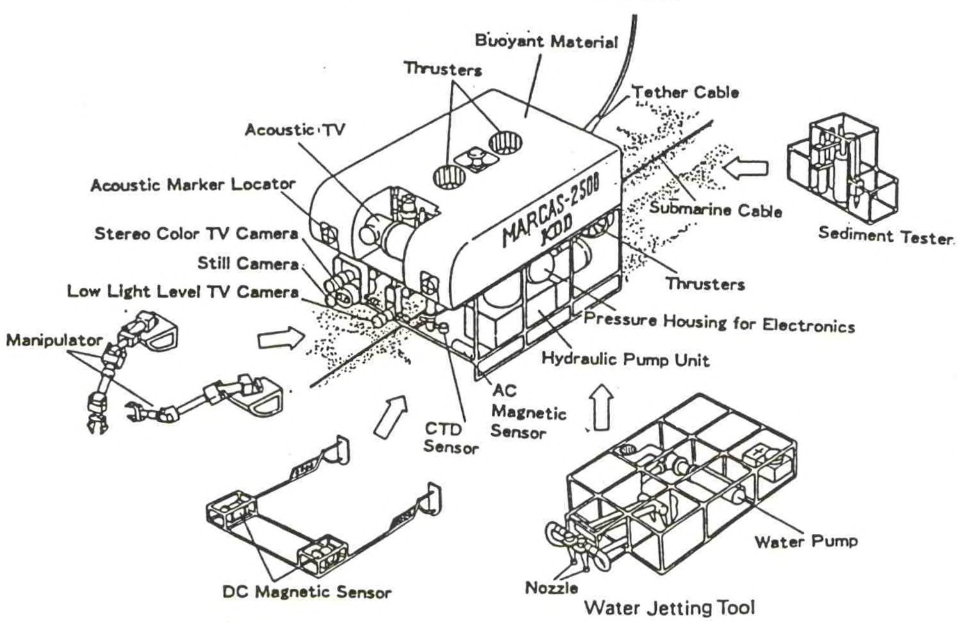


Figure 3 Vehicle Configuration

FEATURES OF MARCAS-2500

MARCAS-2500 has following features.

(1) The world deepest dive capability among ROVs for submarine cable work.

(2) Great flexibility of application by equipping its optional equipments; Manipulators, water jetting tool, DC magnetic sensor and sediment tester.

(3) Adoption of Optical fiber links in order to transmit video signals and high speed data with high quality.

(4) Good maneuverability obtained by controlling six thruster independently and autpilot; heading, attitude and depth.

(5) Adoptability of a small work boat (some hundreds gross tonnage) for mother vessel of MARCAS-2500.

And MARCAS-2500 has the following characteristic functions.

(1) Visual inspection of the seabed and cables by four TV cameras, including a stereo color TV camera

(2) Determination of the seabottom profile and obstacle avoidance by a new acoustic TV

(3) Location and tracking of cables by two types (AC and DC) of magnetic sensors

(4) Burial and reburial of cables by a water jetting tool.

(5) Measurement of sediment hardness and soil sampling by a sediment tester.

(6) Removal of obstacle, cutting of cables and assistance in cable recovery work by two manipulators and tools.

CONCLUSION

MARCAS-2500 underwent the sea trial conducted twice in spring and autumn of 1987. The vehicle successfully dived to 2370 meters depth and the test results were satisfactory.

After the sea trials MARCAS-2500 has gone into service and carried out the burial work of the Transpacific Submarine Cable (TPC-3)

Which is a new optical fiber system. Total diving time of practical use exceeds 200 hours.

Teble 1 MARCAS-2500 specification

Operating depth
  2500m
Dimensions (L × W × H)
  2.65× 1.80× 1.90m
Weight
  3.6tf in air/-20kgf in water
Structure
  titanium open frame
Pressure Housing
  titanium alloy
Buoyant Material
  Syntactic foam
Power requirements
  2250V, 3-phase, 50kw
    for electro-hydraulic unit
  1000V, single-phase, 2kw
    for electronics
Propulsion
  Six hydraulic thrusters
    two for forward-aft (12PS each)
    two for lateral (5PS each)
    two for vertical (7PS each)
Instrumentation
  LLL TV camera on pan& tilt
    Stereo color TV camera on pan & tilt
  B & W cameras on pan & tilt
  B & W cameras
  Still camera on pan & tilt
  Four floodlights
  Two AC magnetic sensors
  Acoustic TV on tilt
  Acoustic maker locator
  Altimeter, Gyrocomass & Magnetic compass
  Attitude sensor, Hydrophone, CTD sensor
  Responder for positioning
Hydraulic-pressure sensor
  Oil temperature sensor, Pinger releaser
(optionally)
  Two Manipulators (7F-Master sleve Type and 5F-Joystick)
  Water jetting tool,
  Two DC magntic sensors
  Sedimeut tester

Table 2 Specification of the Tether Cable

Diameter
  28mm
Weight in water
  314kgf/km
Cable length
  3500m
Breaking strength
  greater than 10tf
Power line
 3-phase line
  resistance: 2.5ohm/km
  reted voltage : 2500V
 single-phase line
  resistance: 9ohm/km
  rated voltage : 1200V
  coaxial type
Optical fiber
  three graded index fibers
Tension member
  Kevlar 49

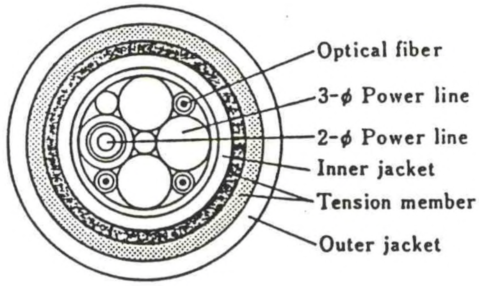


Figure 4

Cross-section of Tether Cable

Operation of MURS-300 MKII

I.Mutoh

Mitui Ocean Development & Engineering Co., Ltd.

1. FORWARD

We introduced the ROV MURS-300 MKII at 13th UJNR MFP in 1985, showing the first trial test at waterdam site.
We would introduce herewith its operation results after that.
The commercial operations were carried out mainly for the inspection of waterdam for electric generation. The operation results were highly evaluated comparing with conventional divers' inspection works, especially by the following advantages.
(1) Inspection time is shorter.
(2) Inspection cost is cheaper.
(3) Real time analysis of video by technical experts on land is possible.
(4) Wider range of operating environment (such as very cold water condition in winter)
(5) Unlimited operational duration.

2. 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.

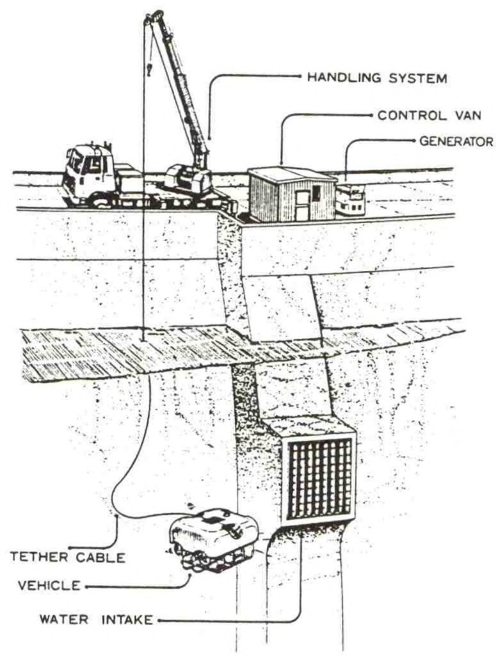


Fig-1 SYSTEM CONFIGURATION

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)

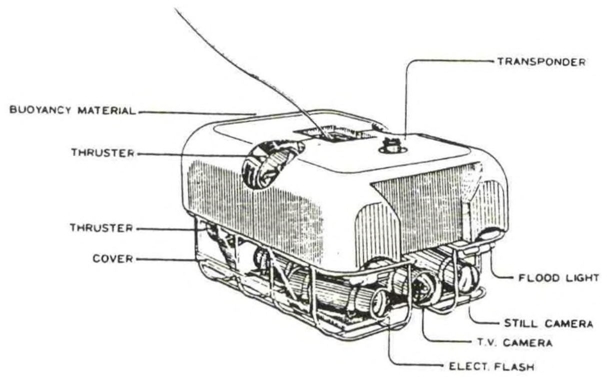


Fig.2 VEHICLE

Type : Open frame
Size : 950mm(L) x 750mm(B) x 600 mm(H)
Weight in Air : abt. 200kg
Maximum Speed : 1.8 kts (ahead)
Payload : abt. 40 kgs
Thruster : 4-300W electric DC brushless motor
(2 sets for forward and aft)
(2 sets for lateral and verical)
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)

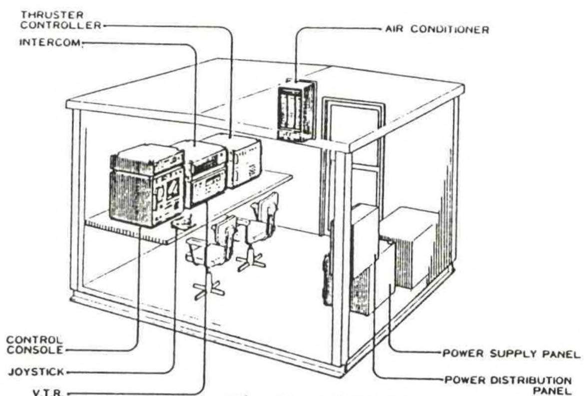


Fig.3 CONTROL VAN

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)

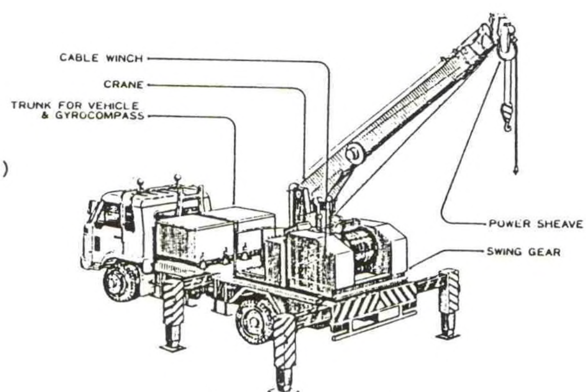


Fig.4 HANDLING SYSTEM

Truck Size : 7.9m(L) x 2.2m(W) x 2.93m(H)
Weight : abt. 8,000 kgs
Equipment : 1) Crane 300 kgs x 15m
2) Cable winch & power sheave
3) Tethercable 17.5 o x 600m
4) Gyro compass

3. OPERATION RESULTS

The operation results are shown in the following table.

No.	Date	Site	Water Depth(m)	Diving Time(hr)	Operation/ Inspection objects	No of inspe- cted dams
1.	'84 Dec.	Nagano Pref.	68	5	Home test	
2	'85 Jun.	Okayama Pref.	5	40	Do.	
3.	'85 Aug.	Nagano Pref.	68	10	Inspection of water intake & outlet screen	1
4.	'85 Nov.	Gumma Pref.	max.80	40	Inspection of water intake & outlet gate	5
5.	'85 Nov.	Nagano Pref.	max.70	25	Do.	4
6.	'85 Dec.	Tochigi Pref.	max.52	5	Inspection of water intake & outlet	2
7.	'86 Mar.	Tokyo	3	15	Performance test	
8.	'86 Mar.	Nagano Pref.	12	8	Inspection of apron crest of dam	2
9.	'86 Nov.	Nagano Pref.	max.135	40	Inspection of water intake pass, outlet mouth, penstock, screen	3
10.	'87 Apr.	Nagano Pref.	30	6	Water intake	1
11.	'87 Oct.	Gumma Pref.	max.100	19	Water intake penstock	2
12.	'87 Oct.	Nagano Pref.	max.90	21	Water intake	3

Note: Number of inspected dams shows the number of inspected dams at onetime mobilization.

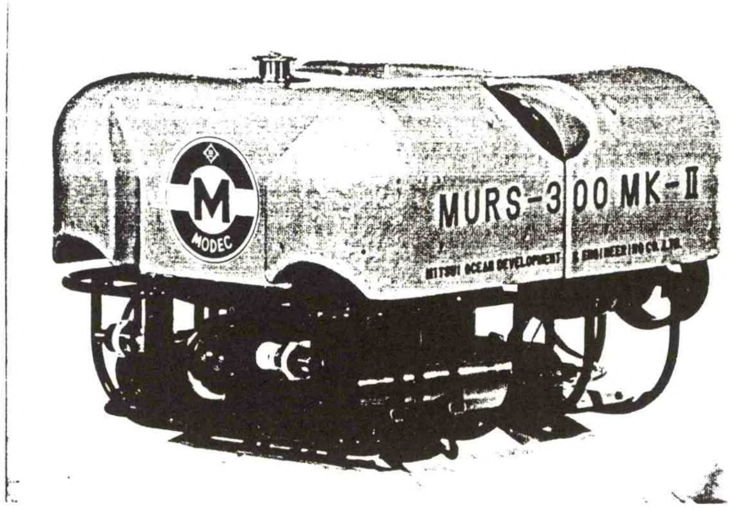


Photo-1 Vehicle

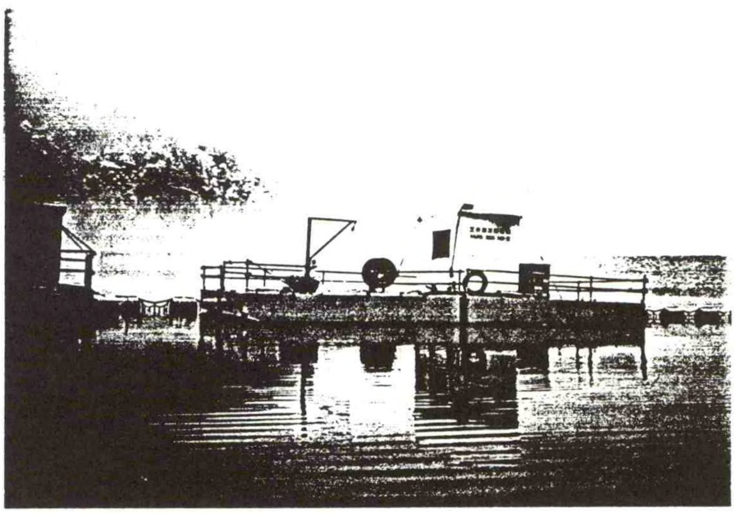


Photo-2 Control van on the pontoon

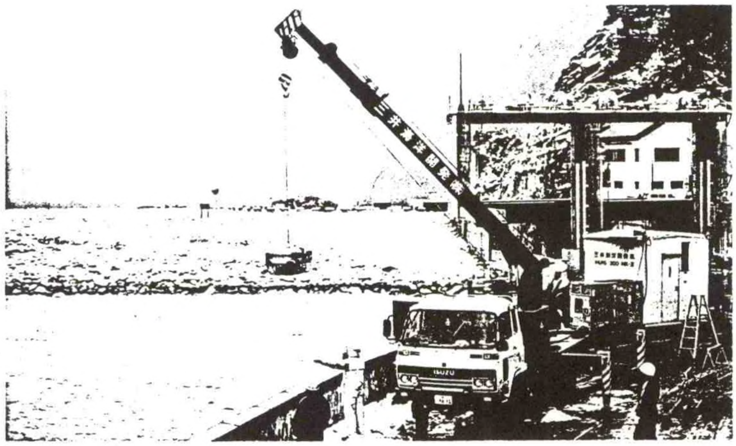


Photo-3 Operation of MURS-300 MKII

UNDERWATER SURVEY SYSTEM "HORNET 500"

Yuuichi Tomita

Sumitomo Heavy Industries, Ltd.

1. Introduction

Underwater survey system Hornet 500 (Hereinafter called simply as Hornet 500) is a tethered remotely operated vehicle developed by Japan Marine Science and Technology Center, with whom Sumitomo has an agreement to manufacture and to sell the system.

As the name implies, Hornet 500 is capable of monitoring continuously the sea bottom down to 500m.

The outline of Hornet 500 is hereby described.

2. General

Hornet 500 consists of a vehicle whose maximum diving depth is 500m, a control console which is to be placed on board, tether cables which link the vehicle and the control console, a cable drum, etc. The system configuration of Hornet 500 is shown on Fig.1. On Fig.1, the control console is subdivided into a monitor TV, a VTR unit, a communication & control unit and a power supply unit, and tether cables are also subdivided into a primary cable and a secondary cable.

As diving depth increases, power and data transmission becomes of a long distance. Therefore, electric power is transmitted to the vehicle at a high voltage and signal transmission is carried out by way of optical fiber cables. As a result, cable diameters of both the primary and the secondary cables can be minified, and tidal effect upon the cables are kept to the minimum. Furthermore, intermediate connector which connects the primary cable and the secondary cable with a certain mass prevents the cables from being swept away by the tidal current. With this system, foot print can be defined as the sphere with a diameter of the length of the secondary cable.

3. Vehicle

As regards the dimension, the vehicle is about 1.19m long, 0.96m wide and 0.7m high. The vehicle's weight in air is about 135kg and the vehicle's weight in water is adjusted to have buoyancy of about 1kg. The vehicle's speeds are 2.3 knots when going ahead and 1.0 knot when going downwards. Photo 1 is an overall view of the vehicle.

3.1 Vehicle Body

Vehicle body is consisted of two pressure tight spheres and a pressure tight pipe which connects the two spheres. The spheres are of aluminum alloy castings and the pipe is of aluminum alloy.

At the fore end of the forward sphere a view port which is made of acryl resin is arranged in order to get the field of vision for a colour TV installed in the forward sphere. This view port is so arranged as to get 10 degree downwards field of vision from horizontal plane. The surface of the acryl resin is specially coated in order not to be damaged by a contact with a foreign object. Furthermore, a grid is placed in front of the view port to guard the acryl resin.

At the lower part of each spheres, a cylindrical pot is attached to house a transformer.

At the upper part of the pressure tight pipe, two vertical & horizontal thrusters are attached. A vehicle frame is provided at the lower part of the pressure tight pipe and two ahead & astern thrusters are attached to the vehicle frame.

At the aft end of the rear sphere, a view port of acryl resin is provided. Unlike the case of the fore view port, the aft view port is arranged to look horizontally.

At the center of the upper part of the pressure tight pipe, a water tight cable connecting device is arranged to connect the secondary cable and the vehicle. This device has freedoms of movements in fore & aft and right & left direction so that the secondary cable is free from any horizontal force.

3.2 Thrusters

Two ahead & astern thrusters which are attached to the vehicle frame are driven by 200W DC motors. Power is transmitted to a propeller by way of a planetary gear with a reduction ratio of 1/5. DC motor, planetary gear and its power output shaft are housed in a pressure tight cylinder of the thruster and power transmission to the propeller shaft and the propeller is achieved with a magnetic coupling.

The propeller is a fixed pitch propeller with three blades. The propeller has a shroud ring for the protection purposes. At the forward part of the pressure tight cylinder of the thruster, a nosecone is provided to reduce hydrodynamic resistance.

Change-over of ahead and astern is achieved by the change-over of the direction of the motor rotation. Vehicle rotation is achieved by one thruster ahead and the other astern.

Two vertical & horizontal thrusters which are attached to the pressure tight pipe are, as in the case of ahead & astern thrusters, driven by 200W DC motors. Power is likewise transmitted to a propeller by way of a planetary gear with a reduction ratio of 1/5. DC motor, planetary gear and its power output shaft are housed in the pressure tight pipe and power transmission to the propeller shaft and propeller is achieved with a magnetic coupling.

The propeller is a fixed pitch propeller with three blades. The propeller has a shroud ring for the protection purposes. Change-over of ascent and descent is achieved by the change-over of the direction of motor rotation. Horizontal sideway movement is achieved by one thruster natural rotation and the other reverse rotation.

3.3 Vehicle Frame

At the lower part of the vehicle body, a vehicle frame is provided. The purpose of this vehicle frame is to protect the vehicle body from directly crashing with the sea bottom. The vehicle frame is made of aluminum pipe and attached to the vehicle body by bolts and nuts. To the vehicle frame, ballast mounting seats as well as two ahead & astern thrusters as aforementioned are attached.

3.4 Equipments Mounted in and on the Vehicle

(1) Color TV camera

A color TV camera of broadcasting use quality is mounted in the forward sphere for observation purpose. Horizontal resolution of this color TV camera is more than 550 lines, S/N ratio is 58dB, minimum required intensity of illumination is 15Lux. Quality of the camera lens is of wide angle, 3.5 times zoomimg magnification with automatic iris mechanism. Zoom, focus, gain and white ballance can be controlled remotely from the mother ship. The color TV camera is mounted on a tilting equipment driven by an electric motor. Tilt angle is about 30 degrees downwards and about 15 degrees upwards.

As an option, a black and white TV camera can be installed in the rear sphere. Horizontal resolution of this black and white TV camera is more than 280 lines, S/N ratio is more than 46dB, minimum required intensity of illumination is 3Lux. If requested, a still camera can be installed in front of the black and white TV camera.

(2) Underwater lights

Two 300W underwater lights with halogen lamp are installed on the forward sphere in order to provide ample illumination to the color TV camera.

If required, two tilting underwater lights can be additionally installed.

(3) Compass

A magnetic compass of fluxgate type is installed to detect the vehicle's heading direction. The signal of this magnetic compass is transmitted to the control console on board the mother ship and utilized as an information for automatic direction keeping. Measuring accuracy of this magnetic compass is plus minus 2%.

(4) Depth meter

A pressure sensor of strain gauge type is installed to detect the vehicle depth. The signal of this depth sensor is transmitted to the control console and utilized as an information for automatic depth keeping. The measuring range of this sensor is 0-70kg/cm2 and hysteresis is plus minus 1%FS.

4. Control Console

4.1 Power Supply Unit

Power supply unit receives electricity of AC100V, single phase, 30A from the mother ship and produces AC1100V, single phase for the transmission to the vehicle. In this unit, an insulation resistance monitor and an electric shock preventive breaker are equipped for safety and security purposes. The insulation resistance monitor is to cut off the ship's electricity at the inlet when electric resistance between the electric system of Hornet 500 and the earth becomes 50 mega ohm and below. The electric shock preventive breaker is to secure operators from being exposed to a certain amount of electric current for a certain duration of time.

4.2 Communication & Control Unit

The communication & control unit is a nerve center of Hornet 500 and a vehicle control box and a TV camera control box are connected to it by way of extension cords. Two joistic levers are arranged on the vehicle control box and by the manipulation of these two joistic levers, vehicle can go ahead & astern, ascend, descend, turn, go sideways. There are an automatic direction keeping switch and an automatic depth keeping switch on the vehicle control box.

On the TV camera control box, there are switches for gain control, zooming, focusing, camera tilting, etc.

Inside the communication & control unit, a micro computer is equipped. Analogue signals from TV camera control box are put into the micro computer by way of A/D signal converter and processed together with signals of direction and depth feedback data, then electric signals is transformed into optical signals and delivered to the vehicle.

On the communication & control unit, swithes for underwater lights on/off and various displays such as vehicle depth, vehicle head direction, number of vehicle rotations, TV camera tilt angle are arranged. State indication lamps such as light on/off, auto depth on/off are also arranged on the communication & control unit.

This unit has so to speak a balance up/balance down function. This is to keep the vertical thruster power constant. For example, if the balance set dial on the communication & control unit is set at balance down 60%, the vehicle keeps on going down at 60% power.

4.3 Monitor TV and VTR Unit

A 9 inch monitor TV is arranged at the upper part of the control console. The standard VTR unit is of 1/2 inch type. If specially clear TV picture is required 1 inch VTR unit of broadcasting quality can be arranged.

5. Tether Cables

Both the primary cable and the secondary cable have two optical fiber cable and a pair of electric power cables in them. The length of the primary cable is 750m and that of the secondary cable is 50m. The secondary cable is of neutral buoyancy. Length marks are put on the surface of both cables at 10m interval so that the operator can judge how long the cable has been drawn out.

One of the two optical fiber cables is to transmit digital command signals from the control console to the vehicle and digital status signals from the vehicle to the control console. The other optical fiber cable is to transmit analogue signals from the color TV camera to the control console. If a black & white TV camera is installed as an option, two kinds of analogue signals having different wave length are transmitted by optical multiplex method to the control console. Two wave length multiplexers are installed in the vehicle for digital signals and for analogue signals, and further two are installed in the communication & control unit.

A pair of electric power cable is to transmit AC1100V from the power supply unit to the vehicle.

As hitherto mentioned, optical fiber cables are used for communication resulting in little electro-magnetic interference from thruster motors, etc. Together with this and high voltage power transmission, diameter of tether cables could be reduced to 9mm or less. Therefore, tether cables are little influenced by tidal currents and, according to our experiments, the vehicle and the intermediate connecter could dive almost right under the mother ship at 1 knot of tidal current.

6. Cable Drum

Hornet 500 has a cable drum on board in order to wind the 750m long primary cable. A standard cable drum is of hand driven. A motor driven cable drum can be supplied by an option. For a standard cable drum, two handles are attached on both sides of the drum, so that, if required, the drum can be handled by two men. The cable drum is equipped with a foot brake to stop drum rotations and a drum stopper of pin insert type to fix the drum. The cable drum is made of aluminum alloy to achieve light weight except for parts transmitting torque which are made of stainless steel. On four legs of the cable drum, four casters are attached for easy transportation. Between each casters, four pedal type lifters are arranged and by treading on a lifter, a caster is lifted a little so that the cable drum can be fixed to the mother ship.

Cable connection between drum rotary part and drum fixed part is of slip ring type for electric power cables and of rotary connecter type for optical fiber cables.

