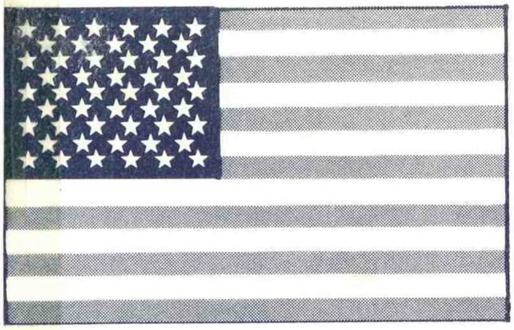
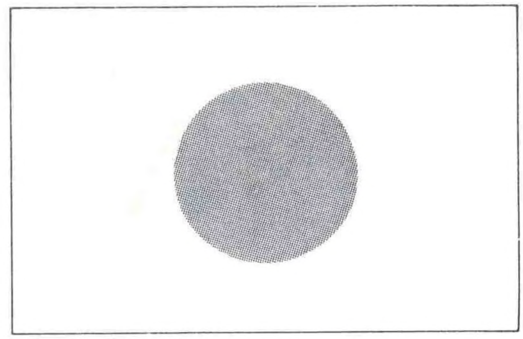




U.S.A.

UJNR

U.S./Japan
Cooperative
Program
in
Natural
Resources

日本

日米天然資源協力プログラム

11TH MEETING U.S. - JAPAN MARINE FACILITIES PANEL

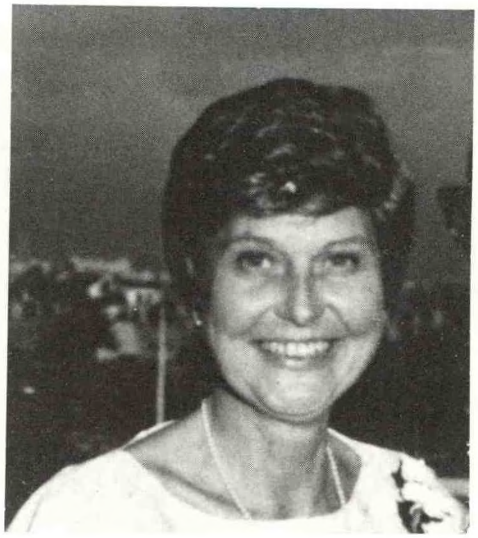
MAY 1982

CONFERENCE RECORD

Eleventh Meeting of the United States - Japan Cooperative Program in Natural Resources (UJNR) Panel on Marine Facilities May 1982

March 1983

DEDICATION



MARY BETH PRITZLAFF

Many of the Japanese and United States members of the Marine Facilities Panel UJNR have fond memories of Mrs. John Pritzlaff who accompanied her husband to Japan to MFP meetings in 1972, 1974, 1977, and 1979. Her absence was sadly noted and appropriately observed in the opening session of the 1982 meeting.

In recognition of the contributions of Mary Beth in promoting affection and understanding among our peoples, we dedicate this Conference Record to her memory.

Muneharu Saeki, Chairman Japan Panel

Morton Smutz (left), Executive Secretary, and
Joseph R. Vadus (right), Chairman US Panel

PREFACE

This document contains 35 papers and 18 special reports presented at the Eleventh Meeting of the Marine Facilities Panel of the United States-Japan Cooperative Program in Natural Resources (UJNR), held May 10-11, 1982 in Tokyo, Japan. Following the meeting, the Panel participated in a study tour of marine facilities from May 12-26, 1982. A final meeting was held May 26, 1982. A schedule of the entire program and a summary report of the meeting and study are provided herein.

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

The United States-Japan Cooperative Program in Natural Resources was established in 1964 to facilitate cooperative efforts and technology exchange in the field of natural resources that would provide a better environment for present and future generations. Seven of the 17 UJNR panels deal with marine science and technology and are a part of the Marine Resources and Engineering Coordination Committee (MRECC) of UJNR.

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

Participation of governmental agencies in the United States include: the Department of Agriculture, Department of Commerce, Department of Energy, Department of Interior, Department of Transportation, Department of State, Department of Defense, and Environmental Protection Agency.

The Marine Facilities Panel meeting enabled a valuable exchange of technical information between key representatives of the ocean community from Japan and the United States. Mr. Muneharu Saeki, Chairman of the Japan Marine Facilities Panel, hosted the Eleventh Meeting and served as Chairman for the meeting. We are grateful to Mr. Saeki and the Japan Panel for their responsiveness to our technical interests and their valuable contributions to the success of the meeting. Special recognition is given to Mr. Tamio Ashino for his excellent planning and coordination of program activities.

We acknowledge and appreciate the valuable advisory assistance and coordination provided by Mr. Gerard F. Helfrich, Scientific Counselor, U.S. Embassy, Tokyo. Special recognition is given to Dr. Morton Smutz, who served as Editor of this document.

Joseph R. Vadus, Chairman
U.S. Marine Facilities Panel
UJNR

OPENING REMARKS

Muneharu Saeki
Chairman Japanese 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 11th Japan-U.S. Joint Meeting of the UJNR Marine Facilities Panel.

As you know, the objectives of the UJNR Program are to contribute to the development and utilization of limited natural resources through the close collaboration of both governments for the benefits common to Japan and the United States. As a part of the UJNR activities, the Marine Facilities Panel was organized in 1968 as one of seven panels under the MRECC. This Joint Meeting marks the eleventh; the first meeting having been held in March 1970 here in Tokyo. Through these meetings, I am quite confident that, in addition to the exchange of valuable technical information or views, our Panel has played an important role in the development and enhancement of technology in marine facilities by fostering the close personal relationships among the members and advisers of both panels.

As we have done until now, let us strive to make our Panel activities more prosperous and to strengthen our cooperative efforts toward the UJNR goals.

Next, I am very sad to say that the U.S. adviser, Mr. John Pritzlaff's wife, Mary Beth passed away in February of this year. She had visited Japan several times along with her husband and participated in a number of field trips. We will never forget that she had shown a profound concern and understanding to the MFP activities. Now, blessing her memory, I would like, on behalf of the Japan Panel, to express our sincere condolence to Mr. John Pritzlaff who is attending this Meeting.

Today, we have met you all again one year and a half after the last meeting in Washington in the fall, 1980 and, through the period, there have been some slight changes in the members and advisers of both panels. What is considered the most important thing for international cooperation like UJNR is perhaps such a face-to-face meeting opportunity through personal contacts. With this view, I certainly look forward to producing constructive results at this Meeting.

In Japan, May is a nice season of fresh green. I do, really, hope that you will enjoy the scenic beauty of early summer while in the sessions and on the field trips, and that your stay here will be a very pleasant one.

Thank you very much.

Joseph R. Vadus
Chairman, United States Panel

Distinguished members and advisers of the UJNR Marine Facilities Panel, on behalf of the U.S. Panel, it is my pleasure to extend our warmest greetings and best wishes to Mr. Muneharu Saeki, Chairman of the Japan Panel and to each of the members and advisers of the Japan Panel. We are pleased to be participating with you in this 11th joint meeting in Tokyo, one of the truly great cities of the world, and we are delighted for this reunion with our many friends from past meetings and having this opportunity to make some new friends.

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

I am saddened to report to you that Mr. John Pritzlaff's wife, Mary Beth passed away in February of this year. They had been involved in UJNR activities for about 10 years and made a number of trips to Japan together. We will always remember her kindness and friendliness, and her enthusiasm for UJNR activities. In her memory, let us share in a moment of silence. (silence). We are grateful that Mr. Pritzlaff was able to join us for this meeting.

Over the last decade, the continued quest for food, energy and minerals from the oceans provides and accelerating demand for the advancement of technology in marine facilities that are essential in the development of the oceans and their resources. The need for marine facilities in Japan and the U.S. has expanded in scope and intensity, and the Panels have responded to this challenge. They cover a broad and active range of interests, and we receive excellent support from the technical community.

At the 10th meeting in Washington, D.C., in October 1980, there were 19 members and advisers from Japan and 25 from the U.S. and a total of 46 papers and reports were exchanged, and reported in conference proceedings in the Japanese and English languages.

The U.S. Panel has appreciated the cooperation, technical ability and cordiality of the Japan Panel, and we find these meetings and tours to be very informative and useful. I trust that we will continue to contribute to the vast information base needed to provide the advanced marine facilities of the future, and keep pace with the accelerating needs. I sincerely hope that both panels will find this 11th meeting and marine facilities tour mutually rewarding and successful.

ITINERARY

Date	Time and Activity
May 8,9	Arrival of U. S. Delegation in Tokyo Accommodations at Sanno Hotel and Hilton Hotel
May 10	0900-1700 Plenary Session, Sasakawa Hall, Tokyo 0900-0930 Opening Remarks Mr. M. Saeki, Chairman, Japan Panel Mr. J. R. Vadus, Chairman of U. S. Panel Mr. M. Tsuge, Chairman of Japan MRECC Dr. W. Telesetsky, Chairman of U. S. MRECC Mr. K. Toda, Secretariat to Minister Mr. G. F. Helfrich, Counsellor for Scientific and Technological Affairs, U. S. Embassy 0930-1700 Technical Program, (Papers herein) 1900-2100 Japan Sponsored Reception, Sasakawa Hall
May 11	0930-1700 Plenary Session Continued, (Papers herein) 1900-2100 U. S. Sponsored Reception, Sanno Hotel, Tokyo
May 12	0900-1700 Marine Resources and Engineering Coordinating Committee (MRECC) Meeting, Ministry of International Trade & Industry, Tokyo
May 13	0830-1300 Visit Sumitomo Heavy Industries, Oppama and inspect Shipyard Construction Projects 1300-1400 Inspect SHINKAI 2000 Submersible and Support Ship NATSUSHIMA, at Uraga Shipyard 1400-1600 Tour Port & Harbor Research Institute at Kurihama
May 14	Visit Tsukuba City 0830-1200 Mechanical Engineering Lab - Projects 1300-1600 Electrotechnical Lab - Projects
May 15	1300 Tokyo to Hiroshima, Flight ANA 677 Hiroshima Grand Hotel

May 16	Sunday-Open Schedule 0900-1200 Hiroshima City Tour 1300-1700 Miyajima Island Tour
May 17	0900-1200 Visit Mitsubishi Heavy Industries Ltd, Kure and Inspect Construction Projects 1400-1500 Visit Chugoku Hydrographic Model Basin By bus to Kurashiki Terminal Hotel, Kurashiki
May 18	1100-1200 Visit Mitsui Shipyard, Tamano 1300-1900 By hydrofoil craft, Uno Port to Takamatsu and Keio Plaza Hotel
May 19	0900-1100 Visit Chugoku Industrial Testing Facilities, Takamatsu 1400-1530 Visit Solar Energy Exhibition, Nio on west coast of Shikoku
May 20	0740-1200 Inspect Shikoku - Honshu Bridge construction at Naruto 1300-1800 By bus to Kyoto, Kyoto Century Hotel
May 21	0900-1600 By train to Kobe. Tour Port of Kobe by Port Authority vessel. Observe Port Facilities at Port and Roko Islands (man-made)
May 22	1300 Leave Kyoto by Bullet Train, Kodama 260 to Atami - Shinnihon Hotel
May 23	0830-1800 Visit Oshima Island via Matsui's Semi-submersible Catamaran, SEA GULL, formerly MESA 80 Transfer to Suikoen Hotel, Atami
May 24	0900-1200 Visit Museum of Art, Atami 1500-1600 Leave Atami by Bullet Train, Kodama 246 to Tokyo. Sanno and Hilton Hotels
May 25	0900-1200 Visit Ship Research Institute, Mikata, Tokyo Final Meeting Session and visit facilities including: Ice Model Facility, Open Basin Test Facility, Models of Offshore Structures, Cavitation Test Facility, and Heavy Structures Division 1300-1500 Lunch and Reception
May 26	U. S. Delegation Departs Tokyo

FINAL MEETING

The final meeting was held at the Ship Research Institute on May 25 with Mr. Saeki presiding as chairman. Mr. Saeki summarized the activities of the 11th meeting and study tour and expressed hope that all objectives were met on both sides. Mr. Saeki indicated that Japan has bilateral agreements in science and technology with several countries in addition to the U. S. He indicated that the panel should extend cooperative activities by exchange of researchers and should propose and develop cooperative projects. Appreciation was expressed to Dr. Alan Powell for technical assistance given to Mr. Mutoh of Mitsui Ocean Development and Engineering Company. Mr. Vadus remarked that the technical program was outstanding with a broad spectrum of topics presented. The field tour was also excellent and precisely coordinated. All topics requested were presented, and all facilities requested to visit were made available. A Conference Record containing summary papers (English version) presented at the 11th meeting will be published and distributed. Mr. Vadus paid special attention to the absence of Mary Beth Pritzlaff who attended many previous meetings and died in February 1982. Mr. Vadus expressed appreciation to Mr. Saeki and to all panel members for their efforts.