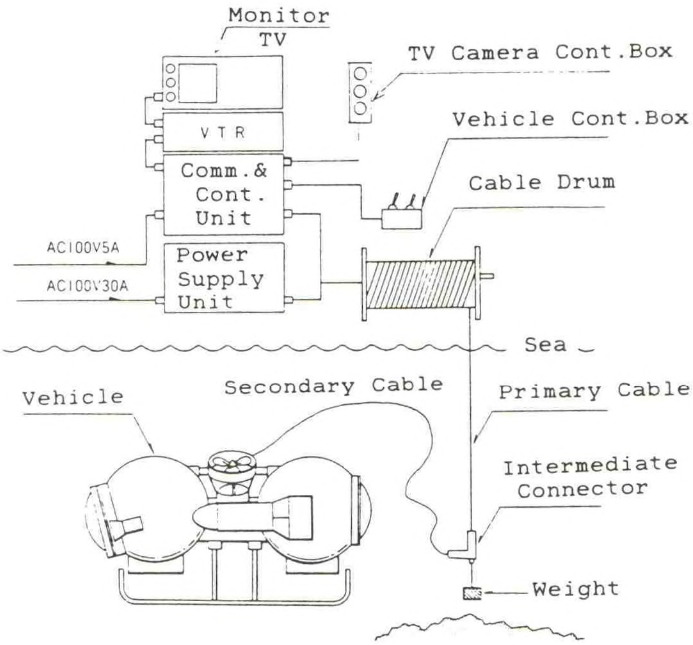


Fig.1 System Configuration of Hornet 500

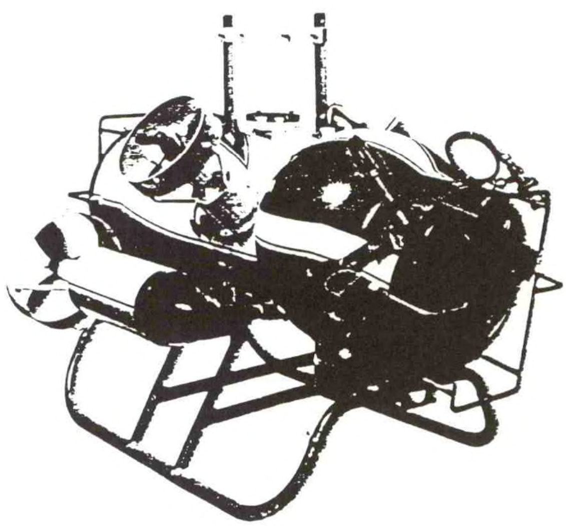


Photo 1 Overall View of the Vehicle

Probing the Deep for *Challenger* Disaster Answers

Submersibles Are Key Players In the Navy-Directed Search For Shuttle Debris Off Florida

By David M. Graham
Editor

A massive U.S. Navy/National Aeronautics & Space Administration (NASA) effort to recover parts of the ill-fated space shuttle *Challenger* drew a swarm of remotely piloted vehicles and manned submersibles to the search. Some met with varying degrees of success. Some met the cable-tangling Gulf Stream currents and were sent back home.

The crowded waters were reminiscent of the underwater search for a missing hydrogen bomb in 1966 off Palomares, Spain. That memorable operation was an 80-day marathon of recovery efforts when an H-bomb dropped accidentally into the sea from a U.S. Air Force B-52 bomber.

At that time, the cream of the then-new and wonderful submersibles crop was outdone ultimately by a Navy contraption called CURV, for Cabled Underwater Recovery Vehicle.

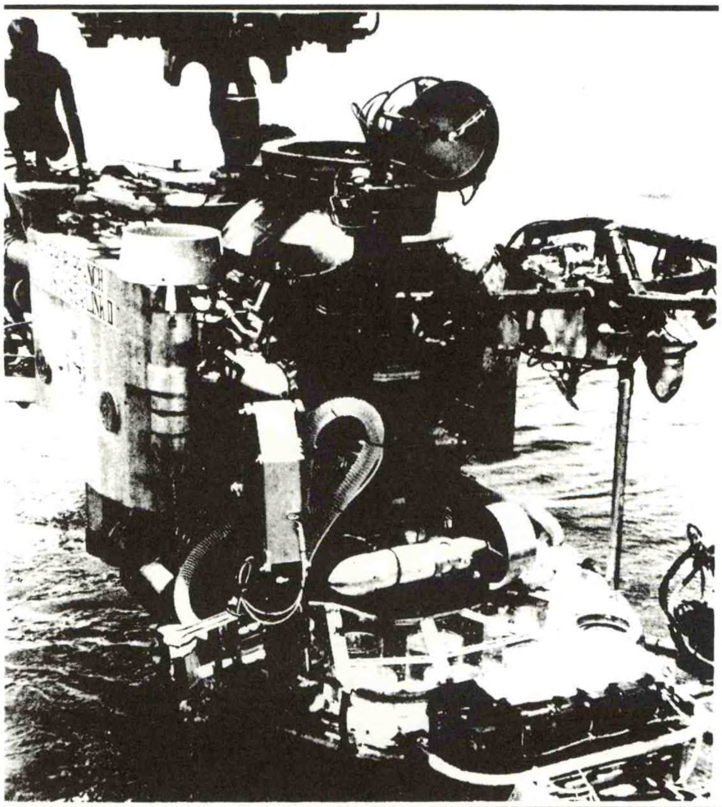
The "H-Bomb Hunt" turned out to be a showcase exercise in those heydays of competing submersibles. This search, on a far more sombre note, has been characterized as closer to a "business as usual" search and recovery mission with a display of the underwater technology the oceanic community now takes for granted.

There have been no high-tech surprises, no broaching the state of the art as in some aspects of the successful *R.M.S. Titanic* search last fall (*Sea Technology*, October 1985, page 70).

Early on, television news watchers following the aftermath of the January 28th disaster above Cape Canaveral saw glimpses of Perry Offshore's new Sprint 101 mini-ROV and Sub Sea Service's Scorpio and Recon IV vehicles as the tide of news shifted to the underwater search for clues to why the disaster happened. The search intensified within days when the Navy and NASA brought in the big guns—Steadfast-Oceaneering Inc. (Falls Church, Virginia) who oversaw the sonar search mission under its contract with the Navy Supervisor of Salvage; Eastport International Inc. (Upper Marlboro, Maryland) who operates ROVs for Navy search and recovery missions, such as the Navy's Deep Drone and Orion vehicles and a borrowed Gemini from Ametek Straza Division; Harbor Branch Foundation Inc.'s (Fort Pierce, Florida) *R/V Seward Johnson* and *Edwin Link* as well as the foundation's four-man submersibles, Johnson-Sea-Link I and II; and the nuclear-powered submersible NR-1.

The bigger vehicles, one source told *Sea Technology*, saved the day because the smaller vehicles were experiencing increasingly tougher sailing in the 5-knot-or-so Gulf Stream currents.

Pressed into service early in the search—partly because of Harbor Branch's proximity to the Cape—the oceanographic research foundation's *Seward Johnson* and the Johnson-Sea-Link II are generally credited with being the first to bring back photographs, video recordings, and some small pieces of debris presumably from the suspect right-hand solid rocket booster.

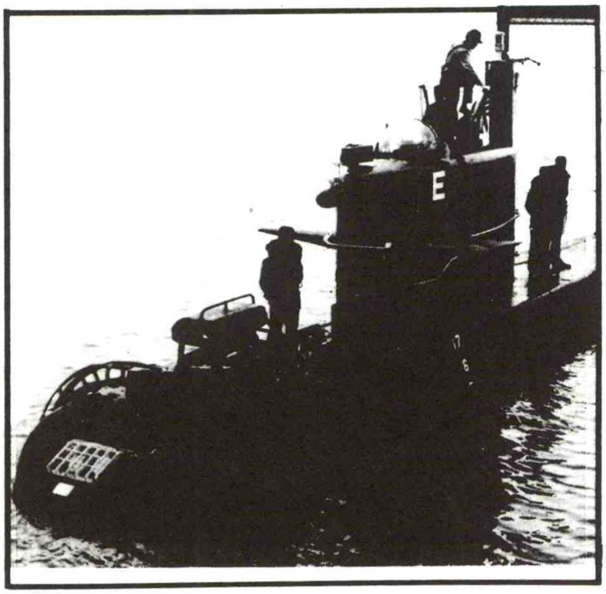


Harbor Branch submersible Johnson-Sea-Link II was first to bring back color photos, video recordings, and pieces of shuttle wreckage. (NASA photo)

A Harbor Branch spokeswoman told *Sea Technology* a small HBF-built ROV collected several small samples, including a small hydrazine bottle (typically used to power the small steering jets on satellites). The foundation's Cabled Observation & Rescue Device—affectionately called CORD—was designed to work and collect samples in the Gulf Stream's 3-7 knot currents and is tethered to a vessel topside with a less-resistant half-inch armored cable. The larger cables used with the bigger and sometimes underpowered ROVs fell prey to the strong currents, which severely restricted controllability, according to some sources. CORD was followed later by the Johnson-Sea-Link II, which resulted in 35mm still photos and what one observer called "fascinating video" from the vehicle's Marine Optical Systems MOS 1000 and MOS 300 high resolution video cameras.

Visibility at depths apparently is not much of a problem, according to Harbor Branch, because the Johnson-Sea-Link II, at least, sports an HBF-built 7000° K arc light and suite of Birns Oceanographics 1000-watt Snoopers and 360-watt Snooperettes to light the way.

It took several days after the explosion rained debris at sea off Cape Canaveral for an organized effort to get underway. NASA's first order of business then was to retrieve pieces of the *Challenger* and the solid rocket boosters. The U.S. Navy was called in shortly thereafter, which service elbowed out the Coast Guard, whose ships had been gathering floating debris.



The Navy's research submersible NR-1 concentrated her searches in the right-hand booster debris field. (NASA photo)

Coordinating Sonar Sweeps

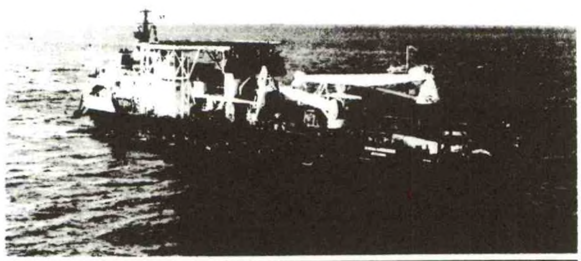
The Navy then concentrated on a side-scan sonar search to comb the bottom for heavy pieces of the two solid rocket boosters and whatever was left of the crew compartment. At this point as well two civilian firms under contract to the Supervisor of Salvage stepped into the picture. Steadfast-Oceaneering handles worldwide search and recovery of marine objects and, as such, began coordinating the tedious task of conducting sonar sweeps of the entire impact area. Eastport International has a similar contract to conduct undersea operations, working with the Navy's Deep Drone ROV and the towed sonar sled Orion.

In charge overall was the Navy's top salvage officer, Capt. Charles Bartholomew, director of the Ocean Engineering Division of the Naval Sea Systems Command.

Steadfast's Ridge Albaugh told *Sea Technology* his firm organized the search off the Cape using "vessels of convenience." He is one of the firm's project managers.

"We started out with two NASA booster recovery ships, the *Liberty Star* and the *Freedom Star*, and then had to add two more search teams and vessels to cover the 430-square-mile area," Albaugh said. "We chartered two Tracor Marine ships out of Fort Lauderdale (Florida), the *G. W. Pierce II* and the *Paul Langevin III*, which we subsequently dubbed the 'PL3'."

Key to the Steadfast operation, he said, was several Klein Associates' side-scan sonars that essentially were off-the-shelf 100 kHz units used of necessity with a variety of recorders. "We were also operating one 500 kHz fish (also Klein's) on whichever ship was doing sonar target localization and identification," he added. Steadfast personnel began running lines as soon as the search grid was established and all possible contacts were recorded and examined on shore by Steadfast president Mike Kutzleb and independent contractor Bob Kutzleb.



Stena Workhorse, and her 100-ton-capacity crane accomplished recovery of large debris. (Northern Coasters Ltd. photo)

Tying In GPS Positioning

At this point, Steadfast's four Magnavox T-Set Global Positioning System (GPS) receivers came into play. "We tied the sonar contacts into the positioning and then calculated what we call 'trail' or the offset to where the sonar fish should be," Albaugh continued. "For this project, we recommended using Loran-C (for primary positioning) because of the distances offshore and then calibrated and corrected it with the GPS system." He told *Sea Technology* the former were four Simrad Taiyo Loran-C sets.

Parent company Oceaneering International even got into the act by supplying chief surveyor Eric Swinney "to help out by getting all the T-Sets and Loran-C systems hooked together" and to oversee use of Oceaneering's pioneering integrated navigation software program for GPS/Loran offshore oil rig positioning.

On the wetter side of search operations, Navy contractor Eastport International, Marine Systems Division, was barely recovered from its recent long-term project to recover wreckage of the Air India 747 jetliner that was lost in the Irish Sea. Project engineer Michael H. Higgins talked to *Sea Technology* about the vehicles and support vessels the firm marshalled for the *Challenger* search.

He said the Eastport team used the three ROVs mentioned earlier. "We added the Gemini at the Navy's request because we needed a system that has more capability than, for example, the Deep Drone (and is a) larger, more powerful vehicle to operate in stronger currents." The third vehicle used was Orion, a towed sonar (Klein 100 kHz) sled with still (Photosea) and video (Colmek) cameras aboard. "Eastport didn't use Orion's sonar as much this time because of the shallow depths and strong currents. Orion's more of a very deep system," Higgins said.

Deep Drone, the tethered ROV capable of 1650-meter-depth operations, worked off NASA's *Independence* on reconnaissance sorties, checking out likely sonar "hits."

Gemini: Heavy Worker

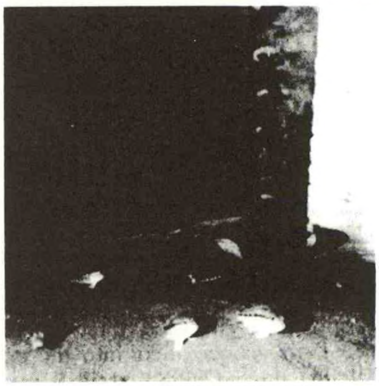
The Gemini, on short-term loan from its manufacturer Ametek Straza Division in El Cajon, California, was working in the same areas as Deep Drone, Higgins added, but was also used for heavier salvage work, such as making attachments to heavier pieces of debris. Gemini's support vessel was the *Stena Workhorse,* a multipurpose offshore maintenance and diving support vessel built and operated by Northern Coasters Ltd. of Aberdeen, Scotland.

Her claim to fame in the *Challenger* search is her 100-ton-capacity revolving deck crane and dynamic positioning features. That was the crane used to lift the burned-through portion of the right-hand solid rocket booster suspected of causing the explosion. *Stena Workhorse* was assisted in that particular recovery by Harbor Branch's Johnson-Sea-Link I—working off the *R/V Edwin Link*—which submersible attached recovery slings and an acoustic marker.

Eastport's Higgins also said Gemini was fitted with two specially designed manipulator arms.

One, according to Canadian builder Robotic Systems International Ltd. (Sidney, British Columbia), is a seven-function spatially correspondent manipulator called Kodiak 1000 that can lift half a ton and reach 1.5 meters. Another, a five-function manipulator "designed and engineered in a matter of days for the *Challenger* recovery" assists by holding the Gemini steady on the ocean floor.

The Navy's salvage operation costs reached nearly $7 million by mid-March, according to news reports. In the early phases of the search, a flotilla of more than a dozen vessels were criss-crossing the target areas. Eight of them were U.S. Navy vessels—including the *U.S.S. Preserver* (ARS-8) whose Navy divers undertook the grim task of recovering the remains of the seven astronauts, and the *U.S.S. Sunbird* (ARS-15), the support ship for the NR-1 submersible.



Photos from Deep Drone ROV show (top) portion of the satellite *Challenger* was to launch, as well as part of left-hand booster lying in 64-meter waters. (NASA photos)

Now that the last critical and "top priority" piece of evidence—the other half of the burned-through rocket booster segment—was recovered April 29, NASA officials have called off the massive 92-day salvage effort. While the shuttle debris search off Florida didn't provide a high-technology showcase, it undoubtedly accomplished much in proving once again the dual concept of effectively using manned as well as unmanned vehicles for performing meaningful work in ocean depths. /st/

SILVER-IRON BATTERY SYSTEM

FOR

ROV AND SUBMERSIBLE POWER SOURCES

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ABSTRACT

As the sophistication of ROV's Autonomous Vehicles and Manned Submersibles increases (in response to demands for additional work functions at greater depths - for longer durations) the power source very often becomes the limiting factor in most designs. Since the real pay off in any of the vehicles is "time over target area" cost effectiveness can be directly related to hours in the water-operating as a percentage of total hours in the operational window. The ability to rapidly recharge a power source and return the vehicle to the water makes operations more effective and often provides considerably more data/or work at a lower cost.

BACKGROUND

Many vehicles in use in the Military and Civilian oceanographic community utilize the silver-zinc alkaline battery system. Until the development/demonstration of the Westinghouse Silver-Iron Alkaline Battery System silver-zinc was the only rechargeable battery available with a stored energy density in excess of 100 watt hours per kilogram.

Silver-zinc cells are, however, subject to the characteristics of the zinc plate which limits cell life to between 10-50 cycles,(for high capacity cells) and causes charge times in excess of 30 hours - with constant monitoring of individual cell voltages (making for a very slow - very labor intensive charge cycle). Dendrites grow during charge cycle (when the dissolved zinc attempts to replate itself back onto the electrode often puncture the separators and cause a dead short (and sometimes a very dangerous energy fire.)

Westinghouse started battery technology development at the Research and Development Center in the early 1960's and this effort was broadly directed at a variety of secondary battery projects including:

- o Iron-Air Batteries for Electric Vehicles
- o Nickel-Iron Batteries for Electric Vehicles
- o Nickel-Cadmium Batteries
- o Lead-Acid Batteries

In the late 1960's Westinghouse started work for the Appliance Division on nickel-cadmium cells for use in battery operated devices. At that time, the R&D Center developed the design and reduced to practice a sintered fibrous grid structure as the current collector for alkaline battery plates. During this period the active material was added to the porous grid structure by a vacuum immersion and electro-chemical conversion process. This vacuum immersion process was then, and still is for many alkaline battery manufacturers, the technology used for both nickel-cadmium electrodes. Westinghouse, over the years, has developed several process advances to the present pasting and sintering processes. Westinghouse has licensed the fiber grid current collector pasting technology to a large battery manufacturer.

During the 1970's the structure and performance of the iron electrode were well characterized in a number of special battery systems. Westinghouse developed and tested two types of iron electrodes in an attempt to improve the Edison iron plate which had a yield of approximately 0.15 Ah/g and required about 30% overcharge to maintain capacity. The Westinghouse "pasted" iron electrode is easy to manufacture and very rugged. These electrodes gave about 0.30 Ah/g and exhibited stable performance for approximately 1000 cycles. The Westinghouse "sintered" iron electrode was designed for increased utilization of the active material and these electrodes gave about 0.40 Ah/g. Both "sintered" and "pasted" electrodes are easy to manufacture, stable in use, and do not put any plate material into solution-neither do they "slump" (as zinc electrodes do). These iron electrodes look the same after 50,500 or 1,000 cycles as they did at the start of cycling.

In 1974 Westinghouse was called upon to supply a silver oxide-iron battery for TCOM (tethered communication aerostats). The type of cells produced at that time are now obsolete and used the electrode iron Meramac/MAPICO pasted unsintered iron oxide formed electrochemically. The cells for this application had capacities of 140 Ah when discharged at the 3 hr. rate.

Early in the 1980's it became obvious that a very stable and durable iron electrode had been developed and demonstrated but it was only part of a cell and in order to make a really advanced cell there had to be work done on a silver plate and a separator system.

In the early 1980's Westinghouse was approached by several of it's Customers about battery problems they were experiencing with silver-zinc cells. The problems ran the gamut from shorter than advertized life to energy fires. When Westinghouse reviewed the "state-of-battery-art" in the early 1980's it appeared that the time was at hand to focus the iron electrode development into a specific size cell that could be tested against a readily available/widely used cell. The 750 A hr silver-zinc cell was selected and Westinghouse discussed their proposed Silver-Iron Battery Testing Project with several principal Customers and their response was favorable. The idea of large scale testing of all the best elements of Westinghouse battery technology was formed into a set of technical objectives, costed out and presented to Corporate Management. After several thoughtful and very detailed reviews it was agreed that the Project would be funded. The Project Team was told that although Westinghouse was not and did not plan to get into the battery manufacturing business that because there were significant silver-zinc battery problems, Westinghouse would work toward the solution of battery problems for specific Customers.

The results to date have been so impressive that an additional phase of Silver-Iron Battery Testing Project was recently proposed to Corporate Management. During Phase 5 it has been proposed that several Silver-Iron batteries be manufactured at the R&D Center and tested under environmental conditions of pressure/temperature ranges. These "compensated" cells would be replacements (when combined into batteries) for existing silver-zinc cells (batteries) in the 750 A hr capacity range. A comprehensive study of performance and cell gassing over a range of temperatures ($0^{o}C$ to $25^{o}C$) and pressures (atmosphere to 220 psi) and operating conditions (i.e., normal, tilted, loss of electrolyte etc.) was proposed and we expect this effort to be underway about 1 December 1987. This testing will provide Westinghouse with fundamental data for compensated Silver-Iron and Silver-Zinc Cells (Batteries). We expect the results of Phase 5 to contribute to our present data base on silver-iron technology and provide us with additional insight into how to improve the product.

SILVER-IRON ELECTROCHEMISTRY

The zinc electrode reaction in concentrated alkali is given as:

$$Zn^{O} + 4OH^{-} = ZN(OH)_4 2- + 2e^{-} \quad E^{O} = -1.265V$$

$$Zn(OH)_4^{-}2 + 2e^{-} * Zn + 4OH^{-}$$

The iron electrode reaction is concentrated alkali is given as

$$Fe(OH)_2 + 2e^{-} * Fe + 2(OH)^{-} \rightarrow E^{O} = -.980 \text{ V}$$

The Silver electrode reactions are generally given as:

$$2AgO + H_2O + Ag_2O + 2OH^{-} \quad E^{O} = +.599$$

$$2Ag_2O + H_2O + 2e^{-} + 2Ag + 2OH^{-} \quad E^{O} = +.342$$

From the above reactions a typical discharge curve for the silver-zinc and silver-iron are identical in shape with the voltage difference between the two cells being .285 volts (1.265 - 0.980 volts). This is shown in Figure 1 and Figure 2 where the voltage characteristics of the two cells are displayed. Table 1 compares the theoretical energy density for the reactions occurring in both cells. The resultant theoretical energy densities are essentially equivalent at 367 Wh/kg for silver-iron and 373 Whr/kg for silver-zinc.

Refer to Figure 1 -Theoretical Voltage of Silver-Iron Zinc Electrodes vs. WHE. Refer to Figure 2 - Theoretical Voltages of Silver-Iron an Silver-Zinc cells. Table 1 shows that the theoretical energy density of Ag-Fe and Ag-Zn is nearly identical.

Table 1.

THEORETICAL ENERGY DENSITY
FOR
SILVER-IRON AND
SILVER -ZINC CELLS

SILVER IRON:

$$AgO + Fe + H_2O \rightarrow Ag + Fe(OH)_2$$

$$\overline{V} = 1.340V$$

SILVER ZINC:

$$AgO + Za + H_2O + 2(OH) \rightarrow Zn(OH)_4 = + Ag$$

$$\overline{V} = 1.675V$$

REACTION SPECIES	SPECIES WEIGHT (grams/amphr)	
$FE(OH)_2$	1.65	
		3.65
Ag	2.00	
		4.48
$Zn(OH)_4$	2.48	

i.e., Ag-Fe has lower specific weight per unit capacity of reaction species

Ag-Fe 367 Whr/kg
Theoretical Energy Densities
Ag-Zn 373 Whr/kg

SILVER-IRON BATTERY TESTING PROJECT

The zinc cell selected for comparison had been improved in design/quality control over those cells that often catastrophically failed during the 1974-1976 time frame. The objectives identified for the Westinghouse silver-iron cell were as follows:

1. Demonstration of a stable Fe electrode of at least 40 A hr capacity.

2. Development of a thin, very long life separator system.

3. Development of a stable Ag electrode of at least 40 A hr capacity.

4. Production and testing of pilot cells and a small battery of 600 A hr capacity cells with stable voltage characteristics and cycle life of greater than 300 deep discharge cycles.

5. Demonstration through high rate charge/ discharge, cell reversal and dead short tests that silver-iron cells are rugged, dependable and abuse tolerant.

6. Development of historical laboratory data on cell performance that would lead to the development of failure mode data.

After approximately two years of focused effort at the 800 + A hr cell Westinghouse has met or exceeded all technical program objectives and is still unaware of the failure mode of silver-iron cells. We are still collecting data at this time and are at greater than 600 cycles on some cells and they are 2 years old (wet).

The high efficiency iron electrodes, have ampere hour efficiencies of greater than 90% and show stable performance against silver electrodes for hundreds of continuous deep discharge cycles. Optimum design of these electrodes provides for operation of the iron-silver couple to the iron upper voltage plateau thus allowing maximum voltage of the battery at the rated capacity.

In choosing a separator system for a silver-iron battery, the following criteria apply. The iron electrode exhibits negligible solubility during the anodic and cathodic processes so that the dendritic phases, and slumping characteristic with cycling zinc electrodes, do not occur. Also the iron electrode experiences absolutely no shape changes or swelling even after hundreds of cycles. Thus, the iron electrode requires a minimum of wrapping which may usually be limited to a single absorbing layer. The silver electrode in the silver-iron system may be wrapped in similar fashion to silver-zinc cells since the silver electrodes used are identical. The separator must have excellent resistance to chemical oxidation by divalent silver and also exhibit long term retardation of silver ion diffusion. The silver-iron battery places a severe age requirement in terms of both time and use on a separator systems since it is designed to last for several years and give hundreds of deep discharge cycles.

The separator parameters with the greatest effect on cell operation (excluding electrolytic resistance) are considered to be ion exchange capacity, electrolyte absorption and resistance to oxidation or reduction in a strong caustic medium. The other important parameters such a tensile strength, swelling and breaking strength are important as the separator must retain its integrity during both cell assembly and prolonged cycling.

An innovative separator system developed by the Westinghouse R&D Center was used to construct a full size 750 A hr Pilot Cell containing 17 Westinghouse sintered iron electrodes and 16 silver electrodes. The iron electrodes were 60 mils thick while silver electrode thickness was 38 mils. Total wrapped stack thickness was 2.18 inches. A typical discharge profile at the 100 amp rate is shown in Figure 3. In this particular discharge the cell produced 650 A hr capacity and was silver electrode limited. Although the charge rate had been 35 amps for 24 hours prior to this discharge, this cycle had followed a series of high rate charging cycles at 100 amps or higher which are not optimum for the high density LR silver electrodes supplied by the manufacturer. Numerous consecutive cycles at the lower charge rate did allow the cell to deliver the 750 A hr rated capacity. Several charging regimes were employed for this experimental cell to determine a combined optimum rate for the two dissimilar (Ag&Fe) electrodes. This cell had more than 60 accumulated cycles and was consistently delivering between 700 and 800 A hrs with about a 10% overcharge. Cells of this construction were used in the 5-cell battery that was tested in Phase 4.

Figure 4 shows the discharge curves at cycle 30 for Westinghouse Ag-Fe cell which remains above 1.0 volt for approximately 7 hours when discharged at the 100 amp rate. The Ag-Zn cell discharged at the 100 amp rate falls below 1.4 volts very abruptly after approximately 6 hours.

FUTURE FOCUS OF EFFORT

We are planning to start the testing of several types of compensated batteries on/before 1 December 1987 at the Westinghouse R&D Center. These batteries will be compensated with insulating oil and subjected to a carefully developed cycling regime that will simulate typical DSRV operational use cycles. We expect this scientific evaluation of the batteries to last approximately eight months. During the conduct of the testing we will be developing considerable data about the gassing characteristics of Ag-Fe and Ag-Zn cells that will prove useful in the design of compensation systems for battery systems.

Westinghouse is in contact with a number of Military organizations that are/have experienced problems with their Silver-Zinc battery systems and we are working on specialized solutions to their problems. The data that we have already developed on the 750 A hr cells that we have tested has provided invaluable data on Silver-Iron cell performance which we are presently using to the benefit of these Customers. We fully expect the data from Phase 5 to provide conclusive data on the only as yet unexplored area - the gassing of compensated cells. This data will provide additional tools for Battery Designers to customize batteries for their specialized needs.