Mr. Vadus proposed that the 12th meeting be held in the U.S. in August 1983, to be coincident with OCEANS 83 in San Francisco, California. Preliminary plans for the meeting, based on the consensus of the U.S. panel members, were proposed. Mr. Saeki expressed agreement on behalf of the Japanese for the next meeting to be scheduled in the U.S. in August 1983. The final arrangements are to be made, as in the past, through correspondence between the chairmen.

In response to Mr. Saeki's request for possible areas of cooperation, the following areas were suggested:

- Dr. Smutz proposed a cooperative program on mooring line components for deep-ocean applications between NOAA and the Government Industrial Research Institute.

- Mr. Vadus described joint interest in undersea facilities such as ROV's with the UJNR Diving Panel and offered to explore the possible assistance he could provide to Dr. Matsuda and Dr. Miller.

- Mr. Hightower expressed an interest in exchange of personnel and information on undersea technology projects such as those developed at JAMSTEC.

- Mr. Gross expressed interest in exchange of information on ship control in ports and harbors and in underwater welding.

In conclusion, Mr. Saeki and Mr. Vadus expressed appreciation to all those who helped make the 11th meeting a success with special thanks to the interpreters who did an outstanding job.

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Attendees, Technical Sessions,
Sasakawa Hall, Tokyo, Japan

FIELD TOUR

May 13-25, 1982

Sumitomo Heavy Industry, Oppama Shipyard (May 13, 1982).

The Oppama Shipyard was constructed on reclaimed land at Yokosuka at the entrance to Tokyo Bay. The first ship was completed in 1972. Shipbuilding steps have been automated and mechanized to reduce labor costs, to enhance quality, and to improve efficiency. The operation of cranes, conveyors, shot-blast machines, steel plate markers, and electric flatcars is computer controlled. Much of the welding is carried out by automatic welding machines. The GAMMA (Grand Assembly in Mechanical Mould Apparatus) has two 600 ton cranes able to work together.

The Japanese Government attempts to balance the work load at the various shipyards through licensing. All are working below design capacity.

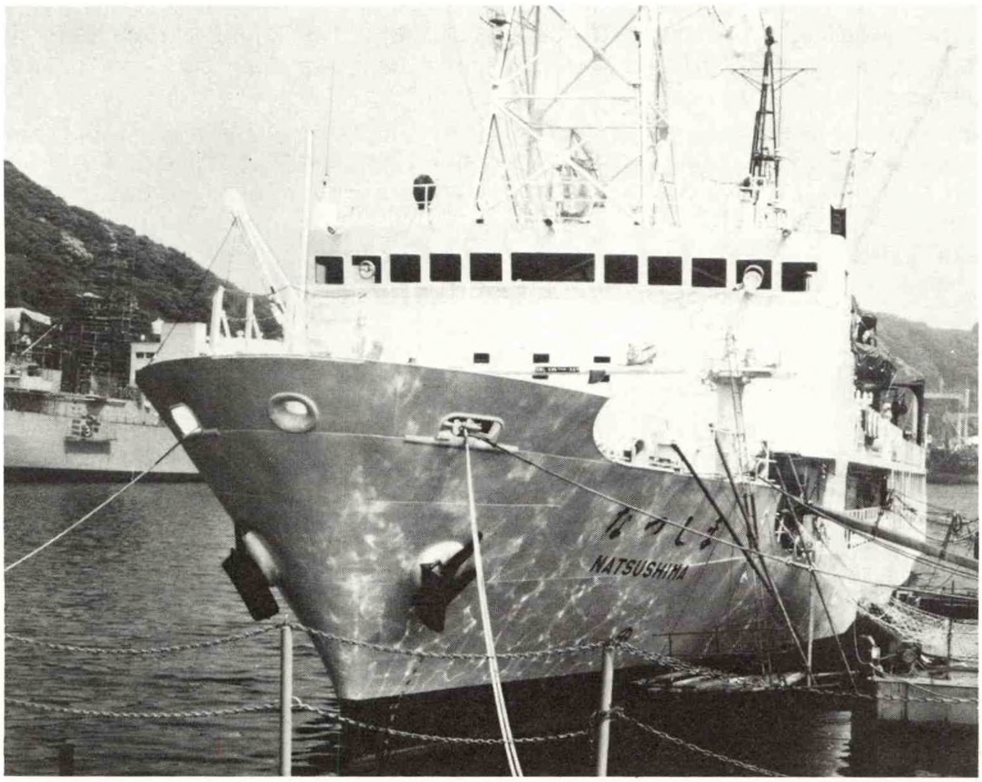
Ocean Ranger II was inspected. It is scheduled for delivery in December 1982.

Offshore Drilling Platform Under Construction
at Oppama Shipyard of Sumitomo Heavy Industry

Sumitomo Heavy Industry, Uraga Shipyard (May 13, 1982).

The Uraga Shipyard, located 5 miles south of the Oppama Shipyard on Tokyo Bay, was established in the 1880's. We visited the SHINKAI submersible at that location which was berthed aft in the Natsushima. Both are quite new and well maintained. The next dive of the SHINKAI was scheduled for May 21 and the 2,000 meter dive is scheduled for September 1982.

SHINKAI 2000 was constructed by Mitsubishi Heavy Industries Ltd. Kobe Shipyard and her support ship NATSUSHIMA constructed by Kawasaki Heavy Industries Ltd. Kobe Works. The principal uses of SHINKAI 2000 will be for research in geophysics, oceanography, and mineral/bioresources and for the inspection of underwater structures.



Support Ship NATSUSHIMA for SHINKAI 2000

Port and Harbor Research Institute, Ministry of Transport, Yokosuka City (May 13, 1982)

The Harbor Laboratory was established in 1946 and moved to the present site in November 1949. As the name implies, it conducts research primarily related to coastal hydraulic engineering. Major research facilities in the Hydraulics Division include a 30 x 20 x 1 meter wave basin, a 105 x 3 x 2.5-m large-scale wave channel, and a large wave basin 50 x 30 x 0.8-m. Major facilities in the Marine Hydrodynamics Division are a 50-m Irregular-Wave-Generating Channel 40 x 1.5 x 1.5-m, and Wind-Wave Channel 66 x 1.5 x 1.3-m, a multipurpose Hydraulic Experimental Basin 58 x 48 x 1-m, and a Purification Hydraulic Basin 40 x 30 x 1-m. The Soils Division, the Structures Division and the design Standards Division also have specialized equipment for their work.

Tsukuba Science City (May 14, 1982)

Tsukuba Science City, located 60-km northeast of Tokyo, was developed by the Government of Japan to enable research and educational institutions to work together in an organized manner and also to relieve pressures for space in Tokyo. Construction began in 1966 and by 1980 43 national research and educational institutions have been completed at a cost of over 1,000,000 x 10^6 yen ($5,000,000,000). The population is now about 130,000. About 6,500 research personnel are among the 11,400 staff members. About half of the total Government research manpower are located at Tsukuba City.

The Mechanical Engineering Laboratory (MEL), established in 1937, moved to its very modern facilities in January 1980. A movie, narrated in English, described current activities:

1. Development of effective utilization of energy and other resources.
2. Sophistication of production technology.
3. Social development technologies.
4. "Extremecal" and basic research.

Projects and facilities described included a wind turbine, high-performance combustion, Stirling engine, high-pressure seals, deep-sea guidance system by acoustics, anechoic water tunnel, traffic sensors, chemical mixing laser, acoustical microprobe, prosthetic arm, pattern recognition, MELKONG (a robot for patient care), MELDOG (a guide-dog robot), anthropomorphic manipulators, etc.

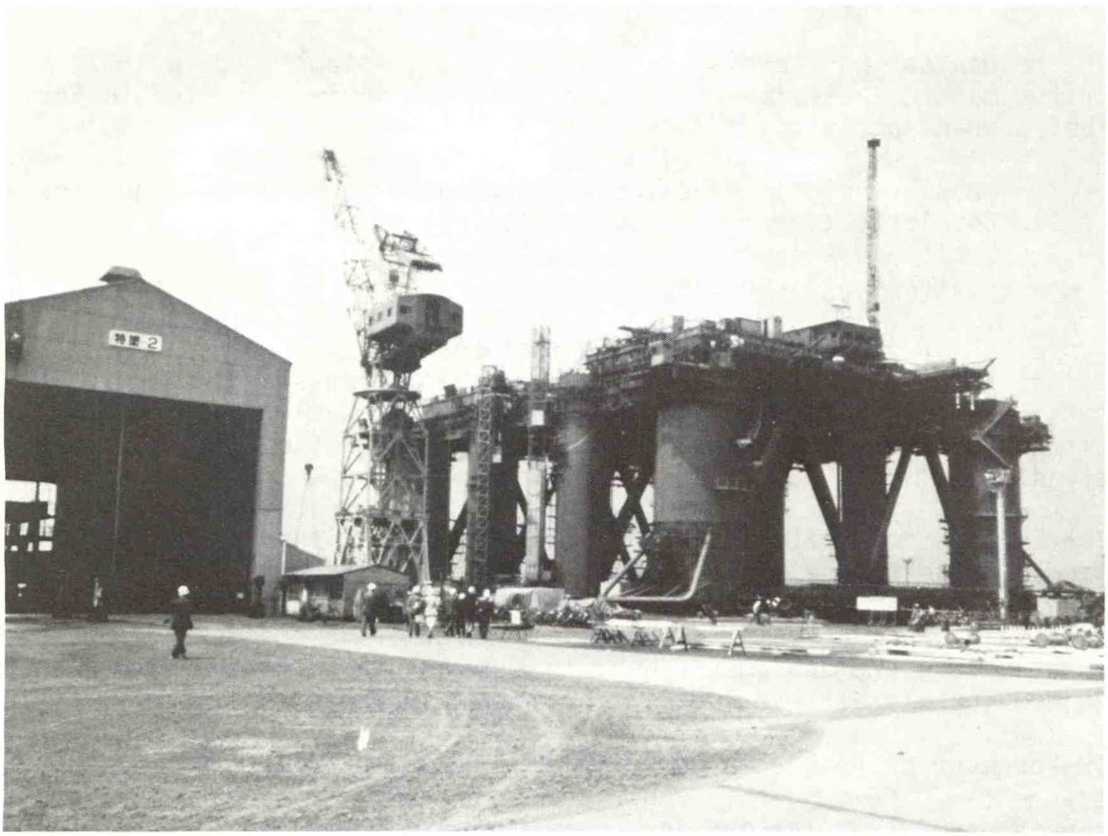
The Electrotechnical Laboratory (ETL) was established in 1981. Like MEL, it belongs to the Agency of Industrial Science and Technology of MITI, the Ministry of International Trade and Industry. ETL is the largest national institute in Japan concerning electronics, information processing, energy and standards. There are 565 researchers in the 722 staff members with a budget of $39,000,000 for fiscal year 1982. The laboratory moved to Tsukaba City in 1979.

Improvement of heat exchanger performance was described as the major activity in the OTEC project. Considerable research has been underway to produce special heat transfer surfaces by powder metallurgy. A closed-cycle pilot plant heat exchange system was in operation "to develop an optimum system design method." ETL has described the "Preliminary Design of a 1-MWe OTEC Test Plant" for the Kumejima test site. The design is for an ocean-based, 1-MWe (gross) test plant employing a closed-cycle power system using ammonia as the working fluid on a barge-type platform with a rigid-arm-type detachable single-buoy mooring system. The steel cold water pipe, 1.8-m inside diameter and 800-m long is suspended from the buoy. The cold water pipe thickness for the top 200-m section is 30-mm and 20-mm for the 200-800-m bottom section.

The robotics work at ETL is highly sophisticated with systems designed to "learn" from sensor readings so that subsequent operations can be carried out more efficiently.

Mitsubishi Marine Structures, Hiroshima (May 17, 1982).

Mitsubishi Heavy Industries, one of the world's largest shipbuilders, has four plants in the Hiroshima Shipyard and Engine Works: Kan-on, Eba, Gion, and Taibi. The 6,500 employees have an annual output of roughly $1,000,000,000. The Works produces dredgers, harbor facilities, offshore oil drilling rigs, bridges, materials handling equipment, steel stack, power systems, large-sized machine tools, processing equipment, compressors, blowers, and cement plants. One of the largest and most advanced semi-submersible drilling platforms ever built was the ill-fated OCEAN RANGER completed at this site in May 1976. The deep-sea research vehicle SHINKAI-2000 was completed in October 1981. Two semi-submersibles under construction were visited.



Offshore Platform Under Construction at
Mitsubishi Shipyard, Hiroshima, Japan

Government Industrial Research Institute, Chugoku (May 17, 1982).

The Institute was founded in June 1971 as one of the 16 national laboratories of the Agency of Industrial Science and Technology. The main feature is the "world's largest hydraulic model" called the Seto Inland Sea Hydraulic Model. It has scale ratios of 1 to 2,000 in the horizontal and 1 to 159 in the vertical. It covers an area of about 7,000 m^2, contains 5,000 tons of water, and cost roughly $10,000,000. The model is roughly 230 meters by 100 meters. It has three separate tide-generating facilities and is controlled by computer. The principal purpose of the current project is modelling the movement of pollutants.

Mitsui Engineering and Shipbuilding Co. Tamano Works, (May 18, 1982)

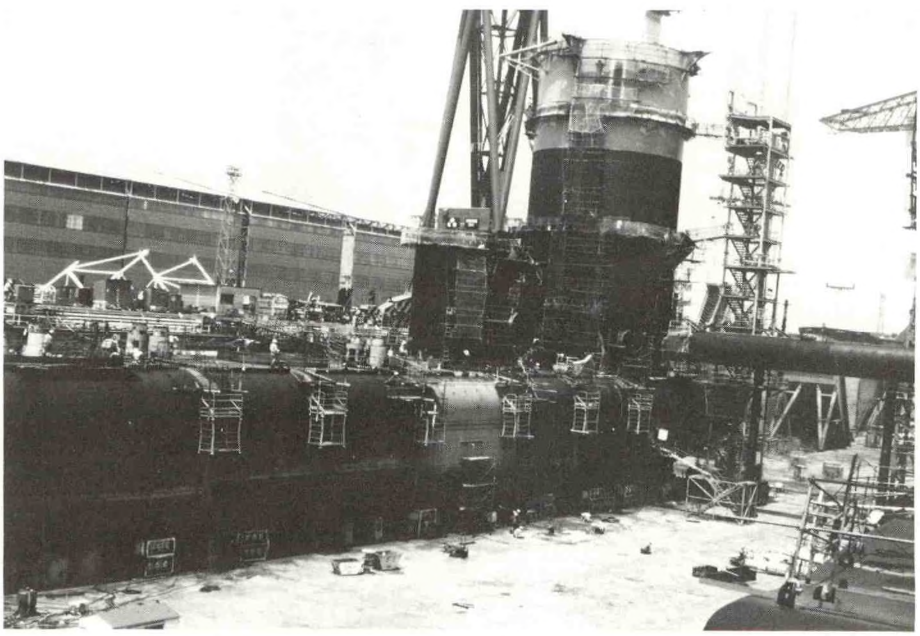
The Tamano Works was founded here in 1917 and started building engines in 1927. The three divisions are the Shipbuilding Division, Steel Structures Division, and the Process Plant and Machinery Division.

The Shipbuilding Division has both a new building section and a ship repair section. Work in the new building section is devoted to the building of tankers and ore carriers up to 140,000-dwt as well as those requiring a high standard of technology. This is the site of the world's first automated cargo ship. The ship repair section has a 150,000-dwt capacity floating dock and well-equipped mooring quays.

The Process Plant and Machinery Division is comprised of shops that manufacture diesel engines, rotary machinery, electric machinery, cranes, chemical plants, boilers, and heavy machinery for casting and forging various products.

Penstocks, lock gates, bridges, steel frames, and large tanks are made in the steel structures division. The facilities are now used in the building of various offshore structures. The division was the "first plant outside the U.S. A. to be designated by the A.I.S.C. (American Institution of steel Construction)."

Half of Mitsui's 12,000 employees work at this plant. Semi-submersible drilling rigs PETROBRAS IX for Petroleo Brasileiro S. A. and SEDCO 710 for SEDCO, Inc., are now under construction. POLYCASTLE, a semi-submersible drilling rig was completed two months ago for Einer Rasmussen to be installed in the North Sea. It was designed to withstand 100 knot winds, 30 meter waves, and 2 knot currents.



Semi-submersible Drilling Rig Under Construction,
Mitsui Engineerig and Shipbuilding Co., Tamano Works

Chugoku Industrial Research Institute, Sikoku, Takamatsu (May 19, 1982)

The laboratory has a total of 46 employees of whom 35 are research personnel. The two principal divisions are Chemistry, and Machinery and Metal Department.

The principals of the dry and wet underwater welding and cutting operations were explained and demonstrated.

The process by which uranium (3-ppb in sea water) is adsorbed on Amidoxime resin and eluted by acid. A cost estimate indicates that uranium can be extracted from sea water on a large scale at a cost of about $100 per pound. This is about double the current selling price. The research on lithium recovery is less well advanced.

Researchers in the Machinery and Metal Department have studied the use of wire ropes and chains cast in rubber as mooring line components. The rubber is cast around the chain links when they are in a loose position thus reducing abrasion. These mooring lines may have applications to tension leg systems.

The Institute has considered the design of a tension-leg mooring system for a spar-type OTEC plant. Model tests of a 10-MW system for Okinawa will be tested in a wave and current tank in the fall of 1982.

Underwater Cutting of 300 mm (11.8 inch)
Thick Stainless-Clad Steel

Pressure vessels of commercial nuclear reactors are made of carbon steel with ¼ to ½ inch stainless steel cladding. Dismantling is achieved underwater to provide adequate radiation shielding for workmen.

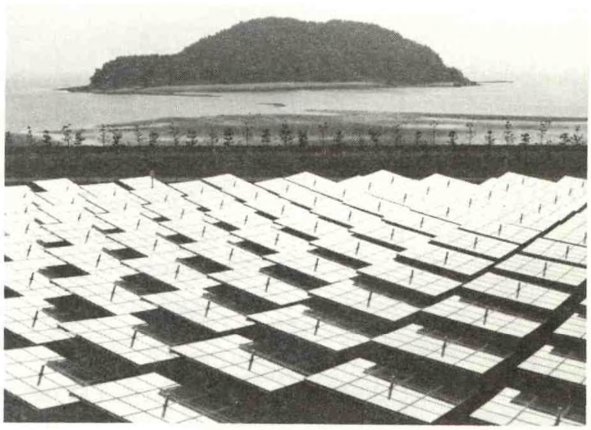
Solar Thermal Energy Pilot Plant, Nio-cho (May 19, 1982)

Research is in progress under Japan's "Sunshine Project" to develop two types of solar energy pilot plants. Two solar power plants, each having an output capacity of one megawatt, have been completed and put in operation side by side. The electricity generated is being transmitted to an existing power network.

In the Plane Parabolic System the direct sunlight falling on plane mirrors is reflected and concentrated on cylingrical parabolic mirrors from which it is further concentrated on heat absorption tubes arranged on the focal point of parabolic mirrors. The superheated steam is passed to a turbine or stored (3 hour limit) by means of a molten salt heat storage tank.

In the Central Receiver System the direct sunlight falling on plane reflection mirrors of numerous heliostats is concentrated on a solar energy collection tower. The resulting superheated steam is sent to a turbine or stored by means of an accumulator.

The facilities cover an area of about 25 acres and is adjacent to the Seto Inland Sea. The plant has been in operation since May 1981. The plants were built at a cost of about $20,000,000. Operating costs are about $2,000,000 per year, and the efficiency is about 10%. A similar installation in California, 10 megawatt, cost about $140,000,000 and has been in operation since early 1980.



Solar Energy Pilot Plants, Nio-cho, Japan
Left: Central Receiver System.
Right: Plane Parabolic System.

Construction of the Naruto Bridge
Giant Whirlpool on right side of photograph.

Honshu-Shikoku Overseas Bridge, Naruto (May 20, 1982).

The Manager of the Naruto site, gave a general description of the overall project which consists of a series of bridges and roadways 81.8 kilometers in length. These bridges will be double-decked over the straights for both highway and rail traffic, and have been designed to withstand earthquakes, typhoons, and strong currents.

The Ohnaruto bridge was started six years ago and will be completed in 1984. Its total length will be 1,629 meters with a center span of 876 meters. This will then be the 10th largest suspension bridge in the world. The cost will be about $400,000,000. The anchorages have been completed and about half of the cable construction completed.

The importance of the project is that this will substantially reduce transportation costs between two of the principal islands.

Kobe Port Authority (May 21, 1982)

Although the Port of Kobe was formally opened in 1868, shortly after Admiral Perry's arrival, it had been used since the third century for limited trading. It is now the world's leading container port with over 20 million tons handled in 1980.

Port Island, the world's largest man-made island, was completed in March 1981 at a cost of about two billion dollars by cutting into a mountain and moving 80,000,000 cubic meters of sand and soil. Its size is about 1100 acres and contains 9 container berths and 15 liner berths.

Rokko Island, a second man-made island, is under construction and will be completed in 1990. Its size is about 1500 acres. The volume of sand and soil to be moved is 120,000,000 cubic meters.

Kobe is also a transit port for trans-shipment of cargo to and from Korea, China, Hong Kong, Viet Nam, etc. Plans call for the construction of an International Conference Center and associated hotel.

Old piers are being modernized with pipe lines to each.

A 3,000 ton crane is available for the transfer of very heavy cargo.

Container Ship at Kobe Port, Japan

High-Speed Semi-Submerged Catamaran (SSC) Passenger Craft, Atami (May 23, 1982).

This SSC was developed by Mitsui and was undergoing sea trials during the UJNR visit in 1979. During the 1979 and 1982 visits, the U.S. Panel was on board for a demonstration. The system is now called SEA GULL and has been in commercial operation since March 1981.

This vessel is now in routine use for transferring passengers to and from Atami to Oshima Island, a distance of about 30 miles. It can carry 446 passengers and a crew of 7. Her speed is little affected by waves and provides a smooth ride with waves of 3.5 meters. It is about 36 meters in length and 17 meters in breadth. Maximum speed in about 27 knots.

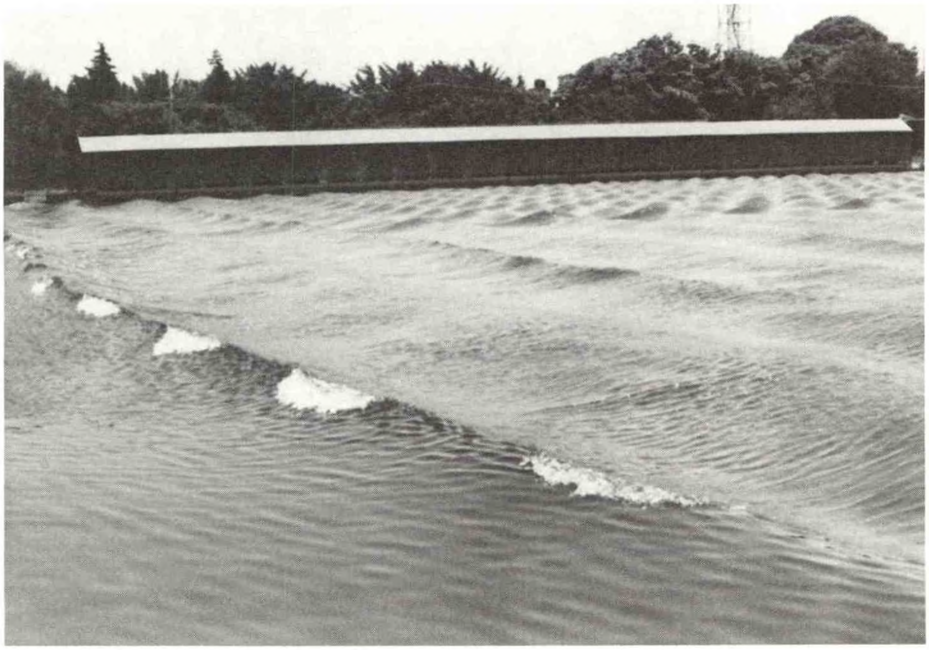
Ship Research Institute, Ministry of Transport, Tokyo (May 25, 1982).