Due to the increased interest from our Customers, Westinghouse will install Ag-Fe battery production facilities at the R&D Center early in 1988. The location of these expanded furnaces and other facilities in close to our laboratory manufacturing facilities and the parallel operation will allow "pilot line" operations to proceed ahead of "production line" operations for large specialized runs. We will have the capability to build Ag-Fe cells of new design or rebuild Ag-Zn cells to Ag-Fe cells on a low or high volume basis.

As we have indicated in several meetings and letters Westinghouse will license technology for large production runs of Ag-Fe cells (batteries). This will provide our Military Customers with the means to satisfy the competition advocate with regard to second sources of Ag-Fe batteries. Westinghouse had deliberately maintained a very low Ag-Fe technology scientific profile during the two years while we ensured the accuracy of our initial results via additional testing. We have decided that the data is solid and the results need to be available so that other battery problems can be solved using Ag-Fe technology. That is the reason for this first paper on Silver-Iron Technology.

SUMMARY/ CONCLUSIONS

Westinghouse believes that Silver-Iron can replace Silver-Zinc in just about every known application and we have or will have the data to prove it. Over 16 years of development and approximately 12 million dollars of research in battery systems stands behind our belief. The Table, Performance Properties in Equivalent Cells is a concise summary of the Silver-Iron cell.

Westinghouse is continuing to develop specialized silver-iron battery systems for its Customer.

We are planning to discuss silver-iron battery characteristics in greater detail in a paper that will be presented in early November 1977 in San Diego at Underseas Defense '87. We will present initial data on Silver-iron battery environmental testing (i.e., Phase 5 previously discussed) in April 1988 at the Intervention '88 in Bergen, Norway. Figure 5 shows the Performance Properties of Equivalent Cells and lists significant characteristics of Ag-Fe and Ag-Zn cells. Figures 6 and 7 shows the Westinghouse LR750 Silver-Iron cell.

Stay in touch with Westinghouse for more information about the advanced battery system for ROV's, Autonomous Vehicles and Manned Submersibles.

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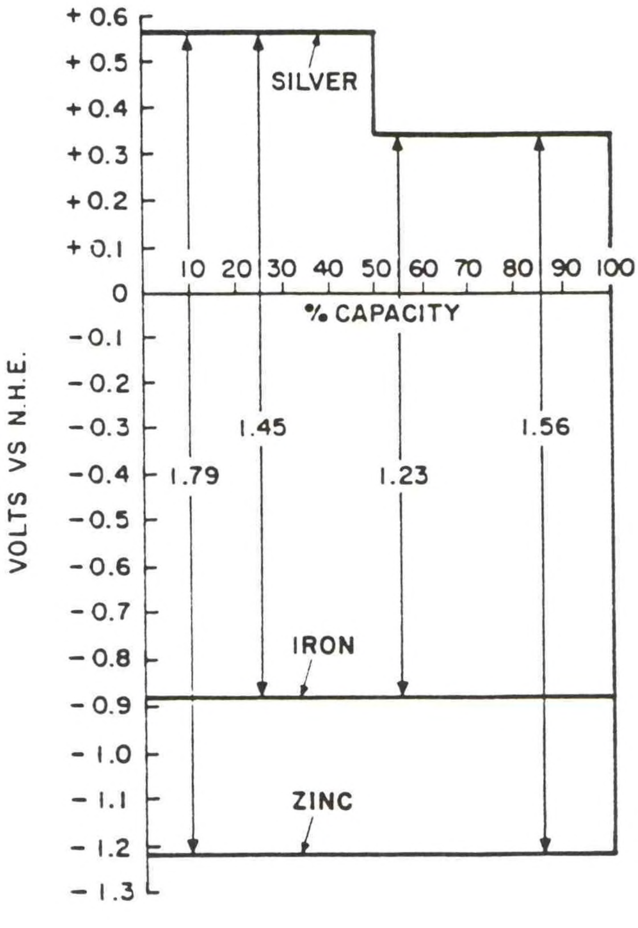

FIGURE 1 – THEORETICAL VOLTAGE OF SILVER – IRON – ZINC ELECTRODES VS N.H.E.

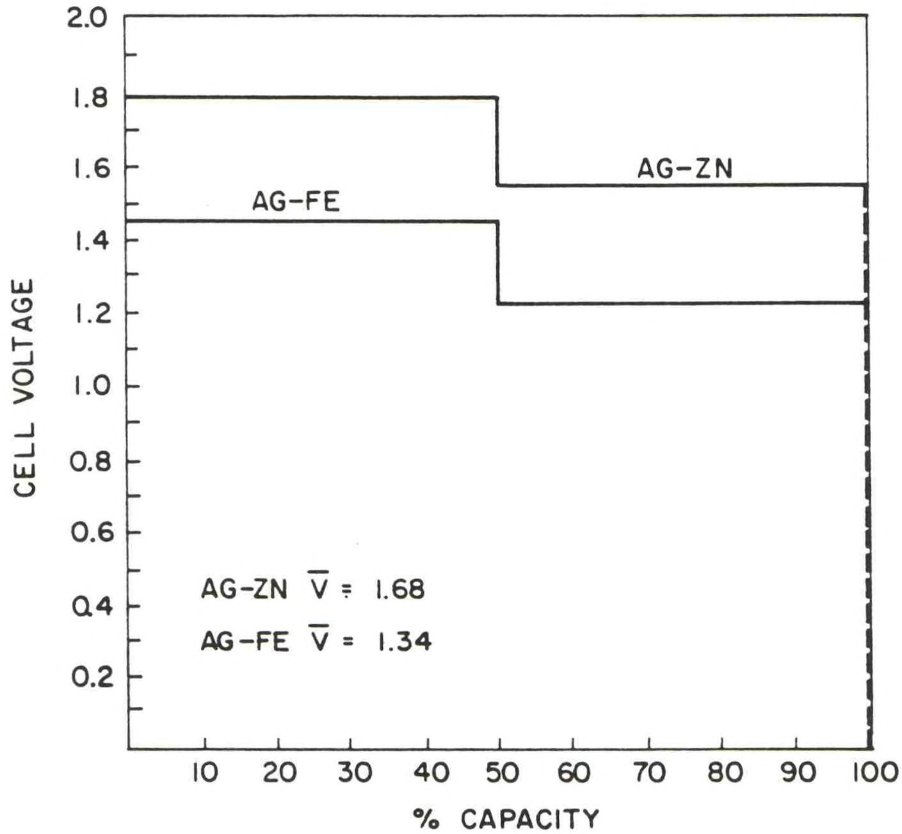

FIGURE 2. THEORETICAL VOLTAGES OF SILVER-IRON COUPLES VS SILVER ZINC

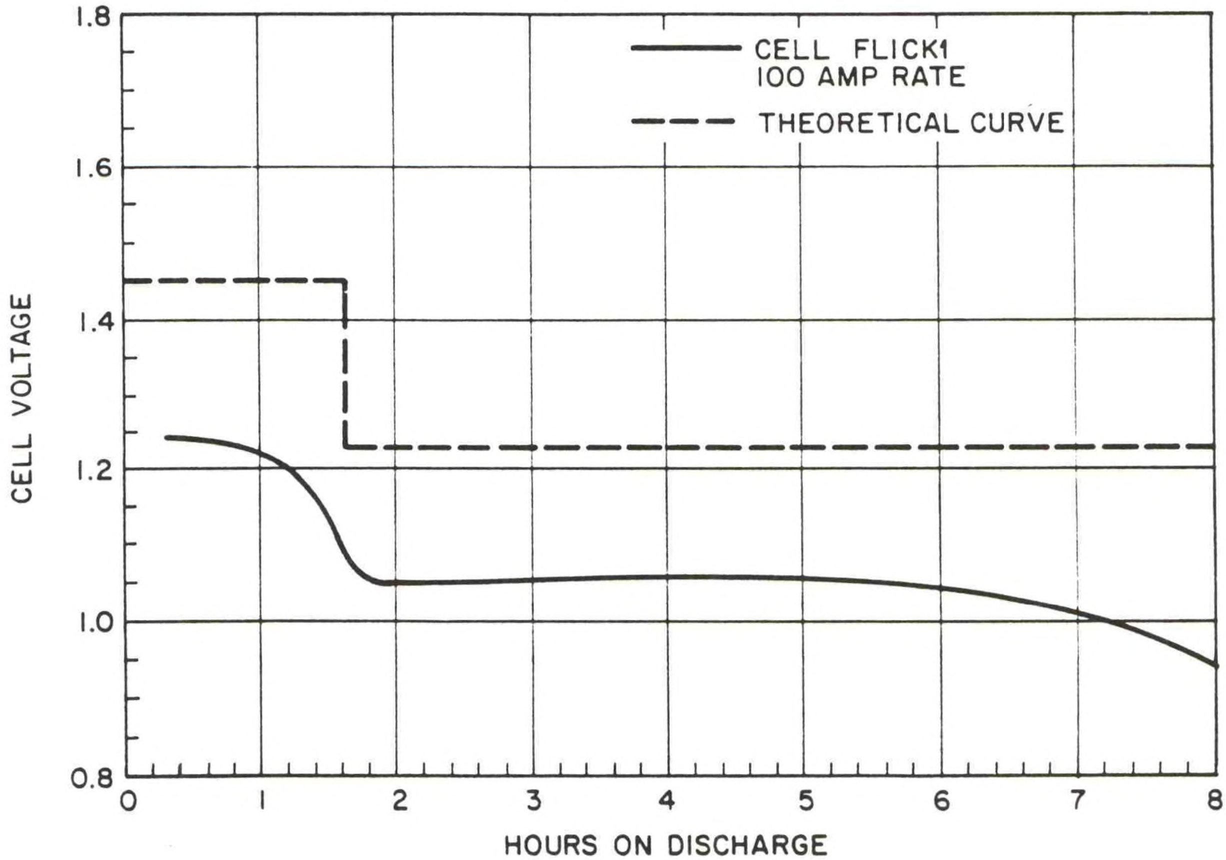

FIGURE 3. SILVER-IRON DISCHARGE CURVE

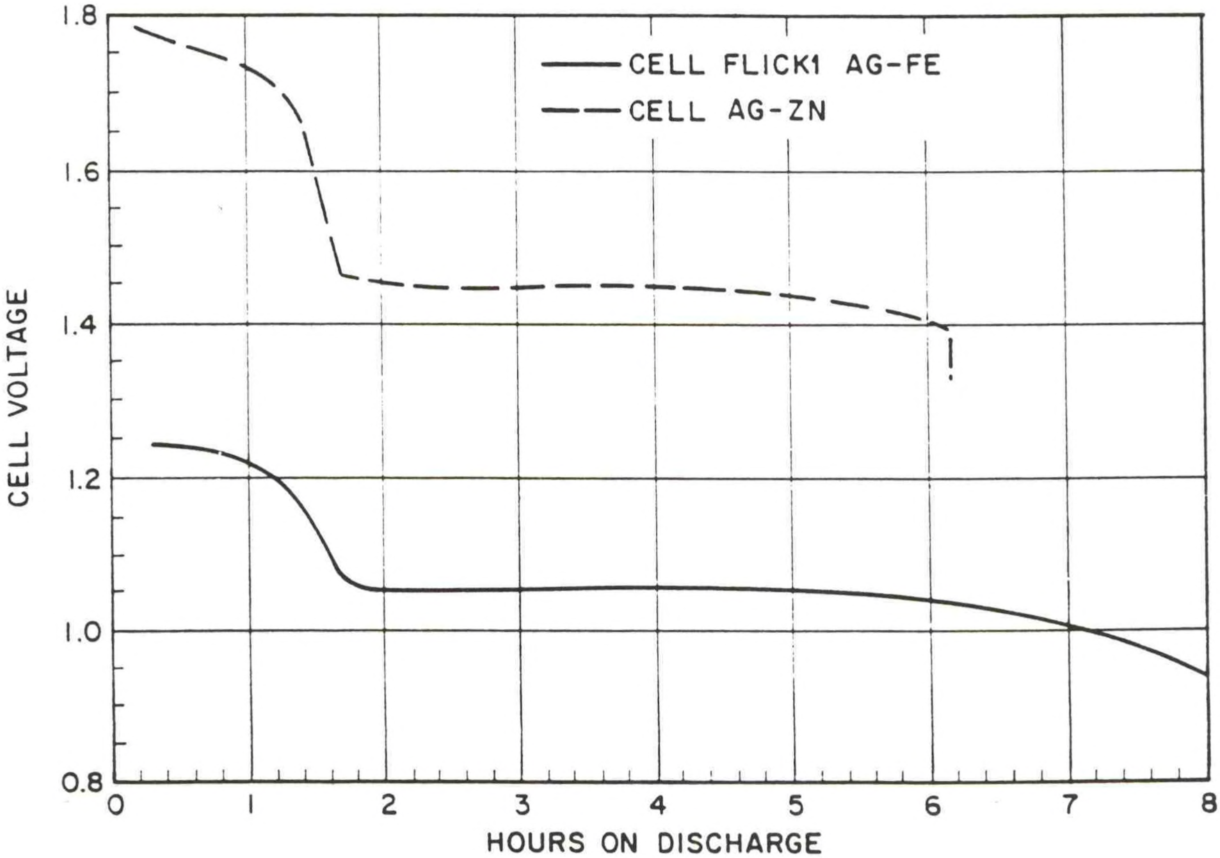

FIGURE 4. DISCHARGE CURVES AT CYCLE 30

SILVER-IRON		SILVER-ZINC
1.1	AVERAGE OUTPUT VOLTS	1.4
750 AHRS	CAPACITY	350-750 AHRS
8 KG	WEIGHT	12 KG
0.7 UNIT	RELATIVE FOOTPRINT	1 UNIT
GREATER THAN 300 CYCLES	CYCLE-LIFE	50 SHALLOW CYCLES
LESS THAN 0.5% PER DAY	SELF-DISCHARGE	LESS THAN 1% PER DAY
WITHSTANDS ABUSE	ABUSE TOLERANCE	INTOLERANT
6 HR/3-6 HR	CHARGE/DISCHARGE	36 HR/8-12 HR
NO HOT SHORTS	FAILURE MODE	HOT SHORTS
GREATER THAN 5 YRS.	SHELFLIFE-WET	18-24 MONTHS
LESS KOH LOSS	MAINTENANCE	KOH MAKEUP

FIGURE 5. PERFORMANCE PROPERTIES - EQUIVALENT CELLS

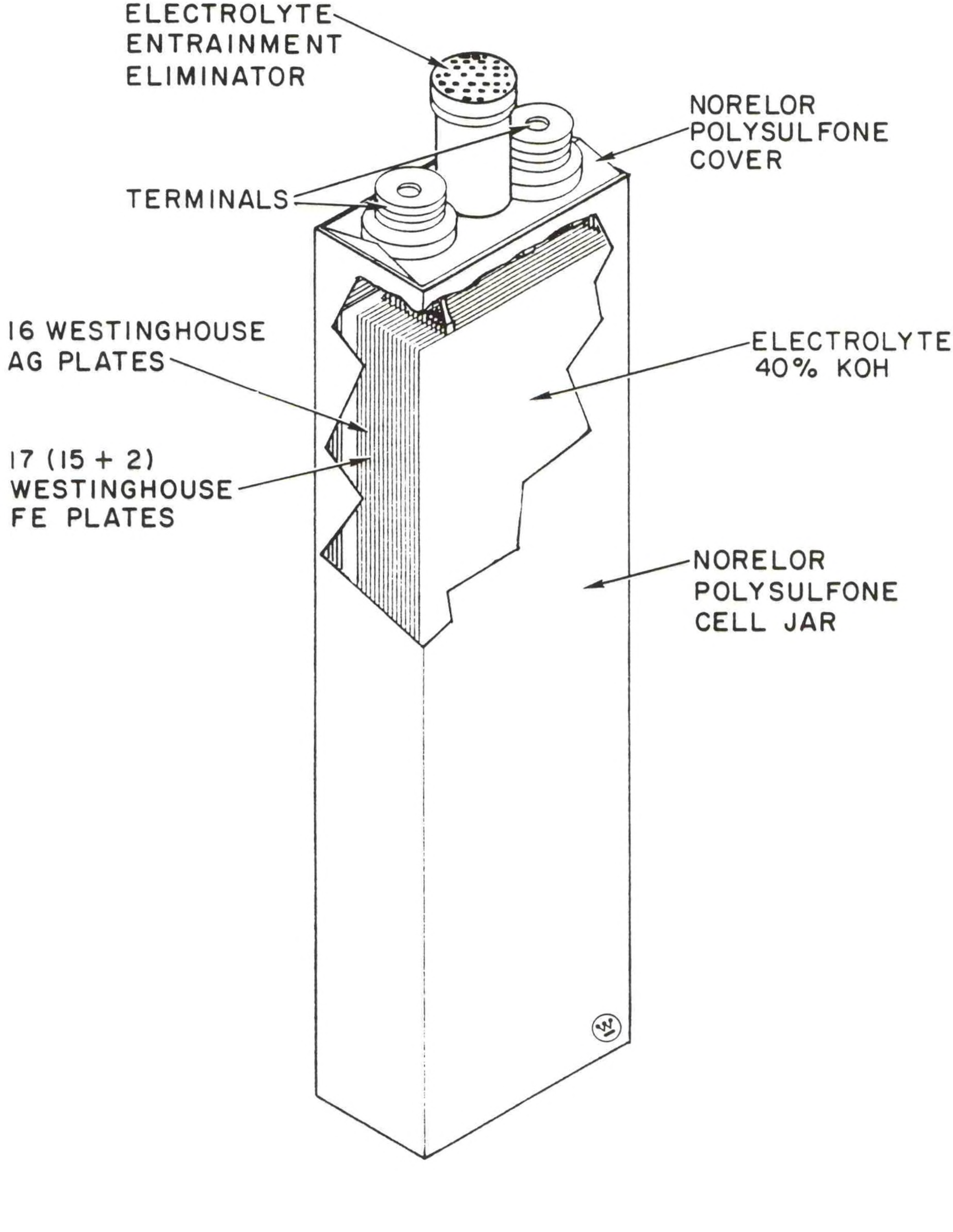

FIGURE 6. — LR WESTINGHOUSE LR750 SILVER—IRON CELL

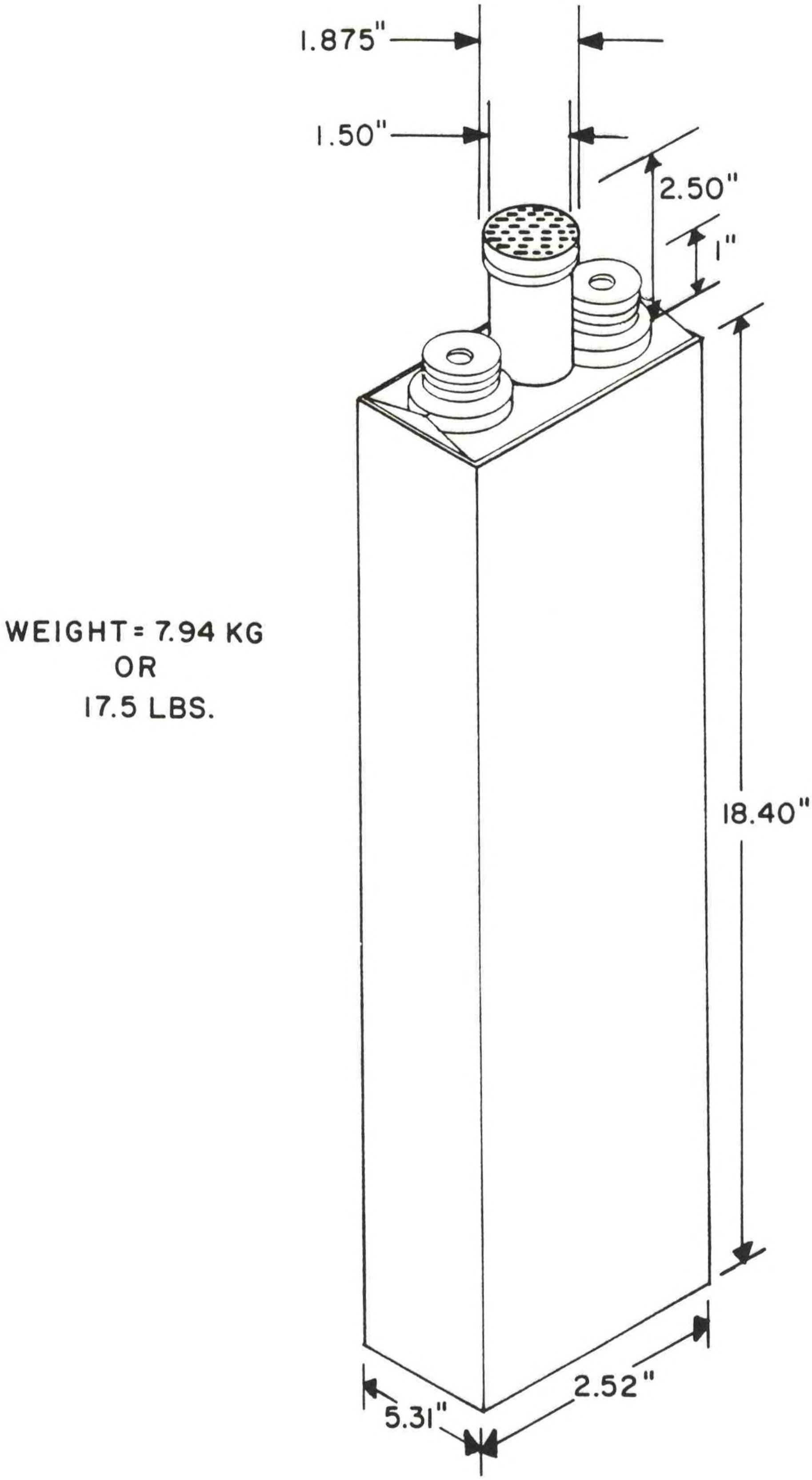

FIGURE 7. SILVER-IRON CELL — LR750 DIMENSIONS / WEIGHT

OPERATIONAL GUIDELINES
for
REMOTELY OPERATED VEHICLES

Marine Technology Society
Washington, DC

A Project of the ROV Subcommittee of the
Undersea Vehicles Committee
Robert L. Wernli, Subcommittee Chairman

G. MURPHY'S LAW—OR, HOW TO LOSE YOUR VEHICLE [1]

This chapter is included to demonstrate how the best laid plans of mice and men ofttimes go astray. Until mice become ROV operators, we humans, unfortunately, will have to bear the brunt of the wide variety of ROV follies. While many of the following incidents have their humorous aspects, they are not included for comic relief. Instead, they serve to provide real-life examples to demonstrate the pressing need for communications. Clear, succinct and immediate communications between the ROV operator and his crew, the ROV operator and the support ship operator, and the ROV operator and the handling system operator. The incidents also demonstrate the need for seamanship (a craft sometimes downgraded in this era of high technology), planning and just plain good sense.

The following vignettes were obtained from a variety of operators. In several instances the lesson(s) learned, according to the donor, is included. These are but a few of the mishaps experienced by the ROV community. After reading some of them the inexperienced might shake his head and wonder: "How could anyone be so dumb?" Sometimes those who donated the incidents might have similiar thoughts. But they are tempered by reminiscences of past events when, that devil incarnate, Mr. Murphy, popped aboard their own vessel, poured himself a cup of coffee and casually strolled out on deck to begin his lessons in humility. Mr. Murphy, by the way, is alive and well, and still teaching.

G.1 ENTANGLEMENT

There are two modes of entanglement: 1) by the umbilical or the tether, and 2) by the vehicle itself. Almost uniformly, when a vehicle has been lost, its umbilical or tether has been tangled. Experience has shown that there are also two objects with which the vehicle's cable will entangle: 1) the ROV support ship or platform and 2) the structure or object the ROV is investigating. The following incidents are, for convenience, grouped under two categories: support ship entanglement and structural entanglement. Several of the following incidents involve the vehicle becoming drawn into the support ship's bow or stern thrusters. While such an incident is not an entanglement, as much as it is a collision, it is nonetheless placed under the entanglement category since no one is ever quite certain that the cable was not first entangled which then pulled the vehicle into the thruster. Whatever the cause, no one can argue the point that the once whole vehicle now reduced to "kit form" after being passed through a thruster had not been "entangled." In the final analysis, Webster's Dictionary defines entanglement as "... conditions causing perplexity, embarassment or anxiety." A condition abundantly fulfilled in the following incidents.

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[1] Excerpted from The Marine Technology Society. 1984. Operational Guidelines for Remotely Operated Vehicles. pp. 171-182.

G.1.1 Support Ship Entanglement

Incident 1:

The weather began deteriorating during an ROV operation from a twin-screw vessel off South America, and the operating crew decided to abort the mission. The ROV was operating from a cage on a 400 ft. tether. The cage cable rewind stopped working. The crew decided to retrieve the cage first and then the vehicle. The crew was so intent on retrieving the cage that no one watched the vehicle. The vehicle's cable fouled on the port screw and was severed. As the vehicle had been made negatively buoyant for the operation, it sunk in over 1000 ft. of water.

Incident 2:

An ROV with a severed tether was floating on the surface. A work boat was sent to retrieve it. The tether got caught in the work boat's propeller and the ROV was dragged at high speed into the propeller where it was reduced to bits and pieces.

Incident 3:

An ROV was conducting a bottom survey off a DP vessel in the Straits of Messina. The current was very fast at full floodtide and the support ship had to moor at the site to hold station. As the cage was being retrieved from 1,200 feet depth, the vessel took a violent turn and began drifting off station. Although it was agreed that the ship's main thrusters were not to be used when the vehicle was in the water, they were. The cable caught in one of the screws and was severed and the vehicle was lost. Another cage/vehicle and umbilical were installed on a winch and deployed. Almost miraculously, the lost vehicle was found within moments. A grappling hook was guided to the cage which was then recovered.

Incident 4:

An ROV had been operating from a new DP vessel in the North Sea. The vehicle was deployed to conduct a hull inspection of the vessel at the end of the primary operation. The standard procedure in this instance was to shut down all screws and thrusters. In the event that the vessel needed to maneuver, the vehicle cage was lowered well below the hull so as to preclude becoming fouled in the screws. In this case the cage was 200 feet below the surface. The vehicle proceeded up toward the ship's hull. After some period of time, the ROV operator could see the silhouette of the vessel but could make no progress toward it. Shortly thereafter, the vehicle was sucked into the ship's bow thruster and was destroyed. The vessel's Master thought he understood the order to be not to turn on the "main" thrusters.

Incident 5:

An ROV was operating from a tugboat. The mission was to inspect a pipeline being installed by a laybarge. The pipeline was being laid from deep to shallow water. As the tug reached shallow water (less than 50ft.) both the vessel's Master and the ROV operator became concerned for the safety of their respective vessels. The decision was made that the tug could remain just outside the surf zone and that the vehicle would operate to the limit of its tether (400 feet) from the cage. The vehicle accomplished the inspection into 20 feet of water and was returning to its cage when an unusually large wave was seen advancing on the tug. Fearing that he might broach, the tugboat Master put his screws in reverse to gain some sea room. The tether was caught in the screw and dragged the vehicle into it where the vehicle was destroyed.

Incident 6:

An ROV in the Gulf of Mexico was live-boating in excess of 300 feet of water. The vehicle was operating without a garage, but with a neutrally buoyant umbilical. The current was running steady at one to one and a half knots. The dive plan called for launching the vehicle on the down-current side of the area of interest and, after reaching bottom, it would proceed up-current and navigate on the bottom while the support ship maneuvered toward the target.

As the assembly was advanced up-current, the drag on the tether from the current caused the vehicle to lift off the bottom. In order to move the vessel up-current, the Captain found it necessary to turn the ship's bow into the current which resulted in the ROV tether streaming aft, dangerously near the vessel's port screw. After only a brief effort in this mode, it became apparent that this approach was neither safe nor smart. The effort continued until the odds and Murphy's Law overtook the ROV Operations Director resulting in the severing of the ROV tether by the vessel's port screw. The ROV with approximately 400 feet of tether was lost.

A lookout was posted using all available personnel. The vessel was maneuvered down current from the point of loss of the ROV. Within eight minutes after the loss, the ROV was sighted on the surface approximately 3/4 mile from the point of loss. The vessel was maneuvered alongside the ROV and the tether was picked up with a boat hook. The ROV was recovered, the tether reterminated and the ship repositioned for a proper approach to the target. Had the ROV been equipped with a negatively buoyant tether, the ROV would not have floated to the surface, which may have resulted in a total loss of the ROV.

Incident 7:

An ROV was operating in a live-boating mode. Instructions were given to the support ship's Captain by the ROV operator to turn to a given heading, upon which the Captain immediately responded. However, the operator wanted the ship to turn clockwise and the Captain turned counterclockwise. Not surprisingly, the umbilical passed under the ship's stern and was devoured by the thrusters. Murphy's moral to this story: Be sure that your communication with the ship's bridge is totally clear, and be sure that when you instruct the Captain to turn, that you state to starboard (right) or to the port (left). (Clockwise and counterclockwise is swiftly becoming archaic in the age of the digital clock.)

G.1.2 Structural Entanglement

Incident 1:

A vehicle was diving onto a sunken fishing boat to explore the potential for salvage. This type of activity must be undertaken with the utmost caution because of the polypropylene lines present on many boats, especially fishing boats. The operator dived into the area and located the vessel, then proceeded to move down the vessel, became confused as to his position and shortly thereafter became entangled. The umbilical parted due to the ship's heaving on it. One should undertake a full vehicle recovery the instant that one is uncertain about one's position. If possible, assess vessel orientation with a sonar and try to approach from the area which is least likely to have lines. Lastly, GO SLOW.

Incident 2:

This is an entanglement story that was preceded by a series of small failures that ultimately led to a loss of the vehicle. The entire tale will be told so that the reader can get the "flavor" of the operation.

The task was to demonstrate the capabilities of an uncaged ROV to conduct a bottom reconnaissance at about 787ft. depth while live-boating. Five days were allocated to conduct the demonstration. The operating area was 12 hours cruising from the port of embarkation. The vehicle was launched in a 10 to 15 knot wind and the operator proceeded to execute some maneuvers on the surface to get the feel of the vehicle. A strain was put on the cable which pulled it between the sheave and restraining rollers that were added to prevent it from being pulled out of the sheave. The cable ruptured and several conductors were severed 10 minutes after the vehicle was in the water. Twenty four hours were needed to reterminate the cable.

Twenty four hours later the operation began again. The vehicle dived to 450 ft where one of the two viewing lights went out. The vehicle was brought aboard; the light was examined. It could not be repaired. The dive recommenced. The vehicle was at about 210 ft depth when the second light went out. As the vehicle was being brought to the surface, the cable winch ran out of fuel. The vehicle was finally brought aboard but neither light could be fixed because the crew did not bring the spare parts required. The vessel headed back to port to obtain the spare parts being hand carried from the operator's facilities 900 miles away.

After fixing the lights, the ship departed for an alternate demonstration site. Three of the five demonstration days had now passed with no results. Upon arriving on station at midnight the crew immediately commenced operations. The area of operation was in a submarine canyon where numerous deep water lobster pots were planted. The wind had begun to pick up over the past hour. (Those of you who are familiar with underwater operations will now recognize that the plot has ominously thickened, and Murphy's Law, which was operating in low gear to this point, just slammed into high). At this point, the action is best described using entries from the operator's log:

0110 hrs:	Vehicle undergoing onboard checkout, color TV does not work (the only good break in the operation). Replaced with a black & white camera.
0155 hrs:	Vehicle in the water.
0232 hrs:	On the bottom, 492ft. depth. Start operations. Ship keeps dragging vehicle off station. Current too fast to turn vehicle around. Vehicle keeps making contact with bottom. Having a great deal of difficulty keeping cable away from ship's screws.
0251 hrs:	Decided to bring vehicle aboard. Vehicle seems extraordinarily heavy.
0300 hrs:	Cable broke. Lobster pot marker buoy 50 ft. to starboard.
0930 hrs:	Finished retrieving and replanting 26 lobster pots. No vehicle, no pinger response on RS-7 system. Sea 5 to 8 feet.
1105 hrs:	Terminated search. Vehicle lost.

Incident 3:

The vehicle was live-boating from a barge that was propelled by a tug. The Captain didn't seem to fully appreciate what was going on and started to undertake heavy maneuvers while the vehicle was on the work site. This activity finally worked the vehicle to the end of the umbilical. At this point, the vehicle was pulled underneath a boom and jammed in to the extent that it had to be worked loose. When the full load of the tug-barge system came on the cable, it parted. The lesson is, "ensure that the Captain fully understands the nature of the project before you go in the water". Probably, if he had been properly briefed, and had a video monitor and good communications with the operations crew, this would not have happened. Poor ship/sub co-ordination has been responsible for several such losses.

Incident 4:

A diver was undergoing a decompression stop at 65 feet depth in the North Sea. An ROV was deployed to monitor the diver. During the monitoring the sea began to build. After the diver completed his decompression stop, vehicle recovery began. The vehicle, however, was inside a structure and somehow had become wrapped around a brace. Before the vehicle could be worked out of the structure, the support ship had to leave station for safety reasons and the vehicle was sacrificed. The vehicle was later observed on the surface by a tug. One of the tug's crew engaged a boat hook into the motor guard of the vehicle. As he was pulling the vehicle aboard, the tug rolled and the vehicle slammed against its hull. This split the vehicle open and the electronics components dropped to the sea floor. Only the syntactic foam and thruster motors were recovered.

Incident 5:

An uncaged ROV was launched over the outboard side of a vessel tied alongside a platform. The ROV was to inspect the outside face of the structure as well as the riser and tubular at the bottom in 380 feet of water. The operator followed the near leg to the 360 foot depth horizontal member. He then followed a vertical diagonal member to the bottom level and back up the adjacent vertical diagonal to the riser. Visibility was from 6 to 8 feet. Unbeknownst to the pilot, the umbilical was led under a broken bracket above the vehicle and it snagged as it moved horizontally. When the vehicle could no longer move forward and the surface crew could no longer pull the umbilical back to the surface, the operator attempted to locate the snag by following his umbilical to the point of the snag. The pilot became disoriented. The decision was made to attempt to pull the umbilical free from the surface. The boat heave seemed to be a reasonable power source to perform the pulling. As the bottom of the support ship fell, the umbilical slack was taken up and the umbilical was secured to a bit. This was repeated several times until the umbilical was stretched to parting. The vehicle was left securely attached to the platform with over 300 feet of umbilical draped over and around it. This ROV was next seen by its owner when it was graciously presented to him by a competitor with an abundance of the competitor's company decals attached.

Incident 6:

While live-boating along a pipeline, an ROV passed on one side and the support vessel on the opposite side of a nylon buoy line that no longer reached the surface. The ROV's forward progress was slowed by the buoy line dragging on the umbilical. The operator attempted to reverse course to clear the umbilical from the buoy line. After reversing course, the ROV flew into a cloud of silt that had been raised by its initial passing. As a result, the ROV became entangled in the buoy line. The entanglement was worked up the buoy line to within 100 feet of the surface at which point a diver was sent down the umbilical to cut the buoy line free.

G.2 SHIPBOARD PROCEDURES

In this category are incidents where vehicles and systems were lost owing to procedures that took place aboard the support ship or platform. In many instances the result was entanglement, but the root cause was ascribed to the procedures or lack of procedures aboard the support platform.

Incident 1:

An ROV system was installed in the vicinity of a dynamically positioned crane barge's thrusters. During a test dive, the thrusters were inadvertently energized to insure their proper functioning. The ROV and its launcher were immediately sucked into the thruster, destroying both units. This situation would have never happened if the ROV crew had informed barge personnel that the ROV system was being deployed. Obviously, communication between the ROV and vessel crew is imperative any time the ROV is being operated.

Incident 2:

Many ROVs have been run over by surface ships. This has generally happened when the vehicle has become separated from its umbilical and is floating on the surface. As Murphy's Law would have it, this most often occurs near dark and with a rising sea. As most of today's supply boats have almost nothing with which to pick things up at sea as well as little rigging to facilitate a recovery, the inevitable happens: Some sort of grapnel is rigged and the Captain and crew try (under deteriorating conditions) to execute a recovery. They usually fail. Since the vehicle is not going to sink, it would be preferred to attempt to stay with the vehicle with the spotlight on it until conditions moderate.

Incident 3:

A vehicle was provided with a new type of tether termination while on a platform. In spite of suggestions that a proof test might be in order, the manufacturer said it was unnecessary. The vehicle was lifted up over the side and immediately fell over 100 feet into the water. While the plunge was awarded 9 points for artistic impression and 2 points for technical merit, operations were delayed. It is prudent to test new designs in the shop and on sea trials rather than at the work site.

Incident 4:

The lack of understanding of dynamic positioning (DP) has caused several losses. This is because the ROV crew has failed to appreciate that the DP vessel is actively maintaining its position relative to the bottom and the prevailing currents are often affecting the position of the umbilical relative to the ship. This lack of perception coupled with a live-boating umbilical (to allow working long distances from the ship) and an inadequate or inexperienced deck watch provides all the ingredients for a loss. Typically, the following happens: The vehicle is launched over the side and swims away towards the job site. The tide just happens to be favorable and the umbilical forms a catenary that is easy to work with and a substantial amount of cable is let out to allow for comfortable maneuvering. After a few hours of watching the cable, the deck watch loses interest and goes to have a coffee without determining, in consultation with the ship's officers, if there is likely to be a change in tide, weather or ship status. At this point, Murphy takes over: The tide changes; the umbilical comes back on the ship; no one is on deck to take up the slack; the pilot is surprised by the fact that he has suddenly left the bottom and he has almost immediately lost video and power, or as in one case, was surprised to see a large turning propeller in front of the vehicle moments before everything went black.

Incident 5:

Two derrick barges were working on a construction job offshore Malaysia. An ROV system was being shared by the barges and a workboat on an "as needed" basis. At one point the system was transferred from the workboat to one of the derrick barges. The system was installed near the base of a crane, but the ROV operator expressed concern that the location was too near the crane, and that the crane might hit it if it swung around. (For ease of handling the control van, the winch/skid/A-frame assembly and the generator were all mounted as one unit on a steel framework.) In spite of the operator's qualms, the system was set onboard the barge adjacent to the crane. The operator again expressed his fears, but was told to get on with the job. Shortly thereafter, the crane swung around and its counterweight caught on the edge of the generator shack and knocked the entire assembly over the side. Divers were dispatched to attach lift lines (in a depth of about 200 feet). When the unit was lifted above the surface (ironically by the same crane that knocked it overboard), the water inside the control van broke the van's doors open and carried with it all the spare parts and equipment not secured to the deck. The control console was irreparably damaged, the winch motor and winch, and the generator were immediately cleaned and made operable.

G.3 MISCELLANEOUS

This category primarily encompasses a number of incidents that resulted in a lost or damaged vehicle and caused by a variety of factors: weather changes, water changes, lack of communication, operator error or inattentiveness, manufacturing defects, and transportation mishaps. Similar to the incidents in the foregoing section (Shipboard Procedures), the net result was usually entanglement. But, once again, the root cause could be laid to a particular action or lack of action.

Incident 1:

A vehicle was hovering above a cable. Abrupt strain was put on the cable; it drew taught, ascended, and delivered a blow to the vehicle which demolished it.

Incident 2:

A vehicle was operating from a single point mooring in the North Sea. A wave came through the control cabin and knocked out the power. The effects of this occurrence on the vehicle are not known.

Incident 3:

An ROV was operating from a platform where welding was taking place. The vehicle was powered from the same generator the welders were using. At break time the welders turned the generator off. The vehicle floated to the surface, entangled in the platform and was demolished by waves. According to the bearer of this incident: "The welders and divers had a good laugh!"

Incident 4:

In April 1977, a client ordered two ROV systems of the ROV/cage type. The first system was deployed from a workboat. The workboat was in very poor mechanical condition. During the course of the operation, the port engine failed and the starboard rudder fell off; hence, a rudder with no propulsion across it and a propeller with no rudder behind it. The support ship was moored by a single bow line to a structure (about 100 feet between each) in water depth of approximately 300 feet. The vehicle had been deployed and working for several hours. Before the vehicle was retrieved a squall passed through the area and the ship's Master could not keep the ship out of the wave troughs. At one point the ship took an exceptionally heavy roll and the cable went slack, when the ship recovered and rolled the opposite way the cable parted. After recovering the cable and cable stop, it was discovered that the pin that attached the cable stop to the launch cage was missing. The first conclusion was that the pin was installed improperly or the safety cotter key was not installed; hence, operator error. A decision was made to bring a second system, which was being delivered from the manufacturer, to find the first and then decide how to recover the lost vehicle/cage.

When on the job site, the second vehicle located the lost one within two hours. A visual inspection revealed that two welds had parted on the top of the cage and the pin had been ripped out of the cage (the cotter key was still hanging in the end of the main pin). This placed the blame on the manufacturer, i.e., a weld; not operator error. The vehicle itself was out of the cage on 20 feet of tether, and being positively buoyant, was floating above the cage. The cage was sitting upright on the bottom.

Consideration was given to calling in divers or attempting to retrieve the vehicle/cage with the second ROV. During these considerations the sea state was increasing. The time to do something was swiftly decreasing and the client was showing signs of increasing frustration to get on with the job. The manufacturer was contacted to find out the breaking strength of the tether cable: 1,300 lbs. The cage weight (in water) was given at 380 lbs. This, it was assumed, gave better than a 3:1 safety factor if the cage were to be lifted by the tether.

The original idea was to lower a grappling hook on a lift line from the vessel which the second vehicle could maneuver over to the cage and hook it thereto. Since the support ship had only one screw and a broken rudder, maneuveuring of the ship was out of the question. The plan that evolved, therefore, was to wrap the tether of the second vehicle around the tether of the floating first vehicle and tow the vehicle (and cage) into shallow water where a diver could attach a lift line.

The second vehicle made several wraps around the first vehicle's tether and all seemed in order. The winch began to retrieve the second vehicle, and as soon as tension was taken on the winch the tether went out. The tether, however, had not parted, only the video conductor parted. The second vehicle had somehow unwrapped itself from the first vehicle; its cage was brought aboard. The vehicle had to be retrieved by a boat hook since the cage winch was inoperative. The decision to retrieve the first vehicle was nullified, and a new decision to replace the damaged tether and get on with another job on a nearby platform was made. Since the next job would only take about 30 minutes and would be followed by a 12 hour cruise to the next job site, the ship's Master and the ROV crew chief decided that they might as well get the job over and then sleep without interruption.

The ship was moored by its stern to another platform; stern into the current. The riser to be inspected was on the downcurrent side of the structure. The area in which they were working was off the Mississippi River where water visibility was very poor at the surface but improved at depth. The general approach to structure inspection in this area is to lower the cage to a point where its top is level with the water's surface and fly the vehicle out of the cage and proceed on the surface to the structure and then follows a leg or riser to depths where the water is clear. The "tether out/tether in" switch was not mounted on the hand controller. When the operator gave the command "tether out" to another operator at the main control console he meant to pay out only 5 or 6 feet of cable, however, the control console operator though he meant pay out the tether until he was told to stop. Meanwhile, the ship's Master at this point noticed a shift in the wind and, fearing impact of the ship with the structure, put the screw in a slow idle. Very rapidly the tether caught in the screw and the vehicle was drawn in, chewed up and sunk. It was never found although the vehicle's pinger was tracked for 18 hours as it drifted off beneath the surface. Divers retrieved the cage of the first lost vehicle. The vehicle itself was found 60 days later after it drifted ashore 200 miles from the site of the accident; the finder was rewarded with $5000.

Incident 5:

During a subsea blowout an ROV was deployed to check the connection of an hydraulic "kill" line to the BOP. Divers could not be used because of the vortex created by the oil rushing out of the hole. Control of the vehicle was extremely difficult due to the vortex. The client was notified that if the vehicle went any closer to the vortex it would be lost. He insisted and took full responsibility for the loss. On the next dive the vehicle was swept upward, the tether parted and the vehicle was lost. The next day it was picked up by a tug in the vicinity. There was no damage to the vehicle itself. The operation was repeated and again the vehicle was swept upward, but this time in pieces.

Incident 6:

An operation had just successfully terminated off Australia. The ROV system was packaged and sent as deck cargo to Singapore. When the transporting vessel arrived in Singapore some weeks later, it reported that all deck cargo had been lost, including the complete ROV system. A typhoon was blamed for the loss although no inclement weather was reported or seen by satellite during this period. The case was still in litigation (regarding responsibility for the loss) when these guidelines went to press.

Incident 7:

Working in support of a drilling operation off Australia, an ROV was sitting on the bottom waiting to inspect a piece of drilling hardware that was to be mounted on the bottom. The component was lowered directly on the vehicle and crushed it. The vehicle was completely written off.

Incident 8:

An ROV was working outside its cage when it underwent an internal short circuit in its tether. This caused an arc which rent the tether in two. The vehicle ascended and, quite remarkably, free-floated up into its cage and, of its own accord, latched itself securely into the cage. Indeed, so securely that a green light on the control console was activated which indicated that the vehicle was caged and locked in; it was subsequently retrieved. (Demonstrating that a pure heart and righteous cause can, occasionaly, beat Mr. Murphy at his own game.)

Incident 9:

A nylon strap of proper load capability was rigged over the pin of a shackle on the vehicle as it was being launched for a test dive. As the vehicle was lifted over the side the strap broke and the vehicle was unexpectedly launched. Operating personnel had just finished coiling the umbilical on deck and were fortunately clear of the coil when it suddenly followed the vehicle into the water.

Examination of the failed nylon strap showed that it had been cut. Examination of the shackle pin showed that it had been tightened — or loosened using a vicegrip pliers or a pipe wrench on the center load-bearing part of the pin. The pin had many sharp edges on it and easily cut the nylon strap as the load was being applied.

- Lesson 1: Do not use nylon or synthetic line (that stretches under load) on lifting rigs that have sharp edges or that can cut the line.
- Lesson 2: Do not use the wrong tool for the job, i.e., a pipe wrench on the pin of a shackle. A wrench or marlin spike on the eye of the shackle pin is the correct procedure.

Incident 10:

During a recent operation an ROV was being exercised in shallow water near an island. The operation lasted all day which gave adequate time for the environmental conditions to change. When the vehicle was launched, the wind was up-island from the moored, support platform. The large vehicle umbilical was floating near the vehicle but caused no problems until recovery. With a 180 degree change in the wind direction, and a slight change in the current, problems were encountered when the vehicle was on the surface returning to the barge. The wind and current now acted on the umbilical to force it toward the platform. The vehicle did not have enough power to counter the extreme forces acting on the cable and it too was pushed toward the barge. Unfortunately, for proper storage of the umbilical, its floats had to be removed by hand, which prevented the deck crew from keeping up with the umbilical's movement toward the platform. In a very short time the vehicle and the umbilical were next to the platform. The vehicle was thrust to the bottom allowing it to pass below the barge and the barge was quickly disconnected from one of its mooring legs, thereby allowing it to move with the wind and from atop the vehicle. In this position, the vehicle and its umbilical were more easily recovered, however, it was a long night before the platform was back in its moor and the crew resting. Thus, a lesson learned: If the environment is going to change, it will probably change for the worst. Be familiar with local environmental variations and plan for them prior to the operations, not during.

Supervisory Control System for the JASON ROV

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(Invited Paper)

Abstract—**A prototype supervisory control system for a remotely operated vehicle (ROV) is described and several key elements demonstrated in simulation and in-water tests. This system is specifically designed to fill the needs of JASON, a new ROV under development that will perform scientific tasks on the seafloor to depths of 6000 m. JASON will operate from the ARGO towed imaging platform, which is currently operational.**

Supervisory control is a paradigm for combined human and computer control. Several key elements of the supervisory control system are presented. These include the closed-loop positioning system based on a high-resolution acoustic navigation system, a monitoring capability for assessing performance and detecting undesirable changes, and an interface that allows the human operator and the computer system to specify the desired vehicle trajectory jointly.

I. Introduction

THE DEEP SUBMERGENCE Laboratory of the Woods Hole Oceanographic Institution is currently developing JASON, a remotely operated vehicle (ROV) for deep-ocean scientific applications. JASON will be deployed from the ARGO optical and acoustic imaging vehicle [1], which is now operational (Fig. 1). A major emphasis of the JASON program is the refinement of supervisory control techniques that will allow carefully controlled, coordinated movements of both the vehicle and manipulators from high-level commands issued by the human operator.

The supervisory control system will be built on closed-loop trajectory controllers. Closed-loop control of manipulator functions is common in the offshore industry today, and servo-controlled arms are available from several manufacturers. However, the closed-loop control of vehicle movement is not presently available. Although automatic depth and attitude controls are commonly found on many vehicles, full closed-loop control of vehicle translation requires that many difficult problems be solved.

Simultaneous control of both vehicle and manipulator motions can have many important benefits. The need for heavy grabber arms or variable ballast systems that allow the vehicle to park on the seafloor can be avoided by controlling the vehicle movements in closed-loop. Further, eliminating the need to anchor the vehicle can greatly reduce the amount of time required to perform manipulation tasks. Taking advantage of finely controlled vehicle movements can also reduce the number of manipulator degrees of freedom required to execute a specific task. The resulting reductions in vehicle size, weight, power, and mechanical complexity are especially attractive for a full ocean depth vehicle such as JASON. The same vehicle translational controls could greatly improve performance in offshore platform inspection tasks, particularly in the presence of high current and poor visibility.

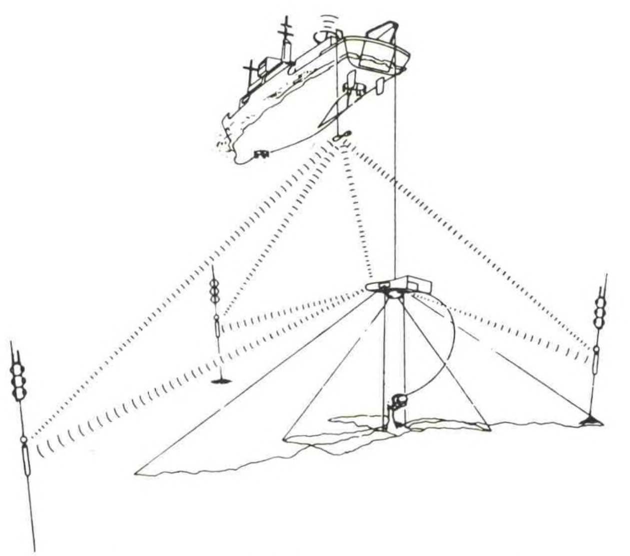

Fig. 1. JASON will be an ROV that can emerge from the towed ARGO platform to perform close-up inspection and manipulation tasks.

An ROV supervisory control system has many elements. The closed-loop control system must insure a high level of performance while being tolerant of poorly known vehicle dynamics and disturbances. The closed-loop systems should contain monitoring features that can provide information to the operator about the state of the system and which can alert him if a problem arises. Finally, the supervisory control system should provide flexible methods for the human operator and the computer system to define the desired trajectory jointly. This allows the human operator to offload portions of the control task to the computer system, while retaining those that require the operator's skill.

This paper describes two important elements of the supervisory control system: the closed-loop control of vehicle translation and the interactive trajectory generation. The closed-loop control is demonstrated in pool tests with a

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prototype vehicle, and the interactive trajectories are demonstrated in simulation trials.

II. Underwater Vehicle Dynamics and Control System Design

Underwater vehicles present control system design problems that are poorly matched to traditional approaches. The dynamics of such vehicles are described by high-order models that are nonlinear and uncertain. A typical model of an ROV has over 200 coefficients representing various nonlinear effects [2], [3].

Although techniques for producing good models of vehicles are well advanced, the corresponding control methods are not. The linear control techniques which are generally used for control system design cannot take advantage of the detailed nonlinear models that modern hydrodynamic analysis provides. Detailed information about the dynamics of the system is discarded when the model is linearized unless the system state remains sufficiently close to that about which the dynamics were linearized.

Linear techniques can produce stable designs for high-order nonlinear systems such as vehicles, but a set of many linearized controllers is required for good performance. The use of a single linearized control law will result in inconsistent performance as the velocity of the vehicle changes. For improved performance, a linear controller for a submarine might use several controllers, each designed using a model of the submarine linearized about one value of forward speed [4]. As the submarine changes speed, the gains will change accordingly.

This approach is impractical for a vehicle that can move in all directions, like many underwater inspection and work vehicles, because there are no obvious operating points about which to linearize. Such a situation could only be handled by a large number of linear controllers designed for different combinations of speed along all axes. However, even if a complex design using many linear controllers were implemented, the stability of such "gain scheduled" systems might be questionable.

A good control system design methodology for underwater vehicles would allow a designer to use a single nonlinear model of vehicle behavior directly, without linearization. This would permit one controller to be used rather than requiring that the controllers change as the speed changes. The methodology should also allow the model upon which the controller is based to be systematically simplified while explicitly preserving stability. The performance implications of all simplifications should also be explicit, so that the designer can preserve the terms that contribute most to performance.

We are pursuing a methodology called sliding control [5] to satisfy these requirements. These techniques have been applied to other difficult nonlinear control system design problems, particularly the trajectory control of high-speed robots [6]. The benefits of the sliding methodology for underwater vehicle control have been demonstrated in simulation [7] and with a test bed underwater vehicle as described later in this paper.

III. Robust Control of Nonlinear Systems Using Sliding Control

This section describes the basic features of sliding control, with emphasis on the design implications. More complete discussions of the underlying theory and details of implementation can be found in [5]–[7].

A. Specification of the Desired Closed-Loop Dynamics

All closed-loop control system design involves transforming the natural dynamics of a system to dynamics that are more desirable. Although vehicle dynamics are nonlinear, it is reasonable that the target closed-loop dynamics be linear.