The Ice Model Facility was completed in April 1981 in order to seek solutions to ice-engineering problems encountered in the design of ships and structures to be used under artic conditions. The building is a single-story prefabricated building 54-m by 25-m containing five primary areas; a test basin, work shop, control room, offices, and machinery area. An undiluted saline water tank is located apart from the main building. The test basin is 6-m wide, 1.8-m deep, and 35-m long. The basin is of concrete, and the side walls are reinforced concrete with steel fiber. The outer surface of the concrete is covered with polyurethane foam. An observation corridor allows underwater viewing. The lowest attainable room temperature is -35^{o}C. The cooling cycle can be controlled by a cassette tape fed to a computer. The computer also can log and plot data from the model tests.

The Open Basin Test Facility, 80-m x 80-m x 4.5-m, allows waves to be produced simultaneously from two directions. One wave maker is of the plunger type, and the other is a blade. Radio-controlled ship models can be used with pitch, roll, and acceleration data telemetered to the control station.

Models of offshore structures can be modelled in another 40-m x 30-m enclosed basin. A recent study involved the modelling of the proposed Osaka floating ariport. They normally use a 1/30-scale model in tests.

Visits were also made to the Cavitation Test Facility and to the Heavy Structures Division. A new testing facility costing about $2,000,000 can provide a compressive force of 500 tons. It will be used to test their ice breaker hulls.



Open-Basin Test Facility,
Ship Research Institute, Tokyo, Japan

JAPANESE PRESENTATIONS

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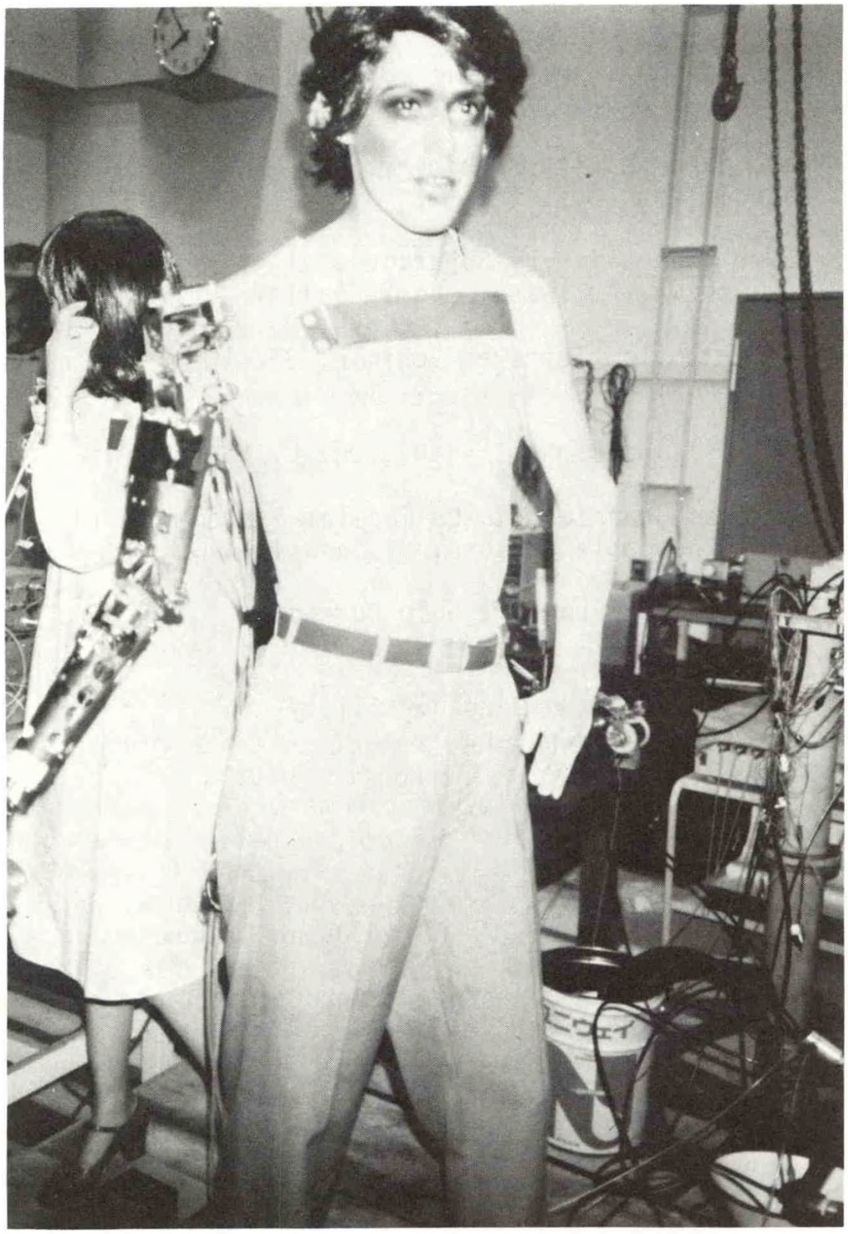


Mannequin Meets Shy "Girlequin" at
Mechanical Engineering Laboratory,
Tsukuba Science City, Japan

DESIGN CONSIDERATION OF THE FLOATING AIRPORT

by

N. Takarada

Sumitomo Heavy Industries, Ltd.
Deputy Chairman - Technical Committee
Marine Airport Special Countermeasures Group

1.0 Introduction

About thirty years ago, there were no remarkable structures on the sea except for vessels and structures at the seaside. However, as a result of the extension of the scope of scientific activities, especially the development of the structures relating to the exploitation of petroleum, various kinds of work vessels, barges, and offshore structures, etc., have been built. These may be divided into two broad categories, i.e. the fixed type and floating type. The fixed type is subdivided into submersible type and jack-up type, and the floating type is also subdivided into semi-submersible type and ship type.

This paper outlines the problems raised and solved with regard to the design of a semi-submersible floating airport, the biggest offshore structure ever conceived. The investigation was carried out by the Shipbuilders' Association of Japan on the assumption that Kansai New International Airport would be built in this manner.

2. The displacement and deflection of the floating airport by environmental force.

2.1 Assessment of environmental conditions at the place where the airport is expected to be constructed.

It is said that in order to assess the environmental conditions, a continuous observation record of more than five years is required. Fortunately, around Senshu, offshore of Osaka Bay where the airport is to be constructed, there are many long-standing local weather stations and very precise records are obtainable by averaging the observed values and by supplementing them. Table 1 was prepared by investigating the wind, wave, tide, atmospheric temperature, water temperature and unusual values resulted from typhoon, high tide, tidal wave, earthquake, etc., as well as the possibility of bore and uneveness of spacious sea surface. A theoretical analysis was made based on these data, and a simulation method was used to reproduce and investigate the conditions.

2.2 Establishment of the model for the floating airport.

An outline of oscillation characteristics is shown in Figure 1.

2.3 Presumption on the environmental force against floating airport.

For the environmental conditions in Table 1, the external force against the floating airport was determined as follows:

(1) To find the values of wind drag, wind-tunnel tests on a partial model and a complete model were carried out. In the experiment on the partial model, values of influence on mutual interference among column-group drag and those of Reynolds number were found. In the experiment on the whole model, the values of column-group drag, frictional resistance at the face of upper structure, and total drag were found. The values of wind drag applicable to actual floating structures were calculated by combining and modifying the values obtained in the experiments above.

(2) The wave external force was calculated by the tank-test using a one-hundredth model and a one-thirtieth model, respectively with respect to the wave-exciting force and wave-drifting force acting on the floating structures elements arranged in many lines and rows, the damping effects of hydrodynamics mutual interference wave, and the synergy of said forces and interference, etc.

(3) The drag coefficient of tidal-current force was determined by finding the values of the effects of mutual interference among the column and Raynolds number, using three kinds of scaled-down models at tank-test.

Judging from the above, the regular external force affecting the actual floating structure is determined as shown in Table 3.

Only model 1 is hereinafter explained.

2.4 Presumption on the motion and mooring force.

Since the mutual interference between the motion comes from the vertical force due to wave and the motion caused by the horizontal force, such as wave, wind, and tidal wave seem to be very slight considering the shape of model of floating airport, the equation of motion descriptive of the motion of the floating airport can be handled by distinguishing the vertical motion (heaving, pitching and rolling) and horizontal motion (swaying, yawing, and surging). The equation of motion was set up as if the floating structure were a rigid body, and the elastic transformation appearing in the vertical motion was considered separately.

The combination of the rigid-body motion, elastic transformation, and vertical motion due to the non-linear specific character of the mooring system, etc., were verified by theoretical calculation on a non-moored floating structure and a moored floating structure, using the model water-tank test.

The vertical motion was confirmed by analytical calculations, and the horizontal motion and mooring force were confirmed by simulation, the result of which were shown in Figure 2. to 4.

2.5 The deflection and stress by external force.

The floating airport would be affected by the difference of temperature, impacts due to take-offs and landings and the concentrated load caused by parked airplanes.

These loads will act independently, or in combination with each other, since each load is different in character.

Stress calculations suggest that the deflection by wave is limited to around the floating airport, and it is negligible inside the floating airport. The stress is also within the permissible limits. In case each individual floating structure is properly combined with each other, the deflection and stress will be further lessened since each individual floating structure has different deflections and stresses.

3. Motions between the airport and airplanes at the time of take-off and landing.

As a floating airport would be an elastic body, the vibration of the airport and airplane would be due to the following:

(1) Rapid increase and decrease of lift and thrust (breaking force)
(2) Relationship between travelling speed and natural frequency of airplane and airport
(3) Rough surfaces in the runway, periodicity of supporting structure rigidity to the direction of runway.
(4) Lateral vibration of the airport by wave force

Study of these factors are necessary as a base in studying the influences which affect the navigation support facilities, etc., in addition to the travelling performance. Unpredictable uneven subsidence may cause trouble.

3.1 Model development of system and simulation effects

As indicated in Figure 7, an airplane system is modeled by a vibration system with two degrees of freedom, partial transformation at the touchdown point of the runway is a flat plate with circumference fixed. The airport system is assumed to be a flat plate including shearing deflection supported by hydrostatic restoring spring and fluid influence.

Simulation will be made by establishing the input data of each system into the motion equation, but for the input data of the airplane, values of Boeing 747 are used.

Maximum values of the response obtained by the simulation are indicated in Table 11, vibration response of the airplane system are indicated in Figure 8, response at the wheel contact point at the time of landing at the main landing zone is indicated in Figure 10, response at the position of glidepass transmitter is indicated in Figure 11.

3.2 Study of the take-off and landing function

(1) In the course of landing, airplane vibration becomes heaviest just after landing, and rapidly decreases thereby vibrating.

(2) Vibration amplitude becomes smaller with the order of airplane body, wheel, and airport.

(3) Airplane once jumps up after landing and the contact force becomes biggest at the second landing.

Ratio between touchdown force and tare is 1.61 when considered as elastic floating body and 1.63 when considered as rigid body. This means there is almost no difference.

As shown above, if it is an elastic floating body, the take-off and landing function is equivalent to that of an ordinary land-based airport. In this calculation, a damping ratio of airport ζ=0.01 is applied only to the structure taking into consideration the vibration energy which dissipates into the sea through pavement and column. The damping ratio is assumed to be over 0.02.

3.3 Study of influence caused to navigation support facilities.

(1) MLS Method:
MLS electric wave moves by the landing of the prior airplane; and in the point of periodicity, the flight route of succeeding small airplane completely follows; and the flight route of large airplane generally follows. However, even if it is presumed that it completely follows, the vertical acceleration of the airplane is small, and ordinarily passengers do not feel it at all.

Even at the maximum time when the prior airplane with the abnormal landing weight of 500 ton, passengers can scarcely feel it.

(2) ILS Method:

On the pass by the inclination of glidepass antenna, first relationship between DDM (Difference in Depth of Modulation) and change of displacement current is obtained, and after comparison with the actual inclination of antenna, the inclination of antenna is quite small. So, the DDM and values of displacement current are quite small and the amount of pass-angle change is quite small.

By the above, in case of the future MLS in addition to the existing ILS, vibration of electro magnetic wave by the elastic deflection response in the floating airport is quite small, so the influence on the airplanes ready for take-off is practically negligible.

4. Magnetizing and demagnetizing

If the floating airport is built of steel, a strongly magnetic material, magnetostriction occurs at the circumferential area in connection with the geomagnetic field. Two kinds of magnetic distortion are possible, one is a permanent magnetic field which detects horizontal component of force of terrestrial magnetism by the use of flux valve. When any distortion should arise in the terrestrial magnetism, deviation in the gyrosyn compass indication arises thereby causing inconvenience. The relationship between induced magnetic field and permanent magnetic field is indicated in Table 13, and by the use of these characteristics, we have only to control the magnetostriction within the permissible limits.