Traditional regulators are not sufficient for control of the trajectory of a vehicle or a manipulator; tracking controllers are required. For a second-order system, the controller should make reasonable compromises between position and velocity errors along the desired trajectory. This requires that the target dynamics include both position and velocity error terms.

For a system of order n, the control system design can be simplified considerably by choosing *a priori* well-behaved target dynamics of order $n - 1$. This permits us to deal only with first-order, if nonlinear, differential equations in the controller design [5].

For a second-order mechanical system, reasonable linear target dynamics would specify a stable first-order relationship between position and velocity errors, for example,

$$0 = \dot{\tilde{x}} + \lambda \tilde{x} \tag{1}$$

where $\tilde{x}$ is the displacement error, $\dot{\tilde{x}}$ is the velocity error, and λ is a constant used to set the break frequency of the desired first-order error response.

Linear error dynamics such as this can be represented as a surface in state space that passes through the desired state. For a second-order example, this corresponds to a line that passes through the point $(x, \dot{x})$. As shown in Fig. 2, this line will move with the desired state. If the system state can be forced to remain on the line, then the target dynamics are exactly achieved and the state will proceed toward the desired state in a manner consistent with the target dynamics. As a result, the state "slides" along the line, which is called the *sliding surface.* As detailed in [5] and [6], this concept can be directly extended to higher order systems.

In the case where the desired dynamics are not perfectly obtained, the sliding surface also provides a convenient metric of the error. The variable s is a measure of the algebraic distance between the sliding surface and the current state

$$s = \dot{\tilde{x}} + \lambda \tilde{x}. \tag{2}$$

The error metric s that is used in the feedback term in the feedback control law is also useful in system monitoring.

B. The Sliding Control Law

For a single-degree-of-freedom system, the sliding control law consists of two parts. The first part is a model-based or "computed" element, and the second part is a nonlinear feedback component

$$u = \hat{u} - k(X;\ t)\ \mathrm{sgn}\ (s) \tag{3}$$

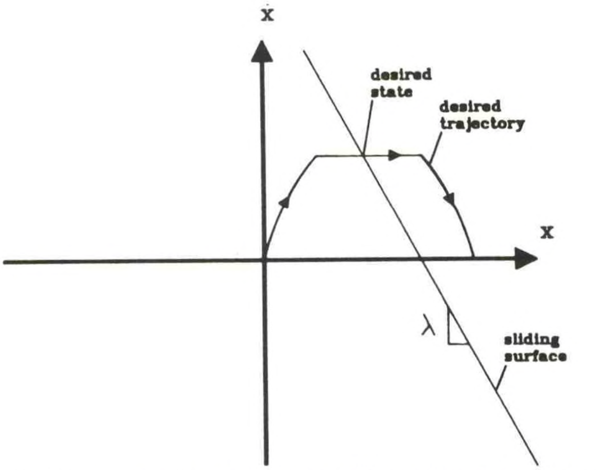


Fig. 2. For a second-order system, a typical sliding surface consists of a line that passes through the current desired state.

where sgn is the signum function

$$\text{sgn}\ (x) = 1, \qquad \text{for } x > 0$$

$$\text{sgn}\ (x) = -1, \qquad \text{for } x < 0.$$

The computed control $\hat{u}$ uses the available model of the system dynamics and the sliding surface definition to determine a control action that would keep the state on the sliding surface if the model were perfect. The feedback component insures that the state will be drawn to and remain on the sliding surface despite uncertainty in the model and the resulting imperfection in $\hat{u}$. The function $k(X;\ t)$ can be determined directly from Lyapunov stability considerations given the system model, the sliding surface definition, and estimates of model uncertainty and disturbances [5], [6]. Generally speaking, $k(X;\ t)$ increases as $\hat{u}$ becomes less precise, since a larger discontinuity is required to keep the state on the sliding surface.

This type of control law can guarantee that the system state remains on the sliding surface. In other words, the target dynamics are exactly achieved and tracking is perfect. However, the control action resulting from the discontinuous feedback term will produce control chattering that is unsuitable for most applications, since it may excite high-frequency unmodeled dynamics. Structural modes and actuator time delays are potential sources of these unmodeled dynamics.

The control law can be modified to solve this problem. The bandwidth of the feedback portion of the control action can be limited if the control action is smoothed over a "boundary layer" of variable thickness ϕ that lies on each side of the sliding surface (Fig. 3). The continuous control law may be written as

$$u = \hat{u} - k(X;\ t)\ \text{sat}\ (s/\phi) \tag{4}$$

where sat is the saturation function

$$\text{sat}\ (x) = x, \qquad \text{for } |x| < 1$$

$$\text{sat}\ (x) = 1, \qquad \text{for } x > 1$$

$$\text{sat}\ (x) = -1, \qquad \text{for } x < -1.$$

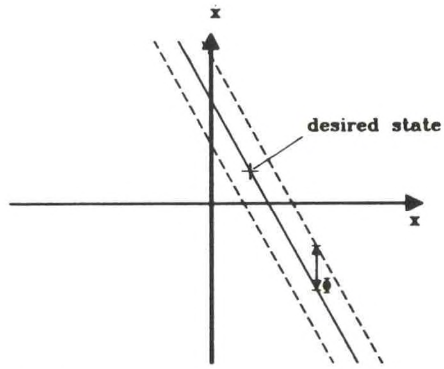


Fig. 3. The bandwidth of the control action can be limited by interpolating the control action across a "boundary layer." This interpolation produces a trade-off between model uncertainty and performance.

This interpolation assigns a low-pass filter structure to the feedback and therefore to the closed-loop dynamics. To obtain this bandwidth-limited control, however, the perfect tracking of theoretical pure sliding control must be slightly compromised. The state will not remain exactly on the sliding surface, yet is guaranteed to remain inside the boundary layer if the uncertainty estimates are valid. In practice, the performance penalty has been found to be slight, and acceptable performance can usually be obtained even with large uncertainty in the model parameters.

This structure can assure stability, guarantee a prescribed level of performance, and insure that high-frequency unmodeled modes in the system are not excited. The procedures for composing $\hat{u}$, $k(X;\ t)$, and ϕ are detailed in [5] and [6], and their application to underwater vehicles is detailed in [7].

C. Extension to Systems with Multiple Degrees of Freedom

The nonlinear equations describing the dynamics of a vehicle or a manipulator are often highly cross-coupled, making the control problem more difficult. If such a nonlinear model is linearized, the resulting linear system is also highly coupled. A high-order linear controller must be designed, or important coupling terms will be ignored. Sliding control allows the control system to be decoupled into a set of low-order controllers, one for each axis, while still explicitly accounting for the coupling terms.

For each axis of the vehicle or manipulator, a separate low-order sliding surface is specified. For most vehicles, each sliding surface can be first order:

$$s_i = \dot{\tilde{x}}_i + \lambda_i \tilde{x}_i. \tag{5}$$

If integral control action is desired, then the sliding surface would be second order.

For a multiaxis system, each axis will have a control law of the form

$$u_i = \hat{u}_i - k_i(X;\ t)\ \text{sat}\ (s_i/\phi_i). \tag{6}$$

The model used to compute $\hat{u}_i$ can contain as many cross-coupling terms as are necessary to obtain the desired performance. All modeled aspects of cross-coupling are used to compute $\hat{u}_i$, while uncertainty in the cross-coupling effects contributes to the magnitude of $k_i(X; t)$. This allows a series of coupled low-order controllers to be used rather than a single high-order controller, producing simpler and more tractable designs.

D. Implications for Modeling and Parameter Estimation

Models of vehicles are uncertain due to errors in the model structure, errors in the model parameters, or because certain parameters have been dropped completely. The sliding control methodology allows the designer to judge the importance of a given element of the model directly in terms of tracking performance. For a nonlinear vehicle model with several hundred terms, many terms can be discarded in the model used to design the controller. The controller can be made explicitly robust to the elimination of these terms with only a small performance penalty but with a large reduction in controller complexity. Similarly, if bounds on the disturbance forces can be estimated, their contribution to tracking error can be computed directly.

The quantitative relationship between model uncertainty, disturbances, and performance has important implications for the entire design process. Rather than starting the control system design with a model with very low uncertainty (probably obtained at great expense and possibly more uncertain than one expects), a much simpler model can be used with confidence. Note that this simplification does not mean linearization, but rather the elimination of coefficients whose influence is small.

Large simplifications in the model can be made without jeopardizing stability and often without significantly degrading performance. Any force term can be eliminated, simplifying the structure of $\hat{u}$ and boosting $k(X; t)$ and ϕ. The increase in ϕ and the resulting change in the performance bounds can be computed directly. Generally, only a few important parameters are required for each axis, greatly reducing the amount of model testing or analysis required and making the controller easier to implement.

E. Sliding Control and Monitoring

Sliding control includes important elements for sophisticated monitoring of the status of the closed-loop system. The key is the quantified tradeoff between uncertainty and performance. If the state remains inside the time-varying boundary layer ($|s(t)| < \phi(t)$), then the total uncertainty is below that acknowledged in the design of the system. However, if the state goes outside the boundary layer, a problem has arisen. The system can either alert the human operator or signal an autonomous subsystem. The information generated when the system is outside the boundary layer can also be used to improve the model of the system on line [9].

IV. Demonstration of Sliding Control for Underwater Vehicles

The control technique was demonstrated in a pool using the Benthos RPV-430 vehicle. These tests provided confirmation of the usefulness of the method following simulation studies [7], [8].

A prototype navigation system was used to provide high-quality position information. The Sonic High-Accuracy Ranging and Positioning System (SHARPS), developed by Applied Sonics Inc., provides high resolution (several millimeters) at update rates exceeding ten samples per second even in high multipath environments. The system consists of a responder placed on the vehicle and a set of hard-wired receivers placed in a triangular net.

Using traditional state estimation techniques, velocity estimates were constructed from the position measurements and the yaw rate measurements from the vehicle. The state estimator was also able to discard bad position fixes caused by vehicle electrical noise.

All functions, including navigation, state estimation, control, data logging, and graphic displays, were implemented on an IBM PC-AT, an 80286-based microcomputer equipped with an 80287 math co-processor. All computations ran at 10 Hz.

A very simple model of the vehicle was used for this test. For each axis controlled by the computer, a single inertia and drag coefficient was determined from simple step response tests using the vehicle and navigation system. Uncertainty estimates were 50 percent for each term. Due to an unmodeled coupling between translation and attitude of the vehicle, the closed-loop bandwidth of the system was limited to 0.2 Hz.

Fig. 4 shows the desired and measured track of the vehicle. Each straight line segment consisted of constant acceleration, constant velocity, and constant deceleration sections. Heading and depth were held constant throughout the test. Position errors are typically less than a few inches at full speed, and very small as the system slows down.

Fig. 5 shows the desired and estimated forward displacement of the vehicle. Errors are very small and transient behavior good despite the extremely low closed-loop bandwidth.

Fig. 6 shows s plotted versus time for the forward motion of the vehicle. The boundary layer thickness ϕ is plotted as well. Uncertainty increases as the vehicle speeds up due to the uncertainty in the drag coefficient, so the boundary layer expands. Errors (as shown by the value of s) also increase; however, they remain below the anticipated magnitude, indicated by ϕ.

Sliding control provides analytical guidance about how performance can be improved. The boundary layer thickness ϕ corresponds to a time-varying bound on the magnitude of the error metric s. The contribution of the uncertainty of each model element, the disturbances, and the desired closed-loop bandwidth λ to the magnitude of ϕ can be examined. For a second-order system, the maximum position error can be related to the boundary layer thickness ϕ by

$$|\tilde{x}|_{max} = \phi/\lambda. \quad (7)$$

Fig. 7 shows the maximum magnitude of the displacement errors at zero and maximum speed as projected by the boundary layer of Fig. 6. This projection can be broken down into components that depend on the following:

a) the specified closed-loop bandwidth λ;

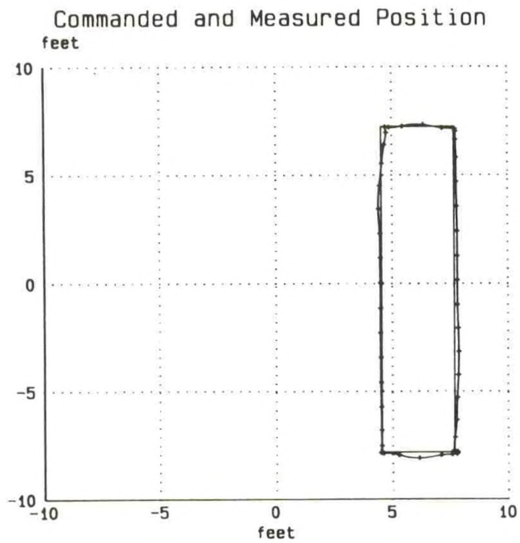


Fig. 4. This plot shows the desired and actual trajectory of the vehicle in a pool test. Each trajectory segment consisted of constant acceleration, constant velocity, and constant deceleration sections. Heading and depth were held constant throughout the run.

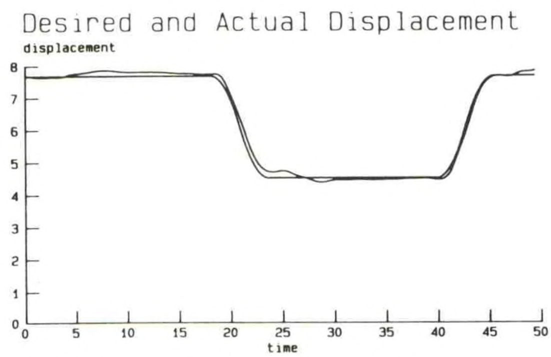


Fig. 5. Desired and estimated displacement in the forward direction is shown as a function of time. Performance was very good despite substantial model uncertainty and limited control bandwidth. Evidence of the attitude oscillations can be seen when the vehicle decelerates.

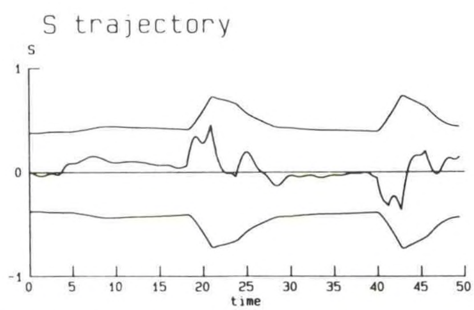


Fig. 6. The error metric s is plotted along with the time-varying boundary layer ϕ. The boundary layer expands when the vehicle speeds up due to uncertainty in the drag force. The state always remains inside the boundary layer, indicating that dynamic uncertainty is always less than the estimated bound.

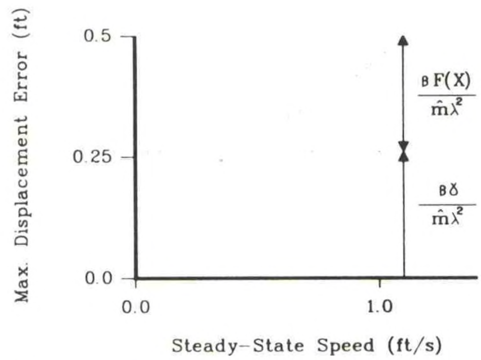


Fig. 7. The maximum displacement error $|\tilde{x}|_{max}$ can be related to the closed-loop bandwidth λ and the model uncertainty. Components of model uncertainty include the multiplicative uncertainty in the mass β, the additive error in the drag force $F(X)$, and the maximum unmodeled force γ. The explicit relationship between the components of model uncertainty and performance will often allow the vehicle model to be simplified with a minimum impact on tracking performance.

b) the estimated effective mass $\hat{m}$;
c) the multiplicative uncertainty in the effective mass β;
d) the additive uncertainty of the drag force $F(X)$; and
e) the maximum disturbance force γ.

This plot shows the relative importance of these terms, and also indicates how their importance varies with speed. All components are inversely proportional to λ^2, and proportional to the multiplicative uncertainty in the effective mass β. The additive uncertainty of the drag $F(X)$ and the disturbance magnitude each contribute in an additive fashion. The ability to compare the influence of these factors in a nonlinear setting is extremely useful to a designer and is a unique feature of this approach.

Increasing the closed-loop bandwidth is clearly the best way to improve performance, as translation errors will be reduced by λ^2. In this implementation, λ could not be increased beyond 1.4 rad/s (0.22 Hz) or the attitude modes of the vehicle would have been excited by translational motion.

The closed-loop bandwidth could be increased if:

1) The coupling between translation and attitude could be reduced. This could be achieved by moving the center of mass closer to the line of action of the horizontal thrusters;
2) The frequency of the attitude oscillations were increased. This could be done by increasing the metacentric height of the vehicle;
3) The attitude oscillations could be measured and their influence on the position measurements removed. Angular displacement and velocity could be measured and their dynamics included in the vehicle model.

Any of these changes would allow the closed-loop bandwidth to be increased. As shown in Fig. 7, any increase in the closed-loop bandwidth contributes strongly to the performance.

Reducing the uncertainty of the effective mass will reduce the maximum displacement error. However, improving the effective mass estimate from the coarse value used here (multiplicative uncertainty of 50 percent, i.e., $\beta = 1.5$) to a precise value (such as $\beta = 1.1$) would reduce the maximum displacement error by less than 30 percent. This might not justify the effort required to produce the refined estimate, but in any case the potential improvement from better modeling is quantified.

Reducing the uncertainty in the drag and disturbance forces will have a direct benefit. With little effort, the uncertainty in the drag force could be reduced through more refined testing. However, unless measurements or estimates of the forces produced by the disturbances are available (such as those produced by a current or the tether), the performance benefits from a very detailed model will not be significant. Likewise, the benefits obtained from instrumenting the tether force or including a current measurement may be much greater.

These techniques provide a much closer coordination between vehicle modeling and control system design efforts. The required model quality and vehicle characteristics can be determined based upon the desired tracking precision. This can lead to reduced modeling and testing as well as a simple control system with known performance.

V. Interactive Trajectory Definition for ROV's

In the uncertain underwater environment, human interaction with the vehicle is essential for most inspection and manipulation tasks. However, the precision and repeatability of automatic control is desirable. The supervisory control system combines the benefits of automatic control while allowing the human operator to continuously command the desired trajectory. The computer is employed to perform the following tasks: positioning the vehicle and rejecting disturbances, accepting and conditioning the operator's command inputs, and presenting the operator with an informative display to help in system monitoring.

The supervisory control system allows the operator to input movement commands in a reference that corresponds naturally to the task. This reference may be a particular Cartesian frame, a very distorted field that conforms to the environment, or the reference may lock the vehicle into a predefined track while allowing the operator to continuously specify vehicle speed along the track. Five versions of coordinate transformations are considered here: body-reference coordinates, fixed-reference joystick coordinates, cylindrical coordinates, complex coordinates, and predefined path or search trajectory coordinates.

A series of simulation trials was undertaken to demonstrate several forms of trajectory definition, and to compare the supervisory control modes to each other and to manual control. These were not controlled experiments, but rather a demonstration of these methods and a qualitative comparison between the control methods. An experienced ROV pilot was used as the subject for the trials.

A. Body-Referenced Coordinates

In the simplest form of supervisory control considered, the operator's commands are similar to manual control commands; commands are defined in a coordinate frame that moves with the vehicle. The operator may even be unaware of the presence of the computer control, except that the dynamics have become much simpler and disturbances are dealt with automatically. For example, when the operator allows the joystick to return to the center position, this does not correspond to zero thrust but to zero velocity, and the vehicle will actively fight currents or tether forces to remain at its present position.

Usually, when an operator is flying an ROV manually, he is viewing the world through the vehicle's video camera. Therefore, joystick coordinates fixed relative to the body coordinates of the vehicle are matched to the operator's view of his environment. These body-referenced coordinates are incompatible with a fixed-referenced (i.e., north up) display, and should be matched to a display in which the environment moves while the vehicle remains fixed.

B. Fixed-Reference Joystick Coordinates

Many tasks are better understood by observing a fixed reference top view or map display of the vehicle and its surroundings. Such a display provides a reference that does not move with the vehicle but is fixed in world coordinates giving the operator a natural coordinate system in which to control vehicle motion. In this case, the joystick commands are compatible with the display. Not surprisingly, controlling the vehicle in a fixed reference frame seems more natural and appears to improve performance when the operator is viewing the map display rather than the vehicle video.

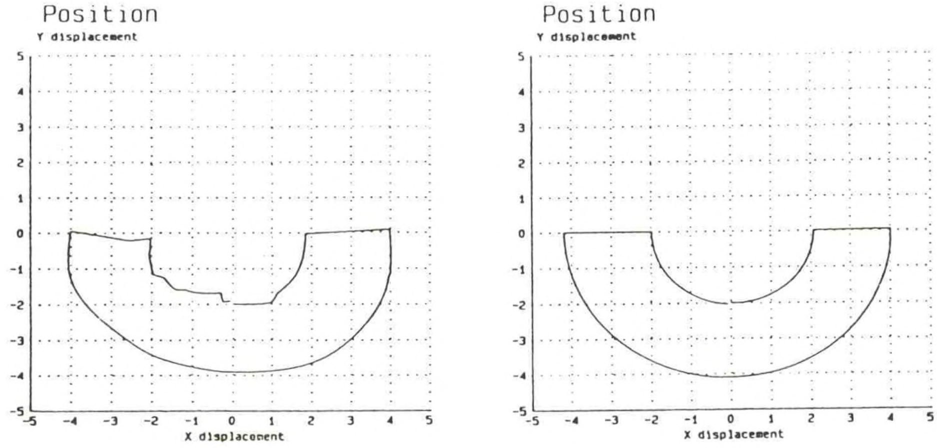
C. Cylindrical Coordinates

A further development of the coordinate system involves warping the Cartesian reference frame into shapes that match the environment, thus reducing the number of degrees of freedom which the operator must simultaneously supervise. In a cylindrical-coordinate mode, the operator can symbolically indicate that the vehicle's workspace centers on a piling or similar upright cylinder. A port or starboard command on the joystick will then result in a translation of the vehicle around the piling, keeping a constant stand-off distance and continuously facing the piling. Forward and aft commands on the joystick will move the vehicle closer to and farther from the piling. The vehicle will remain pointed at the center of the target cylinder at all times. Such a system would be useful, for instance, when inspecting a platform leg, or in guiding a manipulator to a target. Computationally, cylindrical coordinates require only that the vehicle heading be constrained to point at the center of the coordinate system.

A trial of this mode simulated an inspection task where the vehicle was required to fly semicircular paths around a fixed point while keeping the vehicle headed toward the point. In the cylindrical mode, this required only simple joystick commands and was performed quite accurately (see Fig. 8). In the Cartesian-coordinate mode, the operator had to control two displacements and heading to follow the desired track. In this preliminary demonstration, the cylindrical coordinate mode showed better track following performance, and the subject felt the task was made easier.

D. Complex Coordinates

Another method of conforming the operator's commands to the environment can be used in more complex environments, which are modeled as combinations of simple shapes. An



(a) (b)

Fig. 8. Semicircular path trials show better track following cylindrical joystick coordinates than with body-reference joystick commands: (a) shows the less precise vehicle path achieved using Cartesian joystick coordinates; and (b) shows the better vehicle path achieved with cylindrical joystick coordinates.

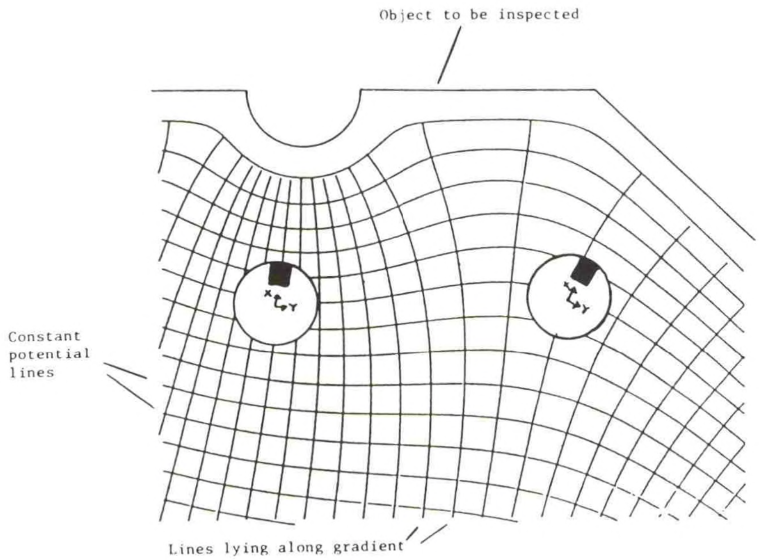


Fig. 9. Fig. 9 shows potential fields for an arbitrary barrier. The topmost line represents the barrier itself, made up of two intersecting walls and a vertical cylinder set into one wall. The lines approximately parallel to the wall are lines of constant potential which will correspond to athwartships joystick commands. The lines orthogonal to the constant potential lines correspond to forward and aft joystick commands. Smooth transitions are made at the corners with the radius of the turn increasing as the vehicle track gets farther from the wall.

example is shown in Fig. 9. This would apply to many types of inspection tasks, where the ROV must be maneuvered around an offshore structure, ship hull, etc. In this scheme, port and starboard joystick commands cause the vehicle to move along the object to be inspected at approximately constant distance. Forward and aft commands move the vehicle closer to and farther from the barrier. Heading is constrained so that the vehicle always points toward the objects to be inspected.

An inspection or search task can be greatly simplified by the complex constraints on vehicle motion. The operator can easily maintain constant distance from the objects and can rapidly scan the surface for interesting features.

The implementation is similar to a well-known technique for path planning and obstacle avoidance [10], [11]. An imaginary "potential field" surrounding each object is defined. The total potential and the gradient of the potential field from all objects are then computed for the current vehicle position. Vehicle heading is then constrained to point up the gradient. Sideways commands move the vehicle along lines of constant potential, while forward and reverse commands move the vehicle along the gradient of the potential field. This results in a coordinate space that conforms around the objects, and provides smooth

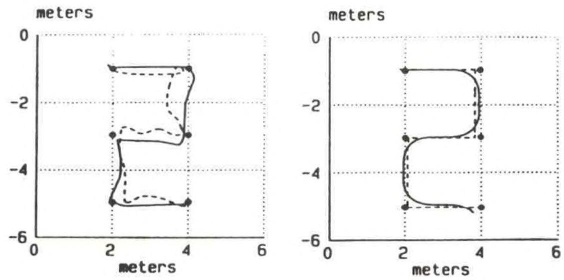


Fig. 10. Fig. 10 compares vehicle paths in the search trajectory trials. Vehicle path in body-reference joystick coordinates using supervisory control (solid line) and with manual control (dashed line) is shown in (a). Vehicle path using predefined trajectory definition (solid line) and fixed-reference joystick coordinates (dashed line) is shown in (b). The corners on the predefined trajectory path are rounded because constant accelerations in both directions were imposed during the supervised transition phases. Qualitative comparisons indicate that the more sophisticated forms of trajectory definition produce better track following as well as reduced operator workload.

transitions between objects. The computational burden is small and increases linearly with the number of objects.

The cylindrical coordinate computation is a simplified form of the complex coordinate computation where the only object is an upright cylinder.

E. Predefined Trajectories

Vehicle degrees of freedom can be further constrained by defining a fixed path for the vehicle to follow. This differs from preprogrammed control by allowing the operator to continuously specify vehicle velocity along the defined track. The operator can fly the vehicle at a comfortable speed, watching for an object of interest, and can stop or even back up, but cannot get off the path or lose track of his absolute position. As in the previous methods, the demands on the operator are shifted so that he can concentrate on that part of the job which only human operators can perform.

F. Supervisory Control Trials

Simulation trials were conducted in which the vehicle was required to fly a grid search pattern. A steady current corresponding to approximately 10 percent of full vehicle thrust in a diagonal direction was simulated, and Gaussian noise was added to measurements of vehicle position and velocity, which were then filtered.

The operator flew the vehicle in the following modes: predefined trajectory in which he controlled only vehicle speed, full trajectory control with body and world coordinate joystick, and a fully open-loop manual mode.

The operator was instructed to fly straight lines between markers on the graphic display, making smooth turns at the corners and keeping the vehicle facing ahead. This corresponded exactly to the predefined trajectory, which the operator ran first (Fig. 10).

These trials demonstrated that these techniques have been successfully implemented and allow preliminary comparisons of performance. Not surprisingly, the predefined trajectory mode showed the best track following and was felt by the subject to be the easiest to use. Fixed-coordinate joystick mode showed better track following than the body-coordinate mode. All supervised modes indicated better track following than open-loop manual control. The supervisory modes also required much simpler, more consistent joystick commands from the operator.

VI. Conclusion

A supervisory control system based on reliable high-performance closed-loop control and a properly designed operator interface can make an ROV much more capable. The overall performance of the system can be improved and the capabilities of the system can be extended to tasks that could otherwise not be performed. Examples of such tasks are those that must be accomplished in low visibility and high currents. Very carefully controlled, repeatable surveys can be performed without sacrificing flexibility or the ability to respond to the unexpected. Overall, vehicle operations are made more efficient and simpler, with a relatively small investment in complexity and cost.

Elements of such a control system have been implemented and will soon be applied to JASON, an ROV for deep-ocean scientific applications. Reliable closed-loop control has been demonstrated in pool tests, and trials with prototype man–machine interfaces have been completed in simulation.

References

[1] R. D. Ballard, "ROV development at Woods Hole's Deep Submergence Laboratory," in *Proc. ROV '84, MTS,* 1984.

[2] D. E. Humphries and K. W. Watkinson, "Hydrodynamic stability and control analyses of the UNH-EAVE autonomous underwater vehicle," Aeronautical Research Associates of Princeton, McLean, VA, Tech. Memo 82-2, Jan. 1982.

[3] D. H. Lewis, J. M. Lipscombe, and P. G. Thomasson, "The simulation of remotely operated vehicles," in *Proc. ROV '84, MTS,* 1984.

[4] L. G. Milliken, "Multivariable control of an underwater submersible," S.M. thesis, Depts. Mech. and Ocean Eng., Massachusetts Inst. Tech., Cambridge, May 1984.

[5] J.-J. E. Slotine, "Tracking control of nonlinear systems using sliding surfaces," Ph.D. dissertation, Dept. Aero. and Astro., Massachusetts Inst. Tech., Cambridge, May 1983.

[6] J.-J. E. Slotine, "The robust control of robot manipulators," *Int. J. Robotics Res.,* vol. 4, no. 2, 1985.

[7] D. R. Yoerger and J.-J. E. Slotine, "Robust trajectory control of underwater vehicles," *IEEE J. Ocean. Eng.,* vol. OE-10, no. 4, pp. 462–470, Oct. 1985.

[8] D. R. Yoerger and J. B. Newman, "Supervisory control of underwater vehicles and manipulators," in *Proc. ROV '85, MTS,* 1985.

[9] J.-J. E. Slotine and J. A. Coetsee, "Adaptive sliding controller synthesis for nonlinear systems," *Int. J. Control,* vol. 43, no. 3, 1986.

[10] O. Khatib and J. F. LeMaitre, "Dynamic control of manipulators operating in a complex environment," in *Proc. 3rd Symp. Theory and Practice of Robots and Manipulators* (Udine, Italy), 1978, pp. 267–282.

[11] N. Hogan, "Impedance control: An approach to manipulation: Part III—Applications," *ASME J. Dynamic Systems, Measurement, and Control,* vol. 107, Mar. 1985.

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FIBER OPTIC-BASED SENSORS FOR CONTINUOUS REMOTE MEASUREMENT OF CHEMICAL CONSTITUENTS IN SEAWATER

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ABSTRACT

This paper describes efforts at the Naval Ocean Systems Center to develop fiber optic-based chemical sensors for the measurement of chemical species in seawater. Ongoing work aimed at development of chemical sensor arrays suitable for use in conjunction with a "real-time" environmental mapping systems is discussed. Novel sensor configurations that exhibit fast and reversible responses to changes in concentrations are described and the use of ultra-fast (nano-second) techniques that permit multi-component mixtures to be deconvolved are presented.

INTRODUCTION

Advances in microprocessor technology now make it possible to routinely monitor and process information from a large number of sensors. These processors permit information from sensors to be sampled nearly continuously and provide real time access to the data. This new technology is being used in many areas (e.g., process control and monitoring, biomedical instrumentation, etc.). Efforts in the Marine Environment Branch at the Naval Ocean Systems Center have led to the development of a microprocessor-based portable environmental mapping system that can be deployed from a small craft and used to continuously map environmental quality parameters such as temperature, salinity, pH, oxygen and light transmission in bays, harbors and coastal marine environments. One of the key elements of the system is an integrated navigation and positioning system that permits incorporation of position information into each data record at sample update rates of up to 0.5 hertz. This system has been demonstrated to be useful for determining spatial and temporal characteristics of highly dynamic marine environments so that discrete measurements of other chemical and related environmental parameters can be interpreted in terms of mechanistic models.

The greatest limitation of present mapping systems is the lack of appropriate chemical sensors that can provide "real-time" measurements (e.g., time scales for sensor response of approximately 1-second) of chemical constituents in seawater. At present, analysis of most chemical compounds in seawater still requires collection of discrete water samples in the field and analysis of the samples back at the laboratory. Obviously, chemical data produced in this manner cannot easily be integrated with information from other "on-line" sensors. At present the only methods that can approach "real-time" measurements of chemical species in seawater are electrochemical techniques and certain spectroscopic analyses that have been adapted to flow injection analysis. Both of these methods are subject to certain limitations. Electrochemical methods are prone to interferences from other species in the complex seawater matrix and electrodes are easily fouled by surface contaminants. Flow injection methods that depend on the formation of a colored product when a sample is injected into a flowing reagent stream provide nearly continuous chemical information but usually require constant supervision to ensure that the pumping system is functioning properly. Also, the requirement for a pumped sample stream does not facilitate concurrent sampling from multiple locations.

FIBER OPTIC-BASED CHEMICAL SENSORS

To fully exploit the processing ability that is now available, new chemical sensors are needed that can make in situ measurements directly in seawater on time scales of 1-second or less. Ideally, these sensors should be suitable for integration into a multiplexed sampling network that can be coupled to a single measurement instrument.

With this goal in mind, work was initiated at the Naval Ocean Systems Center in November of 1985 to develop fiber optic- based chemical sensors that use fluorescence measurements for determining the concentrations of chemical constituents in seawater. Optical-based sensors that couple fluorescence measurements with UV-visible transmitting fiber optic cables offer several advantages over other methods. Fluorescence methods are inherently sensitive. Sub-parts-per-trillion concentrations can be measured directly (1). Fluorescence measurements are very fast. Individual determinations can be made in less than a micro-second. The use of a fiber optic cable to transmit the excitation light to the sample and couple the resulting fluorescence emission back to the detector permits measurements over large distances and multiplexing of sensors at numerous remote locations.

Not all chemical compounds fluoresce directly. Only some organic compounds and almost no inorganic constituents fluoresce naturally. However, analytical chemists have known for years that it is possible to measure chemical species that do not exhibit fluorescence if an indicator molecule is used to form a fluorescent complex with the species of interest. Analytical methods in which the fluorescence of an indicator molecule is either enhanced or quenched have been described for more than half of the elements in the periodic table (2). Fluorescent indicators have also been developed for many organic compounds that do not exhibit fluorescence(3).

Researchers with interests in biomedical instrumentation (4- 5), process control and monitoring (6), and general analytical chemistry (7-8) have recently reported sensor developments in which fluorescence spectroscopy has been coupled to fiber optic cables. Almost all of the sensors described to date are based on the same approach. A fluorogenic indicator molecule is immobilized on the end of a fiber optic cable. Excitation energy is transmitted down the fiber optic light guide and the resulting fluorescence emission signal is transmitted back up the cable, where the wavelength(s) of interest are measured at the detector.

When we first investigated these immobilized indicator systems for making measurements in seawater, it became obvious that, with the exception of sensors that employ pH sensitive indicator molecules, most indicator systems did not respond reversibly to changes in concentration over time scales required for sensors to be useful for mapping small scale spatial features from a moving vessel.

PRESSURIZED MEMBRANE INDICATOR SYSTEM

The requirement for fast, reversible responses to changes in analyte concentrations led to the development in our laboratory of a novel fiber optic-based chemical sensor in which the indicator molecule is continually renewed by forcing the indicator molecule through a membrane that is positioned a few millimeters from the sensing end of the fiber optic probe. Details of this sensor system have already been described (7). The main components of the sensor system are shown schematically in Figure 1. Light of the appropriate wavelength from the excitation source is coupled into a single 320 micron core diameter UV-visible grade fiber optic cable and transmitted down the cable to the sample. Excitation light leaving the cable illuminates a cone-shaped volume of the sample solution and a circular area on the ultrafiltration membrane. The indicator molecule (designated L^{2-} in the figure) is forced under pressure through the membrane, where it comes in contact with the sample solution and forms complexes with the species of interest (M^{2+}). Fluorescent emission from the indicator complex (ML) is coupled into six 320 micron fibers that are located concentrically around the fiber carrying the excitation light. The emission signal is then transmitted back up the cable and spectrally dispersed over a linear photodiode array detector. The complexed indicator is constantly removed from the viewing volume by diffusive/convective mass transport processes and replaced by uncomplexed indicator from the reservoir. Because the flow of the indicator through the membrane is slow (approximately 1 micro-liter/min) a 1 ml reservoir can last up to 20 hours.

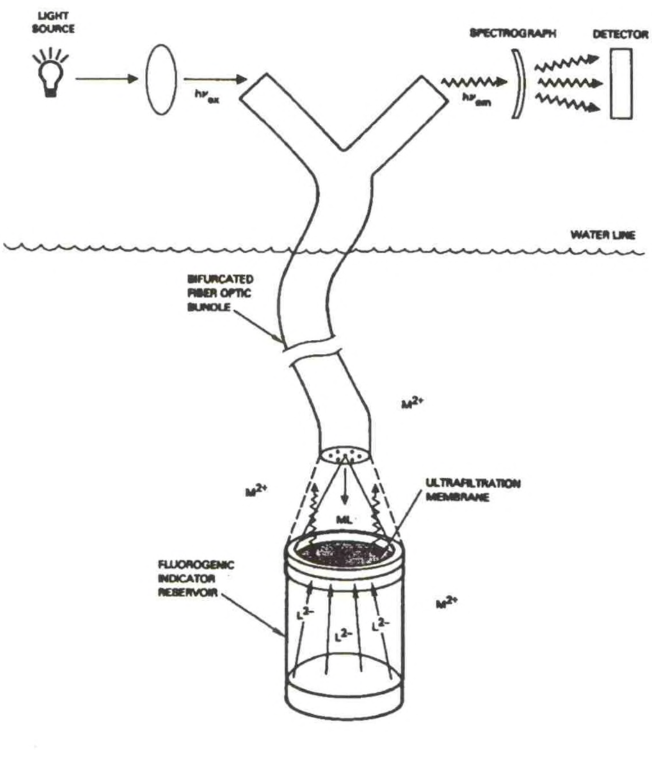

Figure 1. Schematic diagram of pressurized membrane fiber optic chemical sensor system.

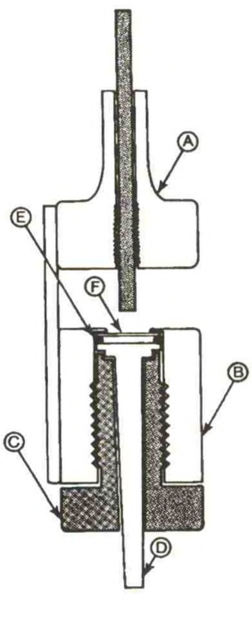

Figure 2. Detailed schematic of pressurized membrane indicator system. (A, upper part of probe with fiber optic; B, lower member of probe; C, reservoir holder; D, reservoir; E, O-ring; F, ultrafiltration membrane)

Details of the prototype sensor used for studies reported here is shown in Figure 2. The device was designed to use 12 mm diameter ultrafiltration membranes that are commercially available in a range of effective pore sizes (Amicon, Inc). The membranes used in this study had the smallest pore size available (a molecular weight cut-off of 500 daltons). A photograph of the prototype sensor is shown in Figure 3. Because size limitations were not a concern during

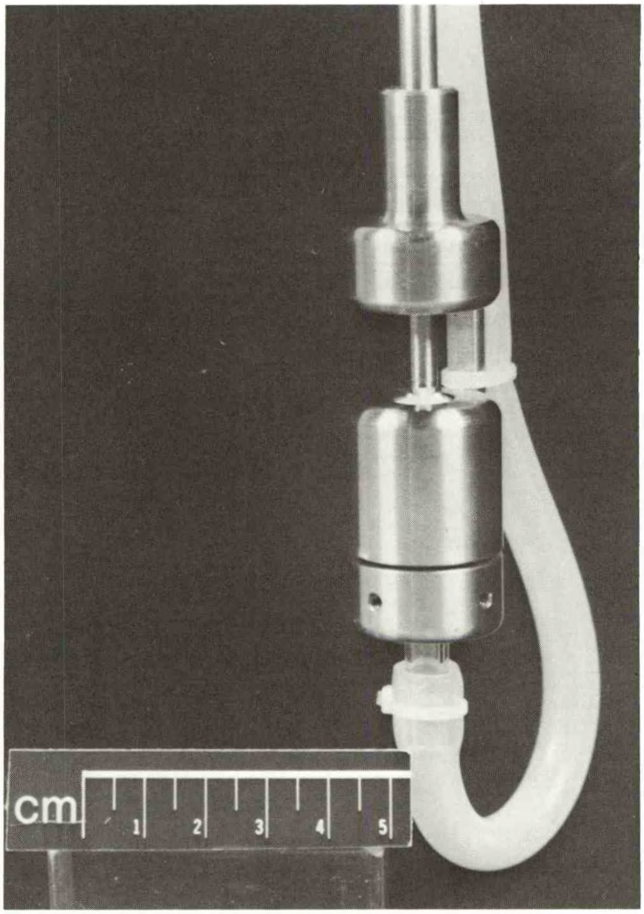

Figure 3. Photograph of prototype fiber optic membrane sensor.

the initial prototype development, the system is much larger than necessary. A second generation sensor is currently being developed that uses a single 200 micron fiber to carry the excitation light to the sample and the return emission signal to the detector.

The reversibility of the pressurized membrane sensor is demonstrated in Figure 4 which shows that

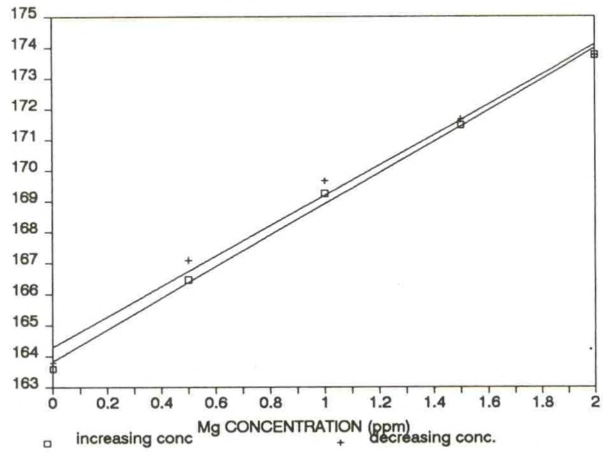

Figure 4. Response of pressurized membrane sensor to 0.5 ppm increases and decreases in Mg concentration.

the response of the sensor to 0.5 ppm increases in Mg ion concentrations is identical to the response observed from subsequent 0.5 ppm decreases in Mg concentrations. The rapid response time of the sensor is dramatically illustrated in the experimental data presented in Figure 5 which shows successive fluorescence emission spectral scans taken 1-second apart as a pumped sample stream was switched from 50% seawater to distilled water. The signal returns to background

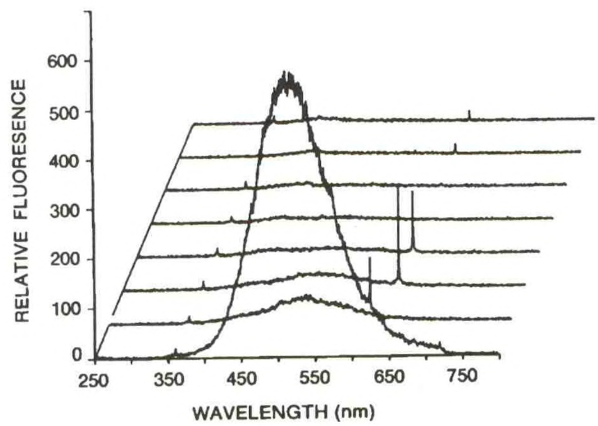

Figure 5. Response time of sensor as observed from successive 1-sec spectral scans of fluorescence emission measured while switching from 50% seawater to distilled water.

levels within approximately 1-second after the sample is switched.

SPECIFICITY OF FIBER OPTIC-BASED SENSORS

The most important issue yet to be resolved that will determine the overall utility of fiber optic-based chemical sensors is the specificity of the sensor for the species of analytical interest. Because seawater is a very complex matrix, containing nearly every element in the periodic table and a wide variety of natural and anthropogenic organic compounds, it is important to be able to distinguish between fluorescence signals from different compounds. We are presently evaluating several approaches for improving the specificity the sensor.

One of the most promising techniques is the use of differences (nano-second time scales) in the fluorescent lifetimes of various species to distinguish and deconvolve spectrally similar fluorescence emissions. Experimentally, this consists of stimulating fluorescence with a pulsed laser source and then monitoring the decay of the resulting fluorescence signal (Figure 6). Preliminary studies indicate that it is possible to deconvolve fluorescence signals from complexes of the trace metals zinc and cadmium with the indicator molecule p- tosyl-amino quinolin in seawater. In other work we are investigating the use of time-resolved fluorescence measurements for the direct determination of selected polyaromatic hydrocarbons (PAH's) in marine and groundwater systems.

SUMMARY AND FUTURE TRENDS

Chemical sensors employing fluorescence measurements via fiber optic cables have potential for a wide range of applications in aquatic environments. So far, we have attempted to take a generic approach toward solving problems associated with this type of sensor. Major accomplishments include the development of the pressurized membrane indicator system for rapid and reversible determination of selected metal ions in seawater. Ongoing efforts are emphasizing the use of fluorescence lifetime measurements as means of enhancing the specificity of the sensor.

As stated in the beginning of this report it is largely the advances in microprocessors that has driven the need for new chemical sensors that can link these

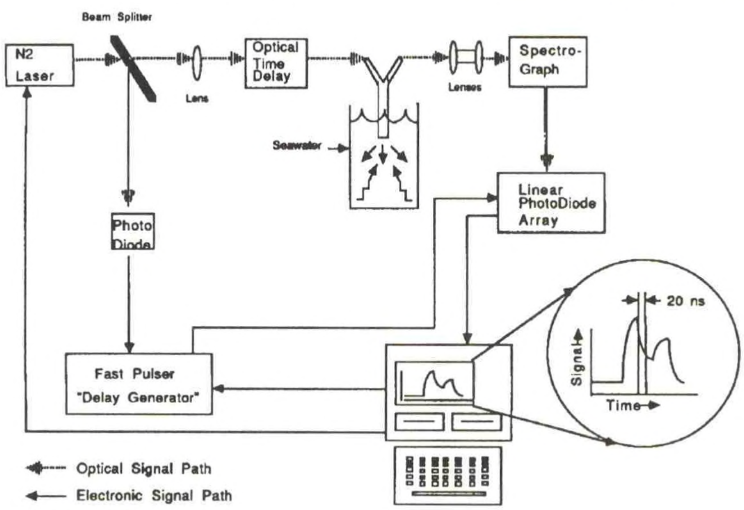

Figure 6. Schematic of instrumentation setup for time-resolved fluorescence measurements over fiber optic cables.

computers to the chemical world. It may very well be these same microprocessors that make "real-time" continuous chemical sensors possible. The current trend emerging in analytical chemistry is to characterize chemical systems by collecting several types of chemical information and then, through "signal processing" techniques, extract the information that can be used to analytically discriminate one chemical constituent from another. This contrasts with traditional chemical techniques that attempt to remove interferences by laborious physical separations. With regard to fiber optic-based chemical sensors, we believe that the full potential of these sensors will only be realized when they are linked to "smart" expert system-type computer interfaces that will permit evaluation of spectral emission information, fluorescence lifetime information, excitation information and other data such as polarization lifetimes. The expert system could then make real-time decisions based on incoming data and actually alter experimental conditions (e.g., wavelength of the excitation energy) to confirm or deny the presence of suspected constituents. Because the fundamental optical measurements with this type of sensor are so fast (a few milli-seconds or less), it should be possible to conduct the entire experiment, including processing of information in seconds. Eventually, we believe this will facilitate the use of fiber optic-based chemical sensor arrays that can be used to generate multi-dimensional maps of chemical data similar to that shown schematically in Figure 7.

REFERENCES

(1) Guilbault, G.G. **Pactical Fluorescence. Theory, Methods and Techniques.** Dekker, New York, 1973.

(2) P.A. St.John. "Fluorometic Methods for Traces of Elements." In: **Trace Analysis: Spectroscopic Methods for Elements,** J.D. Winefordner, Ed., John Wiley & Sons, New York, 1973, 213-277.

(3) Angel, S.M., P.F. Daley and T.J. Kulp. "Optical Chemical Sensors for Environmental Monitoring." In **Chemical Sensors,** Proceedings Vol. 87-9. D.R. Turner, Ed., The Electrochemical Society, Inc., Pennington, N.J., 1987, 484-489.

(4) Peterson, J.I., S.R. Goldstein, R. V. Fitzgerald and D.W. Buckhold. "Fiber Optic pH Probe for Physiological Use." **Anal. Chem.,** 1980, **52**, 864-869.

(5) Peterson, J.I. and G.G. Vurek. "Fiber Optic Sensors for Biomedical Applications." **Science**, 1984, **224**, 123-127.

(6) Hirschfeld, T., T. Deaton, F. Milanovich, S. Klainer. "Feasability of Using Fiber Optics for Monitoring Groundwater Contaminants." **Optical Engr.,** 1983, **22**, 527-531.

(7) Wolfbeis, O.S. "Fluorescence Optical Sensors in Analytical Chemistry." **Trends in Analytical Chemistry**, 1985, **4**, 184-188.

(8) Seitz, W.R. "Chemical Sensors Based on Fiber Optics." **Anal. Chem.,** 1984, **56**, 16A-34A.

(9) Lieberman, S.H., S.M. Inman, E.J. Stromvall. In: **Chemical Sensors.** Proceedings Volume 87-9. D.R. Turner, Ed., The Electrochemical Society, Inc., Pennington, N.J., 1987, 464-475.

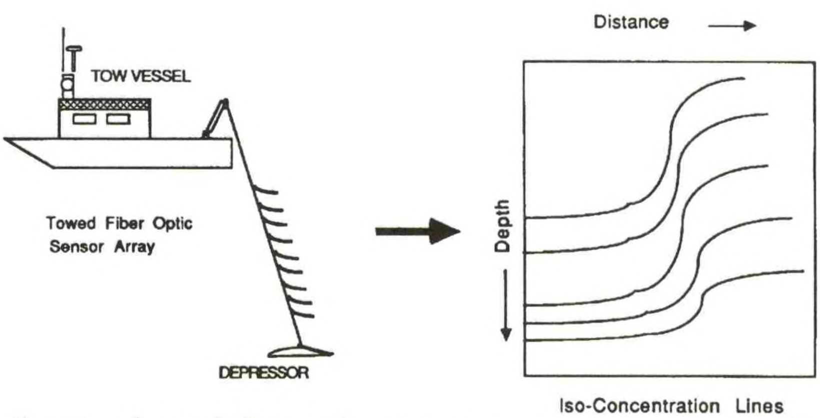

Figure 7. Conceptual diagram of towed fiber optic sensor array showing resulting multi-dimensional chemical mapping capability.

An application of a multiple regression to wave forecasting

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1. INTRODUCTION

A wave forecast information is a fundamental information for the safety operation of working vessels for port construction. There are two different methods for wave forecasting. One is a deterministic method utilizing a numerical model of wind and wave interaction. The other is an empirical model based on a statistical relationship between the weather and the wave data obtained in the past. The former method has often been used for wave hindcasting and the reliability of the models have been discussed. However, practical computation of these models require knowledge of meteorology in the numerical modeling of atmospheric pressure system and the cost of computation. On the other hand, the latter method utilizes linear regression equations and sophiscated knowledge is not necessary in the process of practical computation. This is the advantage of the empirical method.

However, because of the lack of continuous field wave data, detailed study on the latter method has been difficult, and thus only few reports have been presented.

In this report, the possibility of the application of a multiple regression model, which is a simple statistical model, to wave forecasting is examined on the basis of wave records obtained at various locations in Japan.

2. TECHNIQUE USED

The wave forecasting model employed here is a modification of a linear regression model proposed by Suda(1983). It is assumed that a 12-hour forecast of significant wave height at a specific location can be estimated by the following linear regression equation.

$$\ln \hat{x}_1 = a_0 + \sum_{i=1}^{3}(a_i \ln x_i + b_i y_i) + \sum_{i=1}^{3}\sum_{j=1}^{32} c_{ij} z_{ij} + \varepsilon \quad \cdots\cdots (1)$$

where, ln( ): natural logarithms,

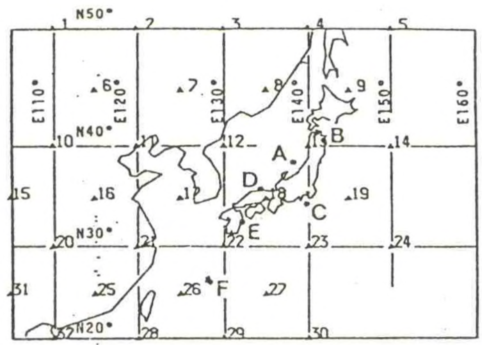
$\hat{x}_1$:12-hour forecast of significant wave height at a specific location,

x_i :observed significant wave height at the location where the wave height is forecast,

y_i :wind speed observed at the nearest point to the location of wave forecast,

z_{ij} :atmospheric pressure read at the location denoted by j=1 to 32 on the weather maps (see Fig. 1),

the subscript i denotes the time, i.e., i=2 denotes the time 12-hour prior and i=3 denotes 24-hour prior to the time of the wave forecast respectively, and a_i , b_i and c_{ij} are the unknown regression coefficients which are determined by the least square method based on the past wave records and the weather maps.