4.1 Estimation of induced magnetic field.

Estimated values of the program of Geology Research Institute are indicated, values along with the entering route and values along with the landing zone. To the entering-route model, induced magnetic field at the respective heights and its deviated angles are indicated in Figure 12, and induced magnetic field at the landing zone is indicated in Table 13.

4.2 Permissible errors of gyrosyn compass and performance.

Permissible errors of gyrosyn compass are as follows:

(a) compass adjustment position: $\pm 0.2^{\circ}$
(b) holding point at the take-off time: $\pm 1.0^{\circ}$
(c) at the landing time: $\pm 1.0^{\circ}$

In the floating airport for main runway in Figure 13, the part which exceeds the above permissible errors are only in the edge of floating body at the height of 40 M except for the compass adjustment position. The gyroaxis of the gyrocompass changes according to the flux-valve input signal which senses the change of the direction of terrestial magnetism. Its follow-up speed is presumed to be 1.5°/min. When we surveyed the follow-up speed at the time when the magnetic field changes stepwise, values of 0.5 to 0.6°/min were obtained. When we assume that the airplane passes through the airport edge for three seconds, the maximum deviation is only 0.045 degree, and it converges to 0.7 to 0.9° as deviated angle of airport surface after rollout. Actually, owing to the existence of highcut characteristics by the gyro inertia, drastic change of deviated angle by the abnormal magnetic field at the airport edge does not occur.

4.3 Countermeasures for demagnetizing

As understood above, it is recommended that degaussing be installed at the compass adjustment area. For further assurance, it is recommended to have degaussing installed at the holding point.

There are problems due to lightning and stress magnetization, but with respect to lightning, the electric current instantly passes without magnetism. With respect to stress magnetization, it is not necessary to take magnetization into consideration as the stress owing to the external force is low; and the wave length of stress owing to the external force is low and the wave length of stress distribution is far smaller within the longitudinal beam space (714 m/m) as compared with the magnitude of the domain. However, a monitor of magnetism condition will be installed at the demagnetization area.

5.0 Influence on the Navigation Support Facilities and Safety

Currently, the operation of airplanes are supported by the Navigation support facilities.

There are many areas that the construction method and material would affect the navigation support facilities. Only the electro-magnetic wave related matters which might bring about problems will be explained here. In the marine airport or the airport facing the sea, a level difference exists between the runway surface and the sea surface irrespective of the construction method.

In case of the semisubmersible floating construction method, this difference is 15 M. We examined the influence this difference would affect the ILS glidepass.

In case concrete is paved on the steel plate, DDM changes depend on the thickness of concrete; but this change is of a fixed nature, and enough adjustment is possible by adjusting the height of antenna.

However, in case of reclaiming construction method which follows protrusion of shore protection, as the adjustment becomes more complicated, considerable study is necessary.

Reflection of electro-magnetic wave on the sea surface, wave in the sea surface, and environmental problems are the common problems to the marine airport irrespective of the construction method. There are other problems in case of floating airport as it is made of steel and is a floating body.

In case of the occurrence of a broken hole and flooding, survivability depends on length of floating body, length of compartment, and number of compartments. In an ordinary passenger ship, the length is about 100 to 200 M; length of compartment is about 12 M; number of compartments are 10 to 20; and in case of drilling rig, those are about 100 M, about 12 M, and only a few compartments. In case of the Alexander L. Kielland, the leg number was 5; and, therefore, when one leg was damaged, 20% of the buoyancy was lost.

In case of the floating airport, the length is 4,000 to 5,000 M; length of compartment is 15 M; and total number of compartments are 7,000 to 18,000. So, even if ten columns were simultaneously damaged, the buoyancy influence would be reduced only 1.4 to 0.1%, and the survivability approaches 1.0

6.0 Influences on the environment

The effects of water-borne noise are indicated at the sea surface and underneath of the floating airport.

As the noise prediction is about 71 db (A) inside the floating structure at the last moment of the landing, and the average noise level of about 49 db (A) by the jet engine and the impact of landing, the noise level by impact at the time of landing approaches zero at distance of about 180 M from the touch-down point.

There is an experimental study that fish begin to react to the sound over 40 db, but they return in a few seconds after one reaction to the sound of about 65 db.

According to the calculated results, it is thought that there will be almost no effects, but the problem deserves further study.

7.0 Conclusions

Although there would be many unique problems in the construction of a floating airport of the size contemplated, there are many new construction techniques available that make the project feasible.

At the same time we recall the tempo of construction of iron ships was quite slow 150 years ago owing to the ease by which marine organisms stuck to iron compared to growth of marine organisms on iron covered by copper.

We wish to express our sincere appreciation for the senior and people of the respective fields who kindly gave valuable suggestions and opinions in conducting this study.

Table 1 Assumption of enviromental, additional and combined load

	Condition	Sign	Wind (m/s)	Wave Height (m)	Wave Period (sec)	Wind, Wave Directions	Current Speed (kn)	Current Direction	Additional Load
Normal condition	Cumulative distribution 70 %	N1	5.85	0.45	3.1	Whole directions	0.56	230°	—
	Cumulative distribution 90 %	N2	8.42	0.75	3.9		0.65	230°	—
	Cumulative distribution 95 %	N3	9.94	1.0	4.2		0.69	230°	—
	Beam wind maximum	N4	16.0	1.3	5.0	320° (M) 0/180°(S)	0.80	230°	—
	Average of each year muximum	N5	25.0	2.4	6.5	270°	0.80	230°	—
	Taking off and landing of an airplane	N6	25.0	2.4	6.5	270°	0.80	230°	Shock load due to taking-off and landing of an air-plane
	Parking of air-planes at night	N7	25.0	2.4	6.5	270°	0.80	230°	Static load deviation due to moving of air-planes for parking
Abnormal cond.	100 year storm	A1	50.0	4.6	9.6	240°	2.00 0.30	230°	Current speed includes 1.5 kn due to high tide
	Earthquake	A2	9.94	1.0	4.2	Whole directions	0.69	230°	—
	Tsunami	A3	9.94	1.0	4.2		1.9	230°	Current speed includes 1.4 kn due to tidal waves
	Collision of a ship	A4	25.0	2.4	6.5	270°	0.8	230°	Shock load due to collision of a ship
	Crash of an airplane	A5	·25.0	2.4	6.5	270°	0.8	230°	Shock load due to crash of an air-plane

Note:

1) (M) means the floating structure for main runway, in followings "Main runway structure", "Main structure" and "Main" are used as same meanings.

(S) means the floating structure for sub runway, in followings "Sub runway structure", "Sub structure" and "Sub" are used as same meanings.

2) Wind speed indicates 10 minutes average and wave height means significant value.

3) In "A1" condition current speed of 2.0 kn includes 1.5 kn due to high tide, and 0.3 kn in transverse direction is also taken into account. In "A3" condition current speed 1.9 kn consists of 1.41 kn due to tidal waves and 0.49 kn as the maximum north flow same as tidal waves in direction.

Table 2 Principal particulars etc. of the floating airport model

	Model 1 Separated facilities on land				Model 2 Centered facilities on the structure	
	Main runway structure		Sub runway structure		Main runway structure	Sub runway structure
Super structure lengh x breadth	5.000M×840M		4.000M×410M		5.000M×1.300M	4.200M×415M
Height (m)	10		10		10	10
Number of buoyancy legs	333×56=18.648		266×27=7.182		250×65=16.250	210×21=4.410
Draft of a buoyancy legs	6.5 M		6.5 M		8.1 M	5.9 M
Displacement of abuoyancy leg (t)	256.4		256.4		620.7	452.1
Total displacement of the structure(t)	4.781.347		1.916.846		10.086.375	1.993.954
Shape of a buoyancy leg	A type	B2 type	A type	B2 type	Octagonal section	Octagonal section
Tons per cm immersion (t) (t)	7.356	4.059	2.949	1.627	12.452	3.380

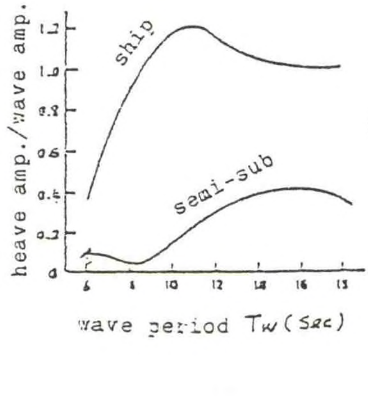
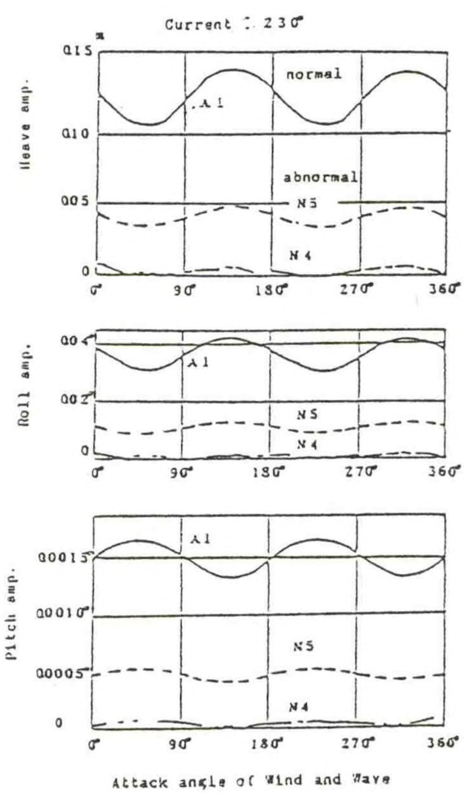


Fig.1 Typical motion of a semi-submersible type structure in waves (heave motion in beam sea)

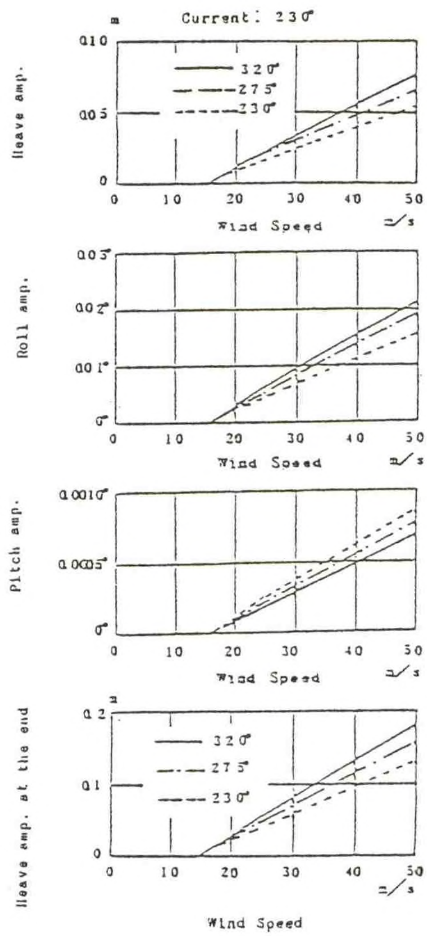
Table 3 Estimated maximum static forces

item		Condition	z	N 3	N 5	A 1	Remarks
Main runway structure	X-direction	Wind force	0°	280 t	1,770 t	7,090 t	
		Wave drift force	45°	340	1,640	2,370	
		Current force	0°	1,530	2,060	12,880	
		Total		2,150	5,470	22,340	
	Y-direction	Wind force	90°	490	3,090	12,370	
		Wave drift force		590	2,800	4,060	
		Current force		—	—	520	
		Total		1,080	5,890	17,050	
Sub runway structure	X-direction	Wind force	0°	160	1,020	4,070	
		Wave drift force	45°	210	810	770	
		Current force		760	1,020	6,400	
		Total		1,130	2,850	11,240	
	Y-direction	Wind force	90°	350	2,190	6,760	
		Wave drift force		390	1,470	1,410	
		Current force	45°	940	1,260	7,160	
		Total		1,680	4,920	17,330	