A:Hajikizaki ▲:Points where pressure is read
B:Mutsu-ogawara
C:Habu
D:Tottori ●:Points of wave forcast
E:Aburatsu
F:Nakagusuku

Fig. 1 Locations where waves are forecasted and atmospheric pressure is read

Incidentally. the reason why the logarithms of the significant wave height instead of wave height itself is employed is to give the estimation error a nature of normal distribution.

The regression equation Eq.(1) include all the 100 candidates for explanatory variables. All these candidates do not equally contribute to waves. It is expected that the inclusion of improper variables in the regression equation generates errors of the forecast wave heights. Therefore, as a the first step of the analysis, the explanatory variables are screened from the view point of a criterion called the AIC (Akaike

Information Criterion), which is defined by the following equation (Akaike,1973).

AIC=- 2 X (Maximum Likelihood of a Model)

+ 2x(number of free parameter of the model) .... (2)

The AIC for a multiple linear regression (Sakamoto, 1983) is defined by

$$AIC = n(\ln 2\pi + 1) + n \ln \hat{\sigma}^2 + 2(m+1) \quad \cdots\cdots(3)$$

where n: sample size, $\hat{\sigma}^2$: estimate of variance of the error ε , m: number of explanatory variables.

3. SELECTION OF EXPLANATORY VARIABLES

The priority of the explanatory variables are given by the following procedure.

(1) Among all the candidates of the explanatory variables included in Eq. (1), select a variable which yields the minimum AIC when it is calculated for a single explanatory variable.

(2) Calculate AIC values for the combination of two explanatory variables : the above chosen variable and another variable, and select the second explanatory variable which yields the minimum AIC.

(3) Calculate AIC values for the combination of three variables : above chosen two variables and one more variable, and select the third variable which minimizes the AIC value.

(4) Reiterating the procedure (3), select the fourth, the fifth, ..., explanatory variables.

(5) The procedure 4 is terminated when the rate of decrease of AIC value by adding one more explanatory variable is negative or less than a certain level.

Figure 2 shows a sample of the variation of AIC values as the number of explanatory variable increases for the wave data at HABU Port (see Fig.1). For wave data obtained in spring (March to June), summer (July to September) and winter (December to February), the values of AIC show its minimum when the number of explanatory variable is from 16 to 18. On the other hand, AIC does not shows minimum for autumn (September to November).

It might be interesting to see how much correlation exists between the atmospheric pressure at various locations and the wave height at the point of wave forecast. Figure 3 shows

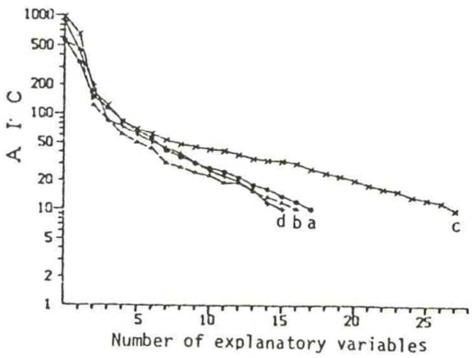


Fig. 2 Variation of AIC due to the number of explanatory variables

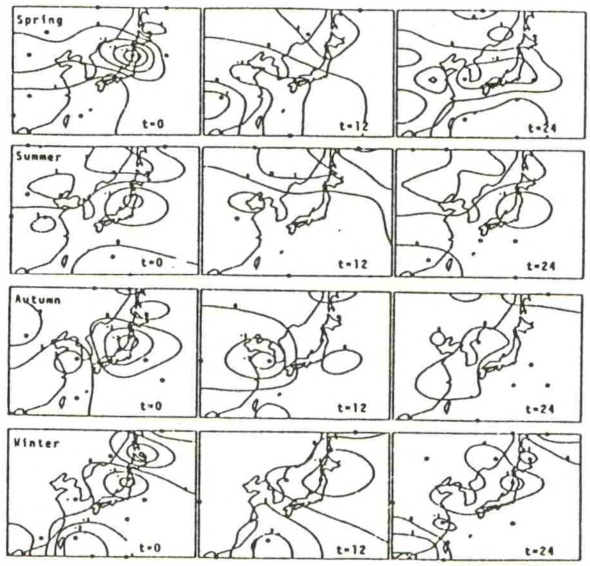


Fig. 3 Correlation between forecast wave height and atmospheric pressure (for Mutsu-ogawara: Pt. B in Fig.1)

other hand, AIC does not shows minimum for autumn (September to November).

It might be interesting to see how much correlation exists between the atmospheric pressure at various locations and the wave height at the point of wave forecast. Figure 3 shows the values of the regression coefficients by contour lines, which express the rate of the contribution of atmospheric pressure to the wave height at Mutsu-ogawara port. In Fig. 3 the wave height at Mutsuogawara Port is highly contributed by the atmospheric pressure there at the time of forecasting (t=0) and the pressure at west to southwest of Japan islands at 12-hour before the forecast (t=12).

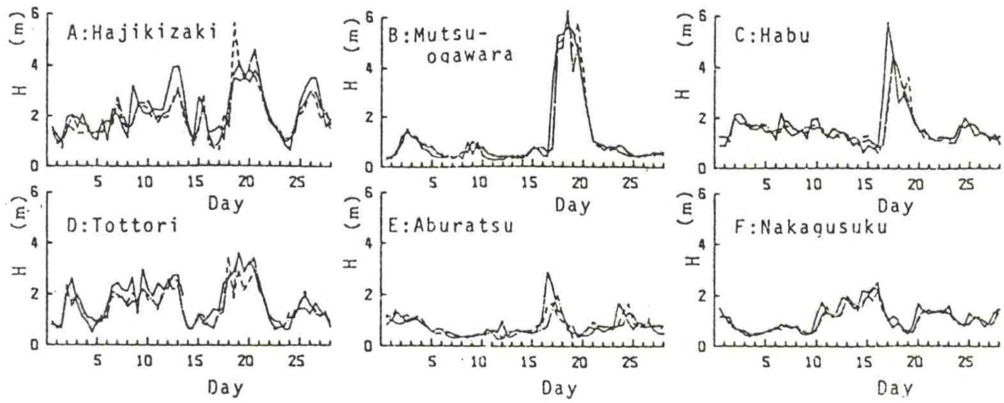


Fig. 4 Comparison between the forecast and the observed wave heights

4. RESULTS OF FORECAST

The regression coefficients for the wave forecasting at 6 locations are determined on the basis of observed wave data at respective locations and the weather maps during the period of three years from January 1, 1980 to December 31,1982. The wave forecasting is simulated for one full year of 1983. Figure 4 shows the comparison between the observed wave heights and 12-hour forecast wave heights at the six locations during February in 1983. In the figure, solid lines, broken lines and chain lines denote the time variation of the observed wave height, the forecast wave height utilizing all the 100 explanatory variables and the forecast wave heights utilizing only selected (about 20 to 30)explanatory variables, respectively.

The variation of the wave height forecasted from the selected explanatory variables more closely follow that of the observed wave heights than the forecast wave height given with all the 100 explanatory variables.

In order to examine the validity of the regression equation for the wave forecast utilizing only weather data, i.e., without utilizing observed wave data, the wave height are forecasted by the regression equation which does not contain the second term of Eq. (1), i.e., $a = b = 0$.

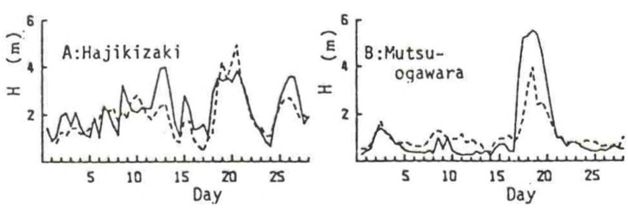


Fig. 5 Comparison between the forecast and the observed wave heights (forecast from pressure only)

The example of the results are illustrated in Fig. 5 for the locations Habu Port and Mutsu-ogawara Port during the same period as shown in Fig. 4. Though the difference between the observed (solid line) and the forecast (broken line) wave heights is larger than that seen in Fig. 4, the result of the forecast wave heights fairly well describes the time variation of observed wave heights.

5. DISCUSSION OF RELIABILITY OF WAVE FORECASTING

The reliability of the wave forecasting can be evaluated by the correlation coefficients between the observed and the forecasted wave heights. Figure 6 shows how the correlation coefficients vary depending on months or seasons at various locations. The regression equation employed here consists of only selected explanatory variables. It is seen in Fig. 6, the values of correlation coefficients vary from month to month and season to season. On the average, however, the correlation coefficients is about 0.8.

The reliability of the wave forecasting is also evaluated from the viewpoint of the magnitude of errors. In practice, it is reasonable that success or failure of the wave forecast can be judged by whether the error exceeds 50 cm or not. Figure 7 shows the percentage of the forecast having errors less than 50 cm. It can be said that the rate of success is about 80 % or higher on the whole.

One of the major purposes of short term wave forecasting is to provide such wave information that the wave height will exceed a certain level

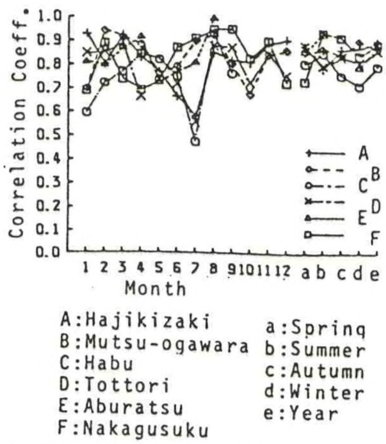


Fig. 6 Correlation coefficients between the forecast and theobserved wave heights

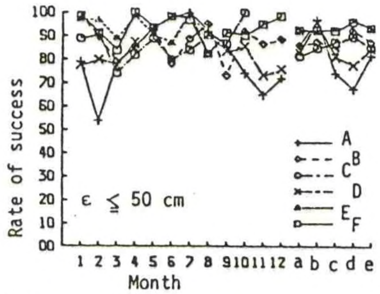


Fig. 7 Rate of success (error is less than 50 cm)

which is determined from the safety operation of working vessels. Thus, the reliability of the forecast wave information must be discussed for relatively calm seas, i.e., the wave height is less than 1.0 m. Figure 8 is drawn for the categorical wave forecast, i.e., whether wave height exceed 1.0m or not. The forecast is judged as success regardless of the magnitude of error, when both of the forecast wave height and the observed wave height fall on the same category , above or below 1.0 m, and it is judged as failure when otherwise forecasted. As seen in Fig. 8 , the rate of success is about 80 % or higher.

Figure 9 shows the correlation coefficients between the observed wave heights and the wave heights forecasted without utilizing the wave heights and wind speed in regression equation (see Fig.5) for Hajikizaki and Mutsu-ogawara. Except summer when the sea is quite calm, the correlation coefficients are 0.6 or higher.

6. CONCLUSIONS

Summing up the discussion above,

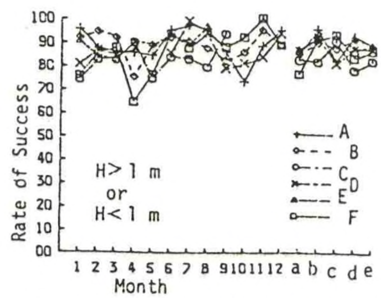


Fig. 8 Rate of success for categorical forecast

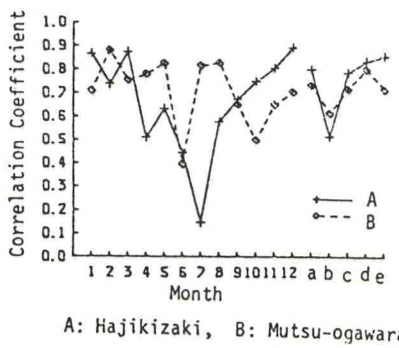


Fig. 9 Correlation coefficients (forecast from pressure only)

the following is the major conclusions.

(1) The multiple regression model can be a useful tool for a short term wave forecast if errors are allowed to a certain extent.

(2) The regression model employed herein handles the time variation and the space variation of the explanatory variable in the same manner. If proper consideration is made on the characteristic difference between these two kind of variations, the reliability of the wave forecast can be improved.

REFERENCES

Akaike,H (1973): Information theory and an extention of the maximum likelihood principle, 2nd Inter. Symp. on Information Theory (Petrov, B. N. and Csaki, F. eds.), Akademiai Kiaido, Budapest, pp. 267 -281.

Sakamoto,Y., M. Ishiguro and G. Kitagawa (1983): Akaike information criterion statistics, D.Reidel Piblishing Co. Dordorecht, Holland.

Suda, H and A. Yuzawa (1983): A fundamental study on the queueing theory of the open sea berth based on the wave forecasting, Proceeding of JSCE, Vol.339

Observation of Directional Spectra at an Offshore Oil Rig

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Ministry of Transport

Introduction

So far, several methods for the estimation of directional spectra have been proposed. No methods has yet taken into consideration the errors emerging from the estimation of cross-power spectra, the base information for the directional spectral estimation. The errors often lead to unusual directional spectra depending on the arrangement and the number of wave probes.

Initially, the authors payed attention to the errors contained in the cross-power spectra, and assumed that the best estimate of a directional spectrum is the one which maximizes the likelihood of the directional spreading function maintaining its smoothness. Then, a new method for the estimation of directional spectra using a Bayesian approach is proposed. The Bayesian approach was originally introduced by Akaike [1] in the field of regression analysis problems where the number of unknown parameters is large compared with the sample size.

The proposed method is examined by numerical simulation and applied to field data analysis in the paper.

Technique used

The relation between the cross-power spectra and the directional spreading function is expressed in the following form after some manipuration of equations:

$$\phi_i(f)=\sum_{k=1}^{K}\alpha_{i,k}(f)\exp(x_k)+\varepsilon_i \qquad (1)$$

$$(i=1,\cdots\cdots,2N)\ ^{\#}$$

where,

$\phi_i(f)$ is normalized cross-power spectrum,

$(\phi_i(f)=\Phi_{mn}(f)/\{S(f)\sqrt{\Phi_{mm}(f)\Phi_{nn}(f)}\})$

$x_k(f)=\ln G(\theta_k|f)$; ($G(\theta_k|f)$:piecewise constant directional spreading function),

$$\alpha_{i,k}(f)=\int_{(k-1)\Delta\theta}^{k\Delta\theta}H_i(f,\theta)\,d\theta$$

ε_i is the error.

$$H_i(f,\theta)=H_m(f,\theta)H_n^*(f,\theta)[\cos\{k(x_{mn}\cos\theta+y_{mn}\sin\theta)-i\sin\{k(x_{mn}\cos\theta+y_{mn}\sin\theta)\}]/\sqrt{\Phi_{mm}(f)\Phi_{nn}(f)}$$

$H_m(f,\theta)$ is the transfer function of quantity m and * denotes complex conjugate.

The likelihood regarding x_k, (k=1,$\cdots$,K), and the variance σ^2 of ε_i is given by Eq.(2).

$$L(x_1,\cdots\cdots,x_K;\sigma^2)=(2\pi\sigma^2)^{-N}\times\exp\left[-\frac{1}{2\sigma^2}\sum_{i=1}^{2N}\{\phi_i-\sum_{k=1}^{K}\alpha_{i,k}\exp(x_k)\}^2\right] \qquad (2)$$

In addition, by the condition that the directional spreading function must be smooth and continuous, the values of

$$\sum_{k=1}^{K}\{x_k-2x_{k-1}+x_{k-2}\}^2$$

$$(x_0=x_k,\ x_{-1}=x_{k-1})$$

must be small. Therefore, the estimate of a series of x_k maximizing the likelihood and minimizing the above mentioned quantity are determined as the estimates which minimize the following quantity:

$$\sum_{i=1}^{2N}\left\{\phi_i-\sum_{k=1}^{K}\alpha_{ik}\exp(x_k)\right\}^2+u^2\left\{\sum_{k=1}^{K}(x_k-2x_{k-1}+x_{k-2})^2\right\} \qquad (3)$$

where, u is a hyperparameter.

The hyperparameter u and the variance σ^2 of the error are determined so that the ABIC (Akaike's Bayesian Information Criterion), defined by Eq.(4), is minimum.

$$\mathrm{ABIC}=-2\ln\int L(x,\sigma^2)p(x|u^2,\sigma^2)dx \qquad (4)$$

Subscripts i=1 to N denote real parts and i=N+1 to 2N denote imaginary parts.

where,

$$p(x \mid u^2, \sigma^2) = \left(\frac{u}{\sqrt{2\pi}\sigma}\right)^K \times \exp\left\{-\frac{u^2}{2\sigma^2}\sum_{k=1}^{K}(x_k - 2x_{k-1} + x_{k-2})^2\right\} \qquad (5)$$

In the practical computation, these equations are linearlized. The estimate of x_k are obtained through numerical iteration starting with initial values of x_k given uniformly.

Results of numerical simulation

Figure 1 shows a result of a bi-directional sea caused by two different wave groups : wind generated waves and a swell. The wave probe array examined is a star array consisting of 4 wave gauges. It is observed in the figure that the estimate of the directional spreading function estimated by the proposed method (denoted by BDM in Fig.1) is very close to the true directional spreading functions. On the other hand, the EMLM estimation shows smaller peak values than the true values and that some leakage of wave energy is seen where the true directional spreading functions are zero.

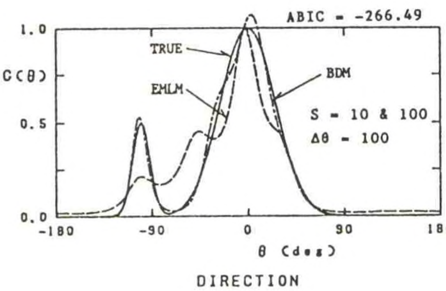


Fig.1 Comparison of the BDM and the EMLM estimates of directional spreading functions.

The effect of the errors contained in the cross-power spectral estimates is illustrated in Fig.2 for three different magnitudes of errors. The values of r in the figure show the ratio of the magnitude of the errors added to the cross-power spectra and the absolute values of cross-power spectrum. In the computation, the same magnitude of errors is equally added to all the four wave properties.

It is noted that as the magnitude of error increases the information of the directional spectrum carried by the cross-power spectra become more biased. In fact, as seen in Fig.2, the BDM estimates become flatter as the magnitudes of errors increases. It is also seen that the BDM yields quite accurate estimates even the time series wave records contain 5% errors. When the cross-power spectra contain larger errors, the EMLM estimates erroneous peaks and sometimes it fails to yield a smooth and continuous estimates of the directional spreading function. On the other hand, the BDM detects the directional peaks properly, though it underestimates the peak values. Thus, the BDM seems to be very robust method against the errors.

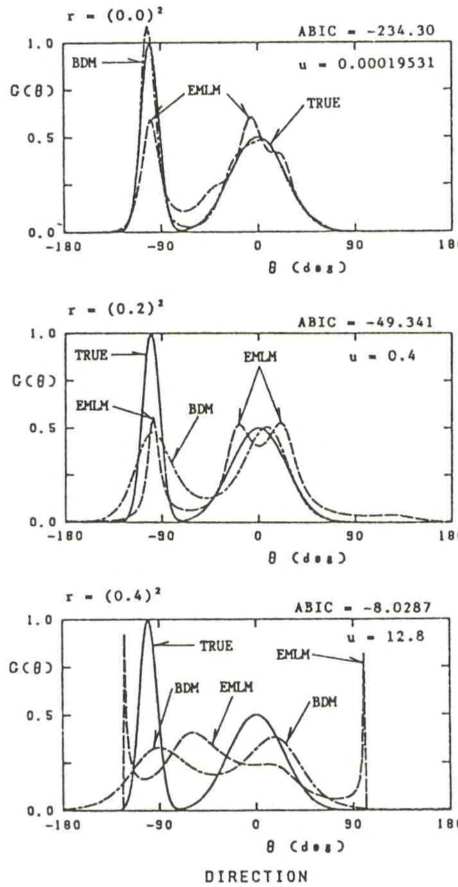


Fig.2 Effect of errors contaminated in the cross-power spectra.

For a star array, it has been recommended that the minimum distance D between the wave probes should be less than a half of the wave length L. However, the BDM estimate is fairly close to the true directional spreading function even the ratio D/L is 2.0 (see Fig.3).

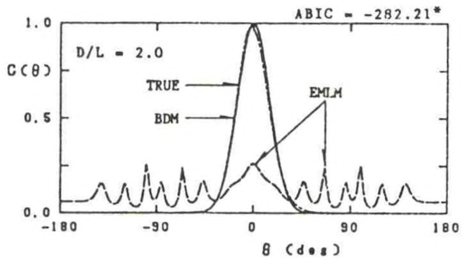


Fig.3 Effect of the dimension of a star array.

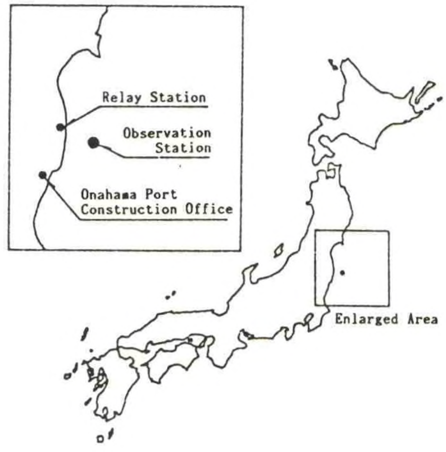


Fig.4 Location of the observation station.

Facilities of directional wave measurement

The new method for the estimation of directional spectrum on the bases of the Bayesian approach mentioned above is applied to the analysis of the wave records acquired at an offshore oil rig 42km off the Iwaki coast (Northeastern coast of the main island of Japan, see Fig.4). The Onahama Port Construction Office (OPCO), the Second Port Construction Bureau, Ministry of Transport, is conducting a multi-element measurement of ocean waves at this location. Figure 5 shows the oil rig where four step type wave gauges and a two-axis directional current meter with a pressure sensor are installed on its legs as shown in Fig.6. The location of the rig is 37°17'49"N and 141°27'47"E, in a water depth of 155m below C.D.L..

The simultaneous measurement of 7 elements is performed for 20 minutes at a time interval of two hours. The wave records as well as the wind records are immediately transmitted by a radio telemetering system to a nearby coastal relay station for landline transmission to the OPCO.

The time series wave data are recorded on a digital magnetic tape. Data are also analyzed immediately following each observation using a mini-computer of the OPCO for real time information such as significant wave height, wave period and mean wave direction. The EMLM is employed for the real time directional analysis at the office. The directional wave analysis presented herein is performed at the Port and Harbour Research Institute using the wave data recorded on the magnetic tapes.

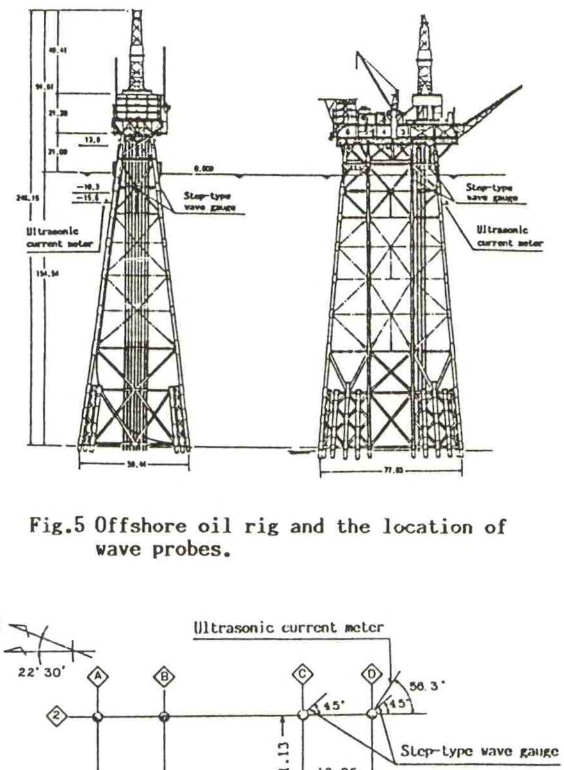


Fig.5 Offshore oil rig and the location of wave probes.

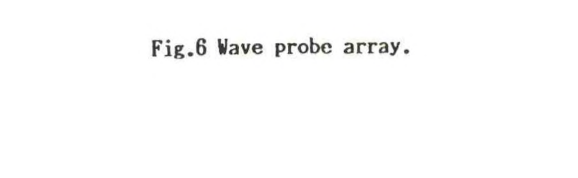


Fig.6 Wave probe array.

Field data analysis

The wave data analyzed here were obtained during the passage of Typhoon No.17 from September 29 to 30 in 1986. At 12:00 on Sept. 30, maximum significant wave height($H_{1/3}$ =6.2m) and period ($T_{1/3}$ =12.5s) were recorded.

Examples of directional spectra estimated by the BDM and the EMLM for uni-directional sea are compared in Fig.7. The upper figure is the BDM estimate and the lower figure is the EMLM estimate. The major difference between the two estimates is that the EMLM estimate is more diffuse and does not show the construction near the peak frequency clearly depicted in the BDM estimate. It is also clear that the peak spectral density given by the EMLM is much lower than that given by the BDM.

Conclusions

Major conclusions of the study are as follows:

(1) The proposed method can be applied to arbitrarily mixed instrument array measurements.

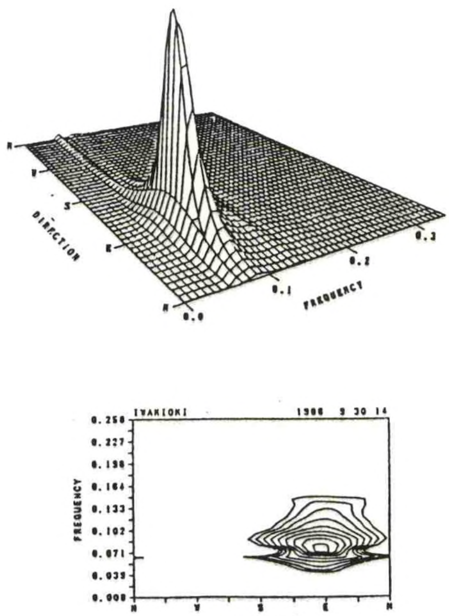
(2) The Bayesian model has a higher resolution power for estimating directional spectrum than other methods.

(3) The Bayesian model is a robust method for the estimation of directional spectra from cross-power spectra contaminated with errors.