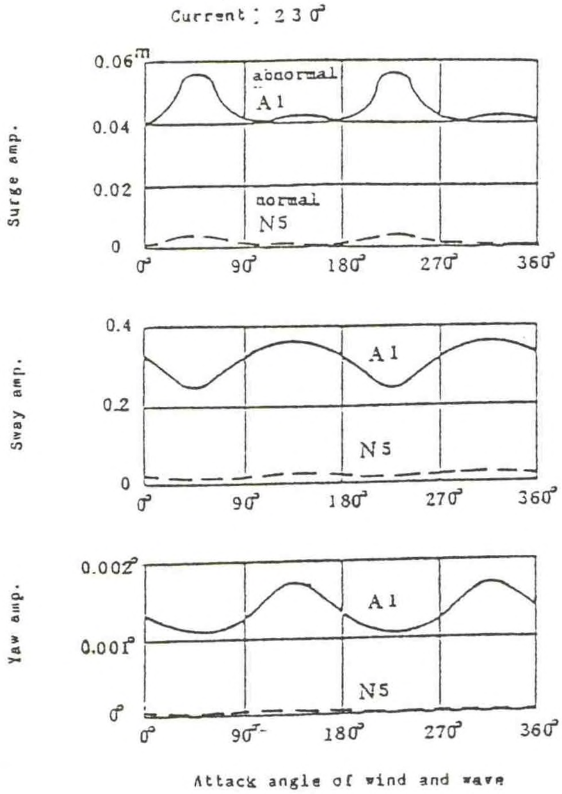
Fig.2 Behavior of the main runway structure in vertical plane



a) 1/1 000 expected maximum

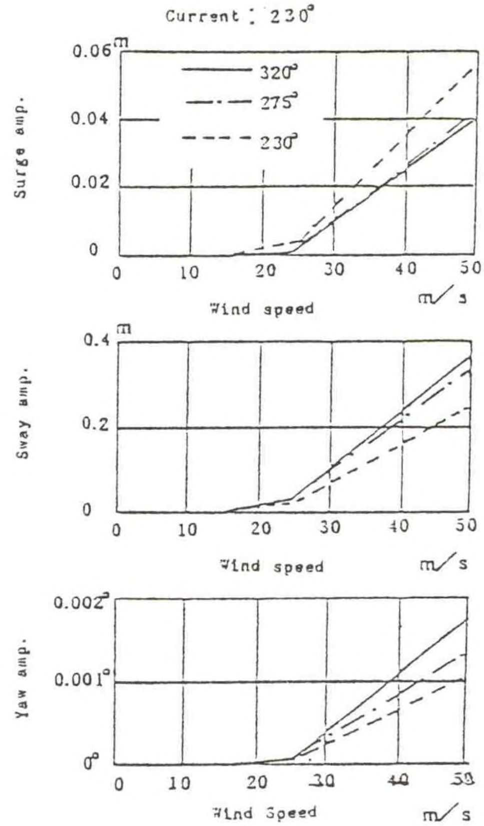


b) Significant value



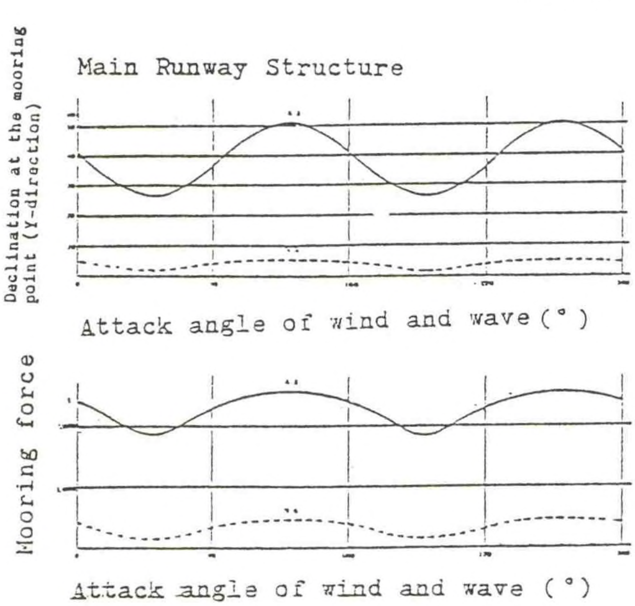
a) Surge, Sway and Yaw

Static deviation+ 1 / 1.000 expected muximum

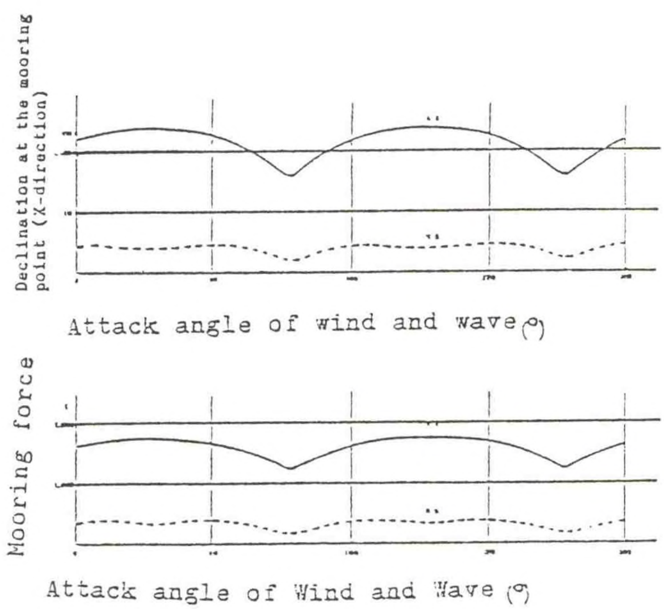


b) Surge, Sway and Yaw

Static deviation+ 1 / 1.000 expected muximum

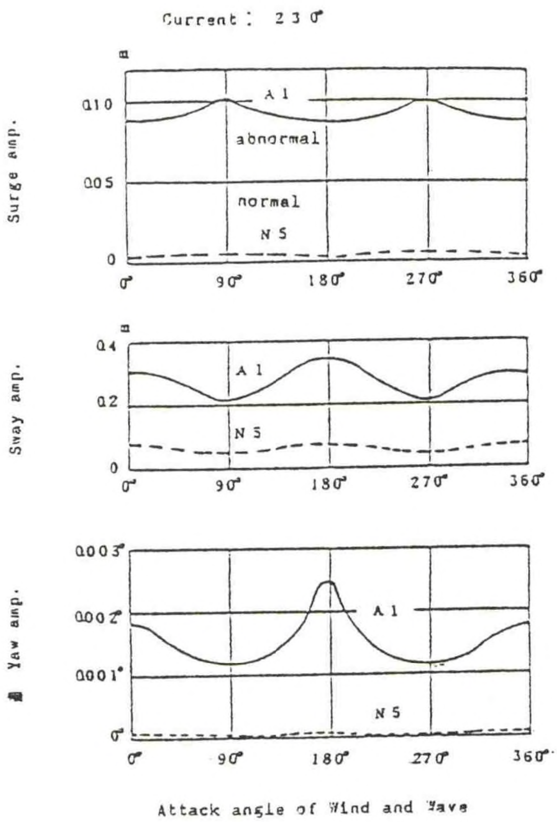


c) Mooring system for the longi. side (Static deviation +1/1000 expected max.)

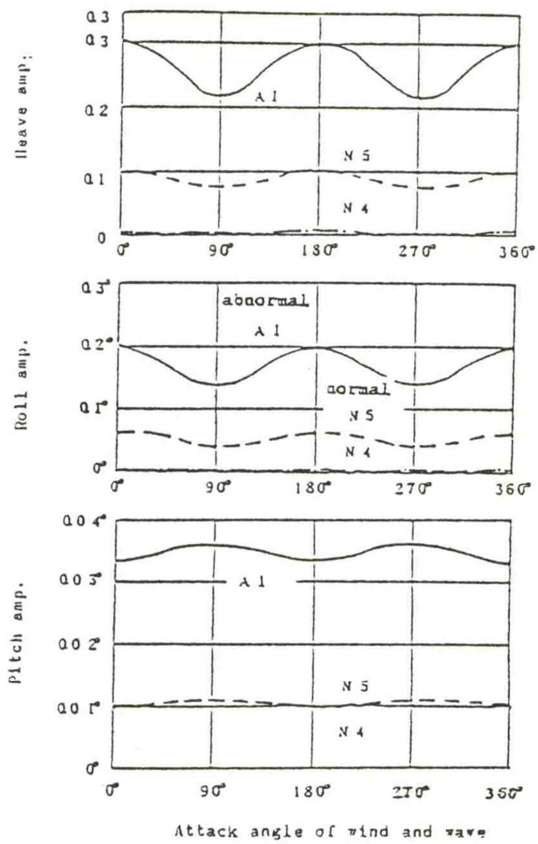


d) Mooring system for the trans. side (Static deviation+1/1000 expected max.)

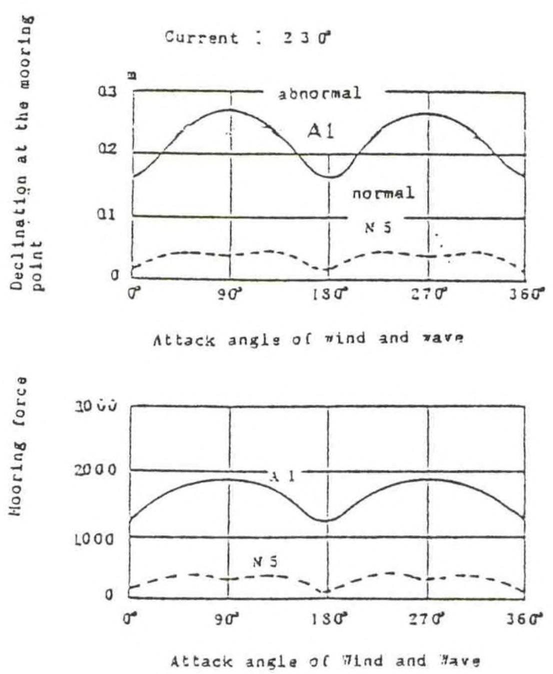
Fig.3 Behavior of the main runway structure in horizontal plane



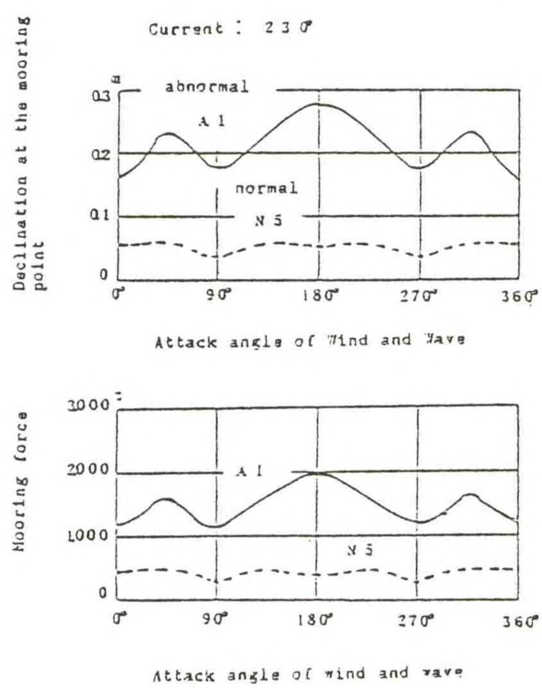
a) Static deviation+Significant



b) 1/1000 expected max.



c) Mooring system for the longi. side
(Static deviation + Significant value)



d) Mooring system for the trans. side
(Static deviation+ Significant value)