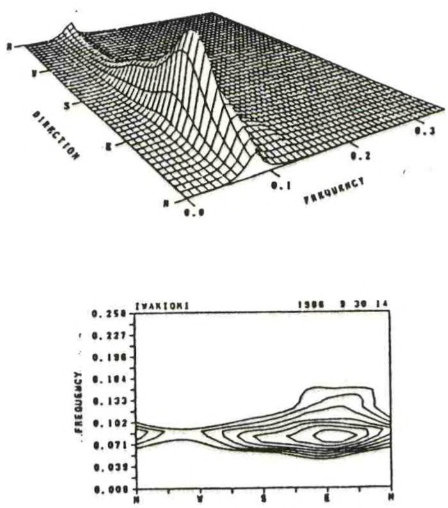
(4) The Bayesian model is more adaptable to reformulation of estimation equations as the study of directional wave spectrum progresses.

Reference

1) Akaike,H : Likelihood and Bayes procedure, Bayesian statistics (Bernardo,J.M., De Groot, M.H., Lindley,D.U. and Smith,A.F.M. eds.) University Press, Valencia, 1980, pp.143-166.



(BDM estimation)



(EMLM estimation)

Fig.7 Sample results of field data analysis.

THE DEVELOPMENT OF THE CONVENIENT MOORING BUOY SYSTEMS.

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ABSTRACT

A convenient mooring buoy system is developed for the sake of measuring wave heights and directions. The buoy system is composed of two parts, the spherical buoy and mooring system.

The spherical buoy has been originally developed as the drifting wave buoy which has a triaxial orthogonal accelerometer mounted on a gimbal.

The buoy system was tested nearby the Hiratsuka Marine Observation Tower , which is located off the coast of Hiratsuka, Kanagawa Pref., Japan, and the wave observations were carried out for about two months, from September to October, 1987. The mooring buoy system worked successfully and maximum wave height of 4.72m was recorded during the test experiment. The wave heights and directions obtained were compared with the observations made on the Tower. Both were agreed reasonably well with each other.

INTRODUCTION

On the coastal area, in addition to the wave height information, the wave directional information is also very important in the field of coastal engineering and monitoring of ocean pollusion. For the purpose of measuring the wave direction, various methods and instruments are used, such as wave gauge arrays, stereo photography, a wave guage/currentmeter combination and floating buoys. The triaxial accelerometer buoy is one of the most convenient to handle and it is effective to measure the wave directions in deep water, same as the pitch-roll buoy [3]. We tried to apply the drifting buoy to mooring system because the drifting buoy is rather expensive.

In this paper, we describe the outline of the mooring buoy system , and compare the obtained buoy data with wave data observed at Tower.

OUTLINE OF THE MOORED BUOY SYSTEM

The buoy system is composed with the floating buoy and the mooring system, as seen in Fig.1. The floating buoy has been originally developed as drifting buoy [1], [2]. The buoy has a spherical body with a diameter of 95cm and weight of 160kg. As the sensor for measuring the wave direction, the triaxial orthogonal accelerometer mounted on the gimbal is used.

The floating buoy is attached to a simple slack mooring system. The mooring system is composed of the chain, nylon rope, subsurface buoys and anchor, as seen in Fig.1. The subsurface buoys are subject to deflection due to wave-induced forces, and the universal swivel atached to the floating buoy allows totally unrestricted rotation in azimuth. The total length of the mooring system was about 1.5 times as long as the depth in our experiment.

The floating buoy measures the heave and the horizontal accelerations using the triaxial accelerometers mounted on a gimbal in the buoy. The raw data of the accelerations $\ddot{Z}$ and $\ddot{X}$, $\ddot{Y}$-comp. are comverted into the heave and horizontal displacements Z, X, Y-comp., by making use of the double integrator. Heave and horizontal displacements are sampled simultaneously, together with a compass (θ) reading to give the buoy heading, at 0.5 sec intervals with use of the data roger instoled in the buoy. The length of each wave records was about 17 min.

Wave measurements were carried out twice or three times a day by the mooring buoy systems. With the off-line handling, the horizontal displacements i.e., X-comp. and Y-comp. were resolved into E/W-comp.(X) and S/N-comp.(Y) of the displacement, using the azimuth angle. All the digitized data Z,X,Y were computed through FFT method using 1024 data points each, with the sampling time Δt = 1 second. After the quadrature spectrum Qzy and Qzx were obtained by the FFT analysis, the wave directions of the component waves, whose energy density have peaks with high-level energy, were given by the following equation. $\bar{\theta} = \tan^{-1}(Q_{zy}/Q_{zx})$.

SITE LOCATION

The data buoy was tested nearby the Hiratsuka Marine Observation Tower of National Research Center of Disaster Prevention which is located off the coast of Hirastuka, Kanagawa Pref., Japan as seen in Fig.2. The location of our mooring buoy system is about 1 km south of the Tower where the water depth is about 100m. At the tower, the wave heights, directions are measured by the wave arrays, and wind speed , wind directions are measured by the anemometer. Our test experiments was carried out from September 21 to October 31,1987.

OBSERVATIONAL RESULTS

1.Wave heights, wave periods and wave directions

During the period of investigation, the moored buoy measured rather heigh waves which were generated by the low-pressure passing by the south coast of the Japan Islands during September 25-26, and by the typhoon (T19) attacked the Japan Islands during October 17-18 as seen in Fig.3. In the figure, significant wave heights, wave periods and wave directions are compared with those measured by the Tower.

The wave heights and wave periods measured by the moored buoy are nearly equal or slightly greater than those measured at Tower. With considering the location of the buoy which is about 1 km south of Tower, it is considered that both are agreed reasonably well with each other.

It is found that the wave directions obtained by the buoy agree well with those at Tower, during Sep. 25-26 ,1987. In the period Oct. 17-18, the wave directions agree fairly well with the directions of winds.

2.Cross spectra

The results of the cross spectra Clm-iQlm (l,m=1,2,3) on the Sep.26.12h ,1987 and on the Oct.17.16h, 1987 are given in Figs.5,6. In these figures, lefthand side ones show the power spectra of the displacement of X,Y,Z-comp.,the middle the coherence and the righthand side, the phase-shift between the elements of X-Y, Z-Y and Z-X , respectively. Wave directions are also shown in the lower lefthand side of the figure. The figure, on the Sep.26.12h the primary spectral-peak of power zz is seen at the frequency of 0.15Hz (T=7sec), and secondary peak is at the frequency of 0.04 Hz (T =25 sec). The former peak means the energy of the wind waves and the latter might be natural resonance of the mooring buoy assembly through hydrodynamic action.

The magnitude of the low frequency peak increases according to the increment of the significant wave height as seen in the Fig.4. The power of the horizontal displacements X,Y increases nearly monotonically with the decrease of frequency toward the peak frequency of 0.04Hz or 0.03Hz.

The coherence between Z(heave) and Y(N/S) shows fairly large values in the frequency range from 0.2 to 0.4Hz (5 2.5sec), and the phase angle between Z and Y is nearly /2.

It is shown that the moored buoy moves following with the orbital motion induced by the waves in this frequency range. The wave directions are nearly from south,which agree with the wind directions.

Fig.6 shows the case of Oct.17.1987. In this case, the wave height was 3.1 ,and the spectral peak of Φzz is seen at the frequency 0.72Hz (14sec). The waves might be the swell induced by the Typhoon No.19. It is worth noticing that the coherence of Rz-y becomes fairly high value in the frequency range from 0.12Hz to 0.3Hz, and that of Rx-z also keeps relatively high value in the frequency range from 0.7 Hz to 0.3Hz. The phase-shift is nearly $\pi/2$ in those frequency range.

It will be concluded that the buoy moves reasonably well following with the wave orbital motion.

CONCLUDED REMARKS

A convenient mooring buoy system was developed and tested nearby the Hiratsuka Marine Observation Tower for two months from September to October, 1987.

Comparison of results from the wave data obtained by this buoy with those obtained at the Tower, indicate that wave heights, wave periods and wave directions agree reasonably well with each other. The cross spectral analysis of the heave (Z) and horizontal displacements (X,Y) indicate that the motion of the moored buoy follows reasonably well the orbital motion of water particle induced by the wind waves. The spectral peak at the low frequency 0.04 Hz (T=25sec) might be natural resonance of the mooring buoy assembly through hydrodynamic action.

But, these natural resonance of low frequency will not effect to the measurement of wind waves.

ACKNOWLEDGEMENT

The field experimental tests have been carried out by a joint project with National Research Center for Disaster Prevention Hiratsuka Branch.

The author expresses appreciation to Dr.M.Tokuda for his valuable consultation and advice through this investigation.

REFERENCES

[1] S.Matsumoto and M.Tsutsumi, "The Experiment Report of Ocean Wave Drifting Buoy", Proceedins of the International Symposium on Marine Data System ,New Orleans,Louisiana, April 30 - May 2,1986.

[2] S.Matsumoto, N.Moritani and M.Tsutsumi, "The design of a Wave - Directional Measuring Buoy Systems", Proceedings of the 14th Joint Meeting UJNR-MFP, Washington,D.C.,Sep.19-20, 1986.

[3] K.Kondo and J.P.A.de Koning, "Comparison of Directional Sea Measurements by an Orbital Following Buoy and a Combination of a Wave Gage and a current Meter", Proceedings of the 5th International Offshore Mechanics and Arctic Engineering Symposium, Vol.1, ASME,1986.

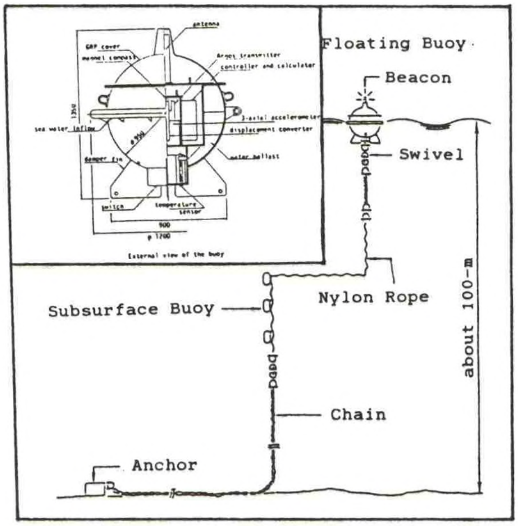

Fig.1. Configuration of the moored buoy system.

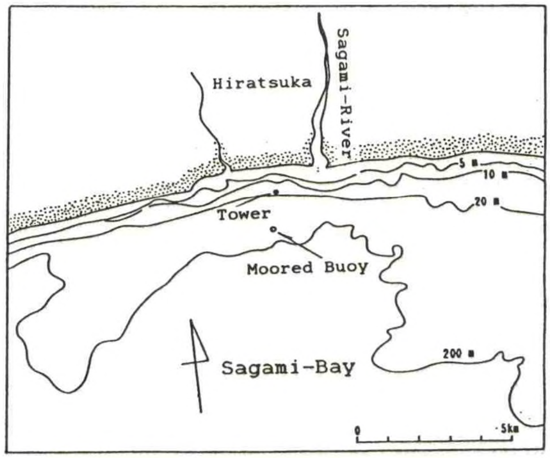

Fig.2. The experimental site of the mooring buoy and Hiratsuka Marine Tower.

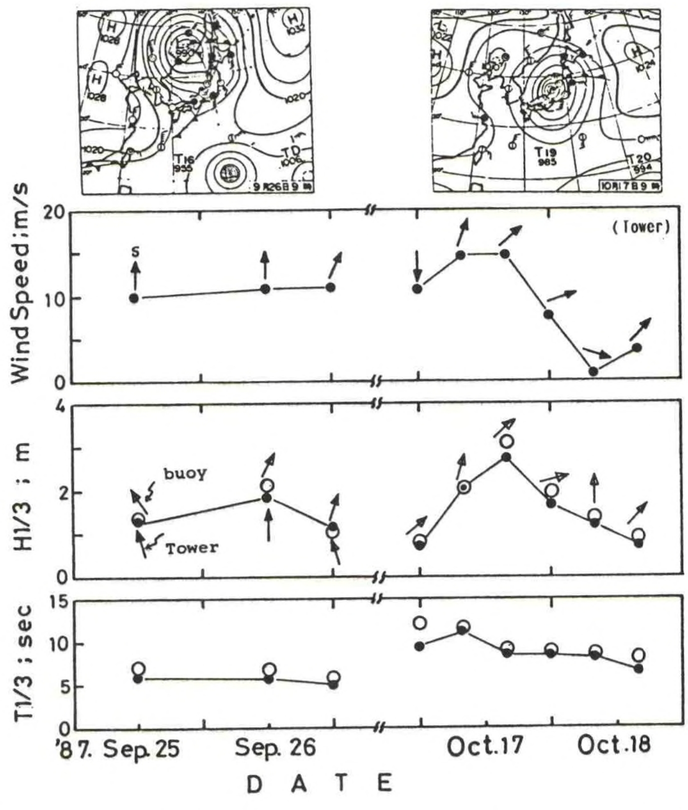

Fig.3. Example of typical wave data obtained by the moored buoy.
In the figure, solid circles and open circles mean the data on Tower and buoy, respectively, and the arrow means the direction of wind speed or wave direction.

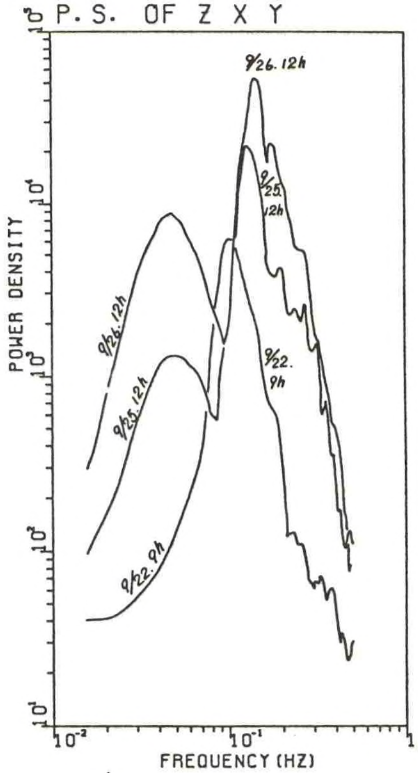

Fig.4. Example of power spectra. In the figure, the spectral peak of the lower frequency might be the natural resonance of the mooring buoy assembly.

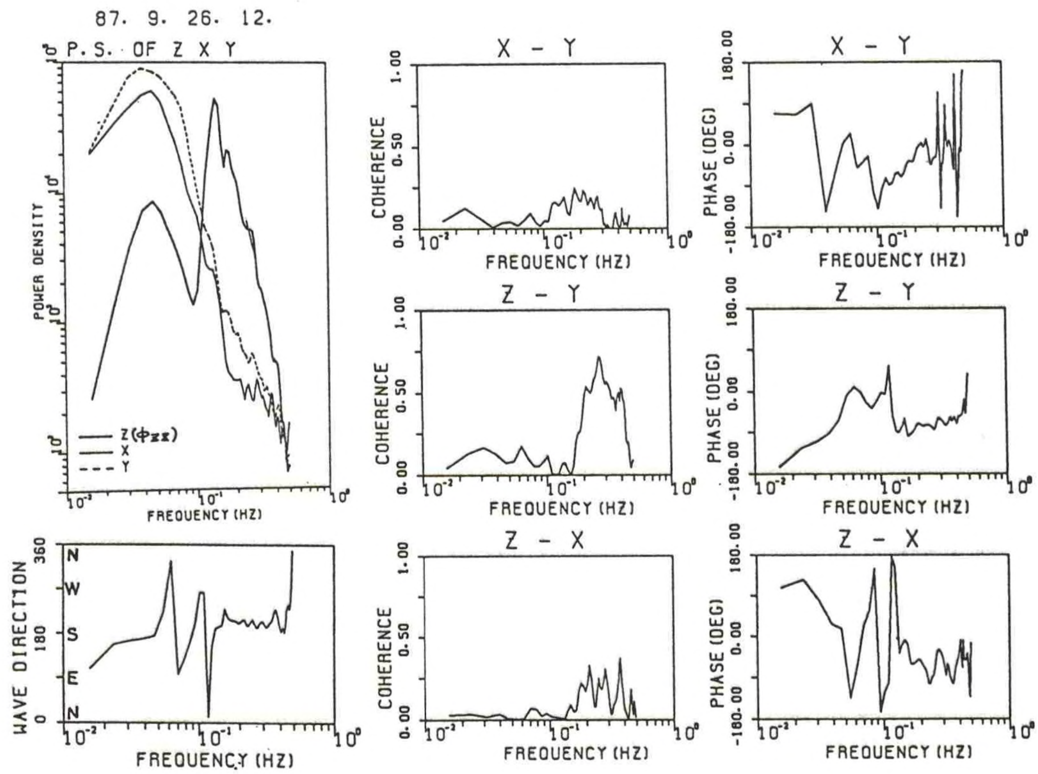

Fig.5. Example of wave spectra, Coherence and phase angle.
In the figure, Z means the heave displacement and X,Y mean the horizontal displacements.

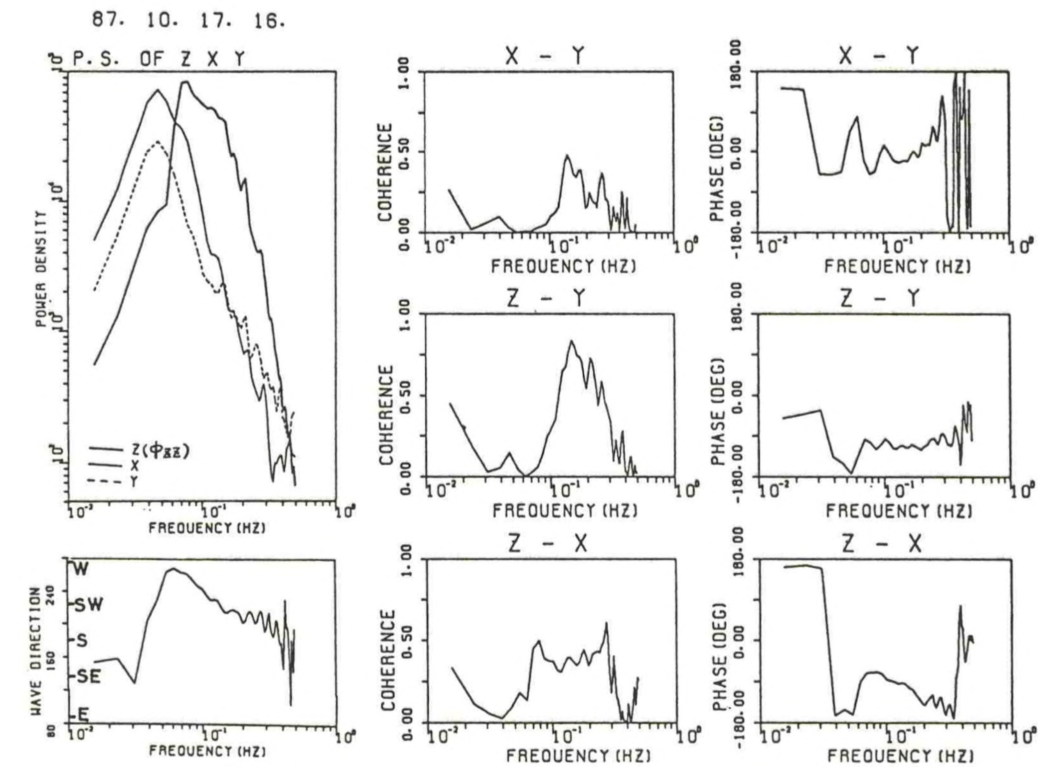

Fig.6. Example of wave spectra, Coherence and phase angle.

COMPUTER MODELING FOR SURFACE DRIFTING OBJECTS IN SAGAMI BAY

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1. INTRODUCTION

It is obvious that the prediction of drifting objects (for example, wrecked ship) is important for search and rescue operation over the ocean. And pediction results sometimes help to identify where some drifting objects come from. But it is not an easy task because the surface current (ocean and tidal) and wind-induced current are very variable. Hydrographic Department of Japan Maritime Safety Agency has been conducting a study for developing a computer modeling of drifting course for recent several years. Three areas, that is, Tokyo Bay, Mikawa Bay and Sagami Bay were chosen as model areas in the study. Among them former two bays are almost inner bays and in them the tidal current and wind-induced current are two important currents. But the last one is a bay which is open to the outer ocean and the current there is strongly affected by ocean current, in this case, Kuroshio.

In this report the study result in Sagami Bay(the last one among three) is briefly introduced.

Fig.1 shows the location of the Sagami Bay.

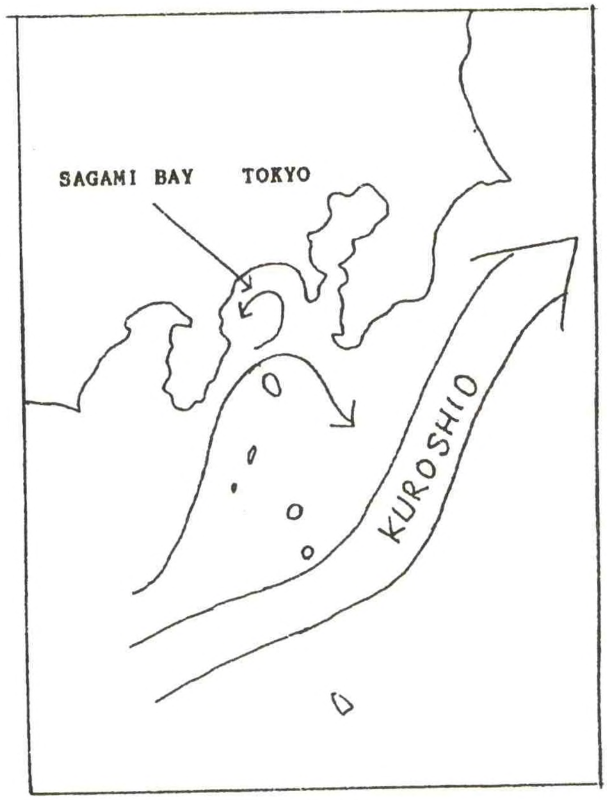

Fig.1 The location of Sagami Bay

2. CURRENT SYSTEM IN THE BAY

This bay has rather large water depths (about 2000m at maximum). Then tidal current may not be a major factor in the current system. A barotropic tide model was used to compute the tidal current in the bay. The result for M2 and K1 tide shows the tidal current is rather weak with less than 4cm/sec over most of the area. So, in this study the ocean current and the wind-induced current are considered as a current system.

3. MODELING OF OCEAN CURRENT

A farily large number of GEK data for the bay are accumulated in Japan Oceanographic Data Center. The are analysed to be found that there are three fundamental flow patterns in the bay. They are named as X-, Y- and Z-pattern. Computer simulation (one layer, in- and outflow boundary condition, 1.25 min meshi size) was used to reproduce those patterns. The analysis also showed that there are good correlation between the occurrence of the above patterns and the strength of the branch current of the Kuroshio which flows into the bay at southwest side of the bay and can be monitored by the tide stations at island. The analysis showed that the sea level at Kozushima island is most appropriate for monitoring of the Kuroshio branch current.

Based on the above result, sea level at Kozushima island (which is tranmitted to the local headquarter of Maritime Safety Agency in real-time.) is used to determine a pattern and the computer simulated result is used to have a current value for each mesh.

4. WIND INDUCED CURRENT

Wind-induced current can be expressed as a superposition of the past wind effect. Preparation of coefficient data table is the quickest way to have the numerical values of the wind current. In order to have the data table, a computer simulation was conducted, in which three layers (0-2m, 2-12m, 12-bottom) are moving viscously with each other.

5. WIND DATA

There are eleven meteorological monitoring stations around Sagami Bay. Mathematical interpolation is conducted using those station data to have surface wind values. Historical ship data of sea surface wind are used to compute the correlation between observed and interpolated data. The result is compiled to prepare data table which is used to correct the interpolated wind values.

6. EXPERIMENT

In order to test the model, four experiments were conducted. In each case, a bouy which have Loran-C receiver is traced for one-day. A comparison between the real trajectory and predicted one is shown in Fig.2. As is seen in the figure, a fairly good agreement is obtained.

This study was conducted under the auspice of Japanese Hydrographic Association with the financial support from Japan Ship Industry Foundation.

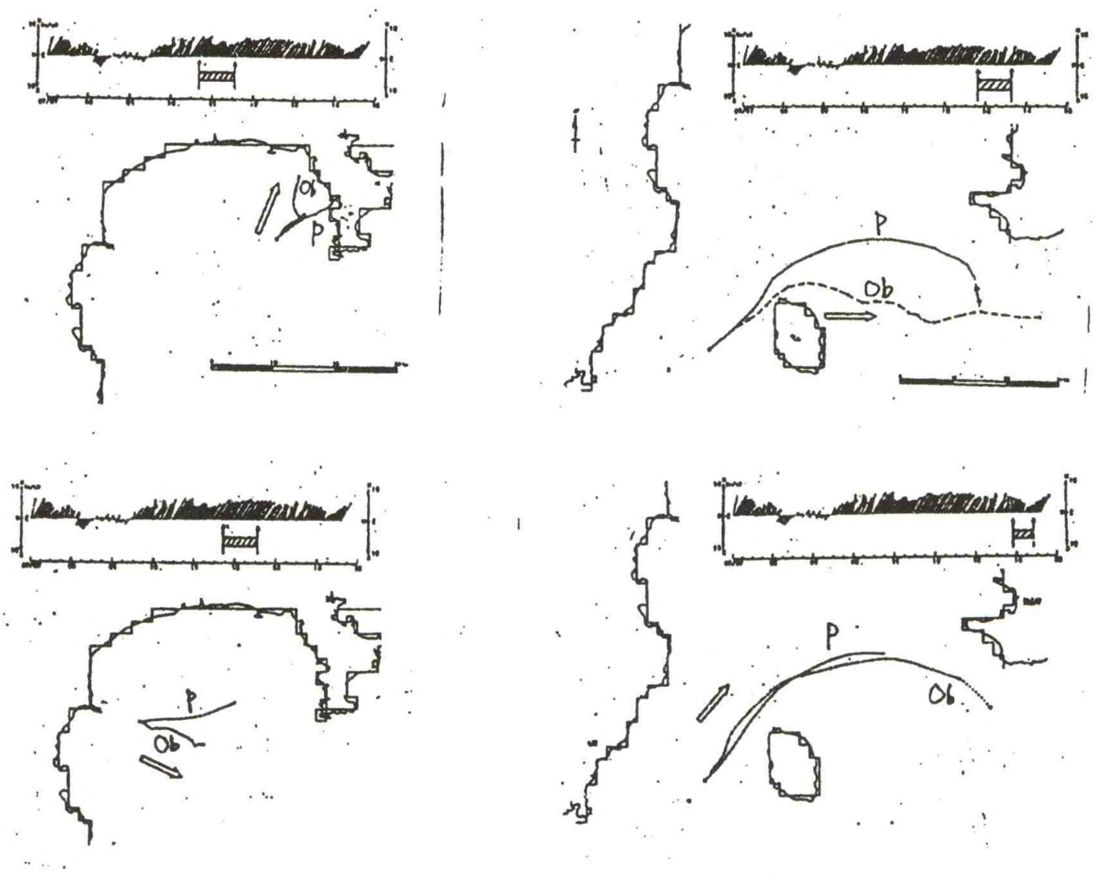

Fig.2 Comparison of drift experiment and predicted course. P stands for predicted and Ob observed.

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