Fig.4 Behavior and mooring force of sub runway structure

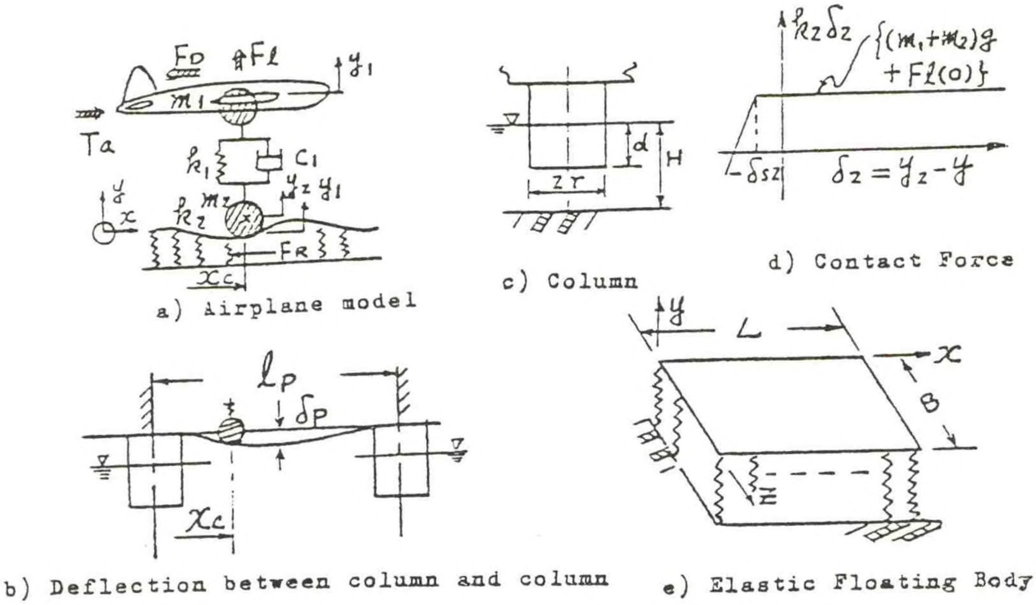


Fig. 7 Model development of Take-Off and Landing

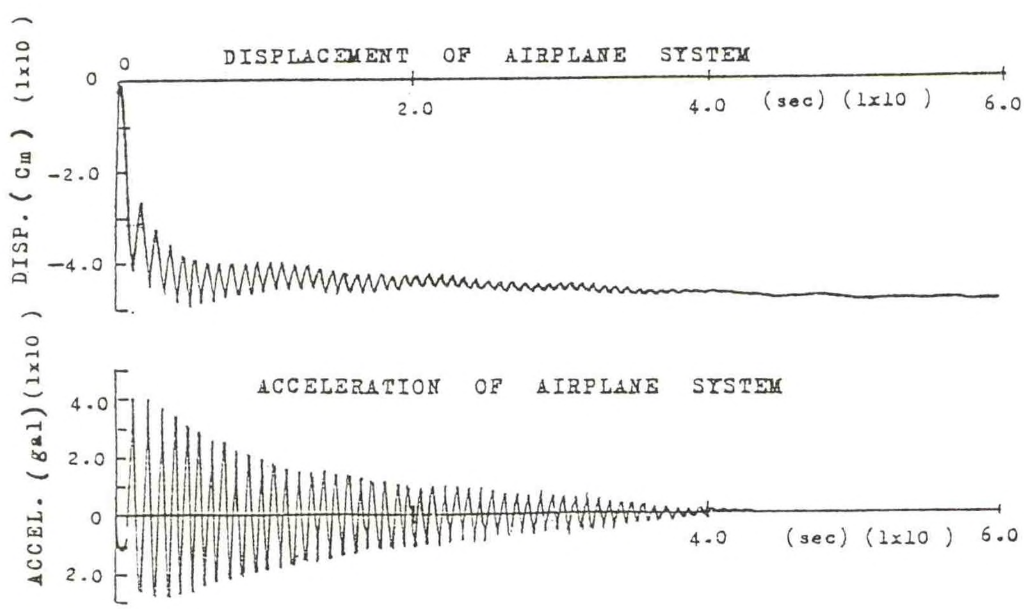


Fig. 8 Vibration response of Airplane System

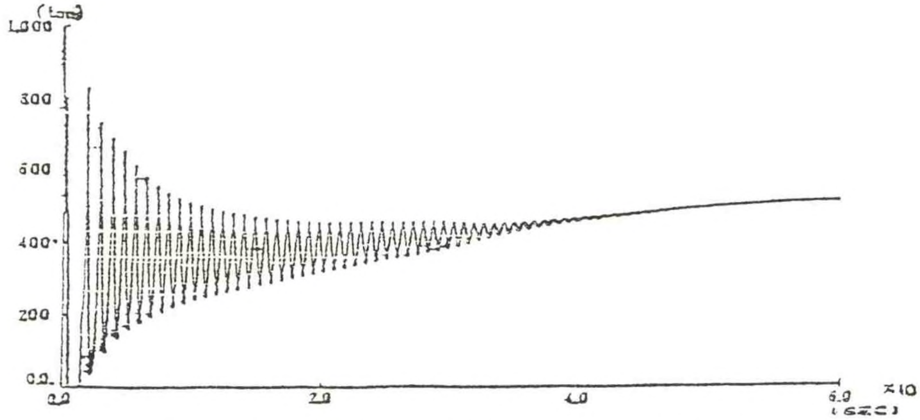


Fig. 9 Contact Force when landing

(Elastic Body, Landing (2))

Table 11 Max. Response of the results of simulation (Landing)

Items		Elastic Body Landing(1)	Elastic Body Landing(2)	Rigid Body Landing(3)	Increasing of acceleration & contact force accounting elastic Deflect. due to wave load %age to case 2
Initial Condition	Touch down point	1.000m	1.000	1.000	
	Vertical Displacement.	0	0	0	
	Vertical Velocity	0m/sec	3.05	3.05	
	Horizontal Velocity	0m/sec	65.9	65.9	
Air plane	Acceleration	4.3cm/sec²	1.43×10^{3}	1.44×10^{3}	0.03
	Displacement.	46.7cm	52.9	52.2	———
Tyre	Displacement	7.8cm	21.9	23.3	———
Contact point	Displacement	1.6cm	2.2	0	———
Tyre ‡ Runway	Contact Force	515 ton	531	539	0.03
	Contact Force/Tare	1.00	1.61	1.63	———

Note; Vertical velocity 0.61m/s(=2ft/s) is normal, 3.05m/s(=10 ft/s) is the worst condition.

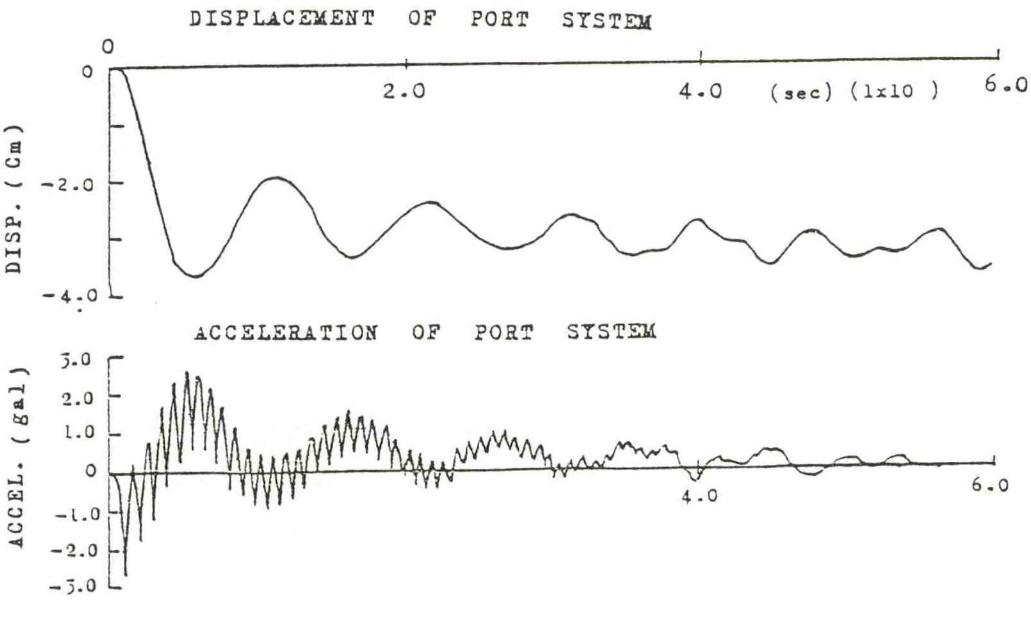


Fig. 10 Displacement and Acceleration of Port System (Wheel touch point of Main Runway; Landing)

Fig. 11 Gradience and Gradience Velocity of Glidepath Transmitter Point (Landing)

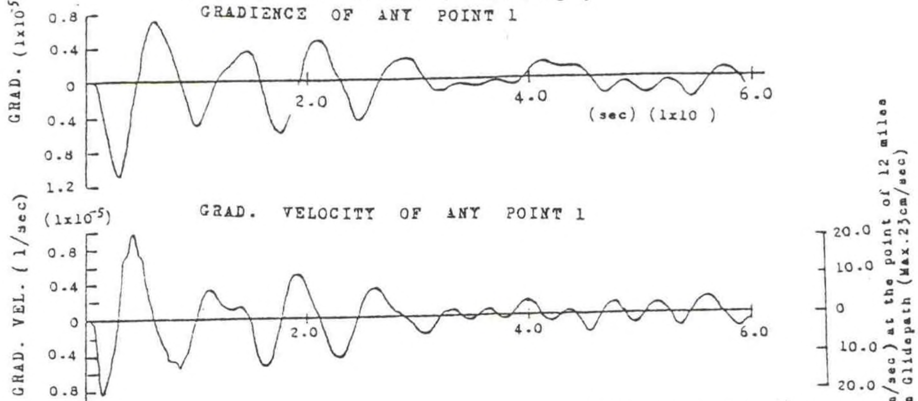
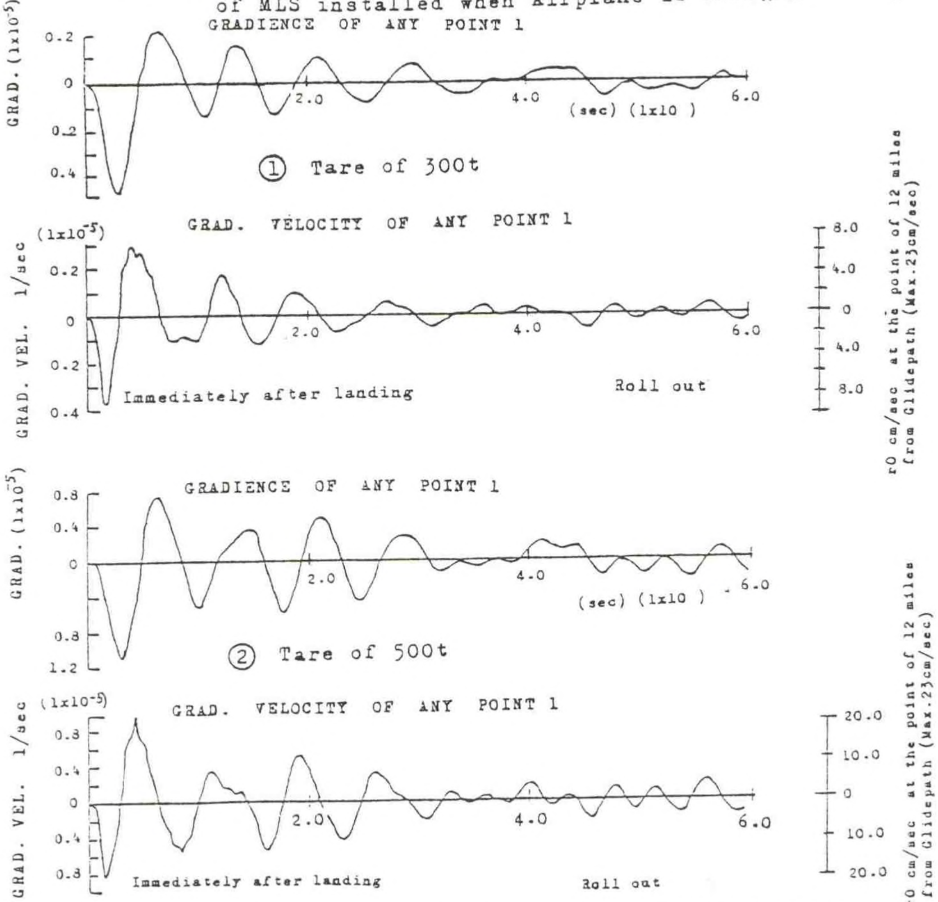


Fig. 12 Deflection and Vibration of Airport at the of MLS installed when Airplane is landing



Items		Condition	Immediately after Landing		Roll-Out	
		Tare of Land.	300t	500t	300t	500t
Inclination $\Delta\vartheta(t)$		Max. Amp.	0.5×10^{-5}	1.2×10^{-5}	0.07×10^{-5}	0.2×10^{-5}
		Period	2.1 sec	2.3 sec	4.0 sec	4.17 sec
		Freq.	0.379 Rad/S	0.356 Rad/S	1.57 Rad/S	1.507 Rad/S
Velocity of Inc.	$\Delta\dot{\vartheta}(t)$	Max Amp.	0.3×10^{-5} Rad/S	1.0×10^{-5} Rad/S	0.05×10^{-5} Rad/S	0.2×10^{-5} Rad/S
Acc. of Inc.	$\Delta\ddot{\vartheta}(t)$	Max. Amp.	0.2×10^{-5} Rad/S²	1.2×10^{-5} Rad/S²	0.08×10^{-5} Rad/S²	0.3×10^{-5} Rad/S²

Table 12-1 Declinations depend on Airplane position
(Main Runway)

	Height from Runway (M)	Horizontal component of induced magnetics (gamma) North Direction	East Direction	Combined Horizontal Magnetics (gamma)	Declination (deg.)
Northeast Side	1.5	-486	-488	30700	-0.9
	5	-462	-472	30800	-0.9
	10	-482	-467	30700	-0.9
	20	-455	-382	30800	-0.7
	30	-573	-276	30680	-0.5
	40	-2165	1632	29130	+3.0
	50	271	-240	31530	-0.4
	100	20	-24	31270	-0.04

-: to the West   +: to the East

Declinations when airplane is landing from Northeast side
(Main Runway)

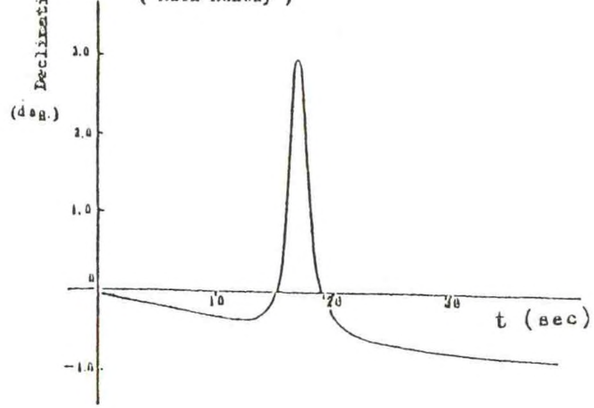


Table 13 Declination onthe runway(1.5 M above runway)

A. Main Runway

1 2 3 4. 5 6 7

Position	Horizontal component of induced magnetics gamma) North Direction	East Direction	Combined Horizontal Magnetics (gamma)	Declination (deg)
1	-480	-380	30780	-0.70
2	-440	-470	30820	-0.87
3	-380	-430	30870	-0.80
4.	-410	-460	30850	-0.86
5	-420	-480	30830	-0.89
6	-390	-430	30860	-0.80
7	-420	-370	30840	-0.68

Fig. 13 Induced Magnetic Field and Parmanent Magnetic field

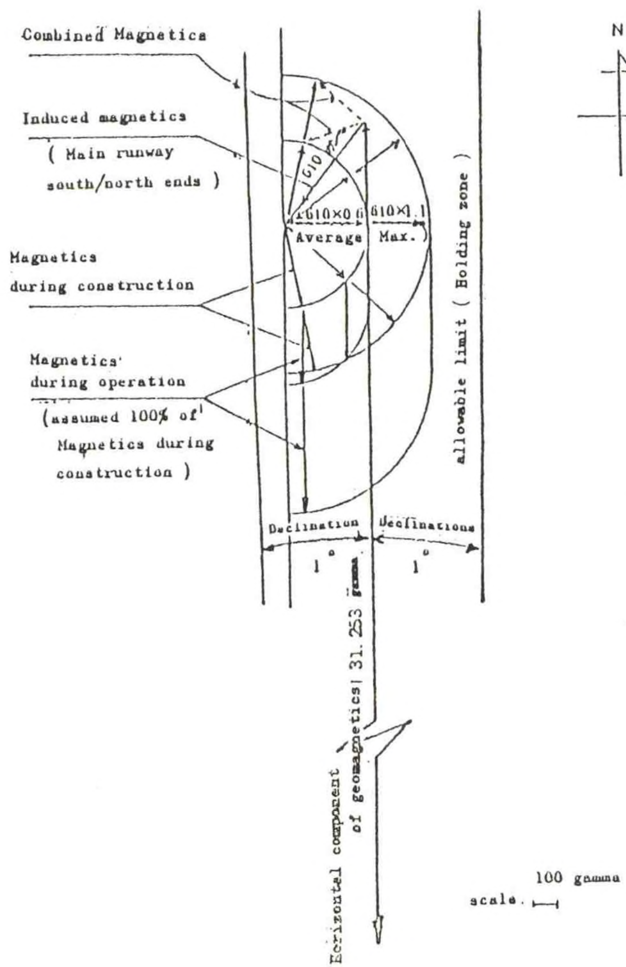
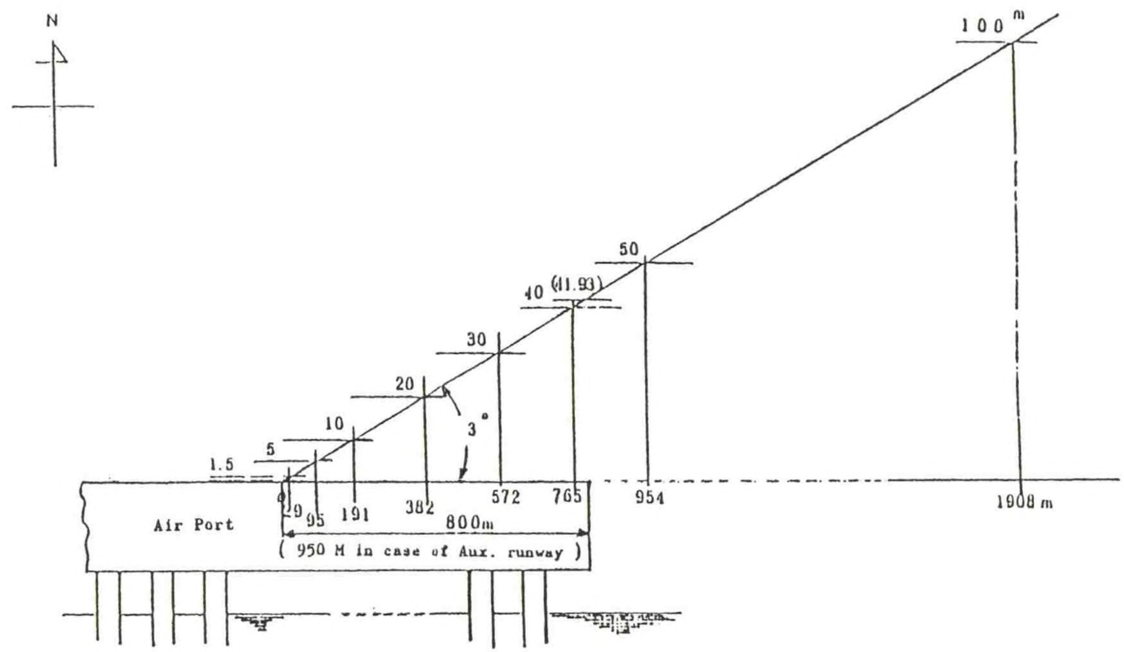


Fig. 14 A route of landing



CURRENT STATUS AND FUTURE PROSPECT

OF THE BARGE MOUNTED PLANT

by

K. Uno
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Tokyo, Japan

Introduction

Today, there is a world-wide demand to achieve development of resources and successful industrialization in remote areas. But, plant construction costs and the time required increases as the remoteness and distance from the developed areas increases. Too rigorous local conditions could result in loss of project feasibility.

Completion of such projects on schedule, and within budget, requires the application of new concepts to relieve such difficulties. To cope with such requirements, the concept of Barge-Mounted Plant has been induced and developed in the field of plant construction in order to solve the various environmental and economic problems at the plant site where the conventional construction methods could not be applied. We at IHI have developed a new concept and call it Industrial Platform System, IP System for short. This epoch making concept has been realized in various kinds of plants.

Construction

Conventional plant construction requires dispatching massive machinery and equipment from the developed country and assembling them at the remote site. On the contrary, the plant using the IP System is assembled in the final configuration on a platform at an established shipyard or factory of the plant supplier, then towed by ocean and river routes to the plant site. At the plant site, the platform can then either be left in the floating position, or grounded for operation.

A major feature of the IP System is that the plant is assembled in a shipyard, which is a comprehensive assembly site. In a shipyard, there is a block assembly shop which turns out the blocks of the hull structure, a pipe shop which fabricates the piping units, a unit assembly shop which assembles the machinery and equipment together into larger units, and a building dock which is used for the final assembly of the ship, and equipped with huge cranes to handle full blocks and units. The shipyard is completely equipped to assemble large numbers of units and items of machinery and equipment speedily and accurately.

A shipyard has in-house capabilities for manufacturing, production supervision, and quality control as well as the support staff indispensable for manufacture, procurement, and assembly. The IP System of plant construction uses the shipyard with its favorable concentration of facilities, engineering staff, and skilled workers, instead of applying such resources at a remote site.

Advantages

As mentioned earlier, conventional plant construction is greatly affected by the natural conditions on the site, the availability and quality of workers, and the degree of development of infrastructure. A long period of construction is generally required and delays in completion can often occur. In contrast, since the principal parts of the plant are assembled at the shipyard, the IP System offers the advantages of the extremely short construction period, and delivery on schedule is assured. A comparision of LNG Plant construction schedules for Middle East is shown in Fig.-1 for example.

In the conventional method of plant construction, the quality and performance of the plant are easily affected by the quality of the available workers and working conditions at the site. In the case of the IP System, the shipyard has established facilities, engineering staff, skilled workers, and the support staff for production and quality control. The result is a plant of high quality and performance.

The superiority of the IP System on the construction period and the plant quality reflects in the total construction cost. Especially, the costs of labour and infrastracture show remarkable differences between the IP System and the conventional method.

An example of cost comparison of the said LNG Plant is shown in Fig.-2, which indicates that assuming the conventional type to be 100, the cost of the floating type is approximately 75, and the grounding type 90. The differences arise principally from the cost difference for the plant site infrastructure, loading facilities, and administration facilities.

In conclusion, the IP System plant as compared with conventional plant features low initial investment, short construction periods, completion on time, good quality and high performance of the plant, and minimizes local infrastructure. Further, the fact that a plant can begin operation promptly means that the investment in the project can be recovered more quickly. The IP System thus provides the customers with multiple advantages in economy.

Construction Record

Our investigation shown in Fig.-3 indicates that 34 barge-mounted plants in total are already completed or under construction. Half of them, that is 17, are power generating plants, and the rest consists of nine oil/gas process plants, three desalination plants, three pulp plants, and others. Itemizing the plant installation site, 12 are in developed countries and 22 in developing countries.

It is noteworthy that until 70's many of these plants have been materialized by the developed countries such as USA and USSR for their domestic use. Afterwards, the projects by IP System for Oil countries have been greatly increasing. The major reason for the trend is that the oil money has met with the excessive shipbuilding facilities caused by 1973's first Oil Crisis.

IHI's Experience

We at IHI constructed the following plant using the IP System: "Pulp Plant for Brazil" (refer to IHI catalogue). This is the first application of IP System in large scale, having a production capacity of 750 tons per day of bleached craft sheet pulp. The plant consists of the pulp production plant and utility power plant, each is built separately on a huge platform. The size of platform is 230 m x 45 m (pulp platform) and 220 m x 45 m (power platform). Two platforms, completely assembled at IHI shipyard in 1978, were towed 25,000 km, halfway around the world, from Japan to the Jari River, an Amazon River tributary and grounded on its shores. The plant started its operation in early spring of 1979 and is fully operating to produce high-grade pulp for export.

The power plant for Bangladesh was equipped with two gas turbine power generators, each with a rated output of 35,500 KW. The gas turbines, generators, and other equipment were assembled and mounted on a barge at IHI shipyard in 1980. The floating power plant was towed to Bangladesh and put into operation moored on the River Bhairao of Khulna district to supply electric power to this area. The size of barge 46 m in length, 17 m in width.

The Polyethylene Plant for Argentina which was ordered by the world-renowned chemical company, Union Carbide Corporation and has a producing capacity of 120,000 tons of polyethylene per year adopting UNIPOL technology, an epoch-making manufacturing process developed by them. The barge itself is compact, 89m in length, 22.5m in width. IHI towed the completed barge 22,000km from Japan to Bahia Blanca, Argentina, where the plant began operations moored in a water channel.

Future Projects

The emergence of the IP System has made possible construction of plants and facilities in locations where development has been regarded as technologically impossible, or economically infeasible.

The IP System has greatly enlarged the range of areas where development is now possible, and it has opened up for the developing countries a way of obtaining quickly and economically the urgently needed plants for industrialization.

We at IHI have been working on plans for various kinds of plants, such as natural gas liquefaction and storage plants, power generation plants, desalination plants, cement plants, steel plants, rolling mills, oil refineries, petrochemical plants, aluminum refineries, nuclear power plants, etc., as summarized in Fig.-4.

The IP System has permitted plant construction in locations with severe natural conditions, and with problems related to infrastructure and availability of workers.

We at IHI are not trying to suggest the IP System is an all-purpose system that can do everything. However, with the integrated plant construction and shipbuilding technology, the Industrial Platform System, will meet the requirements of many prospective customers throughout the world, providing a revolutionary step forward in plant construction methods.

CONSTRUCTION SCHEDULE OF EACH TYPE

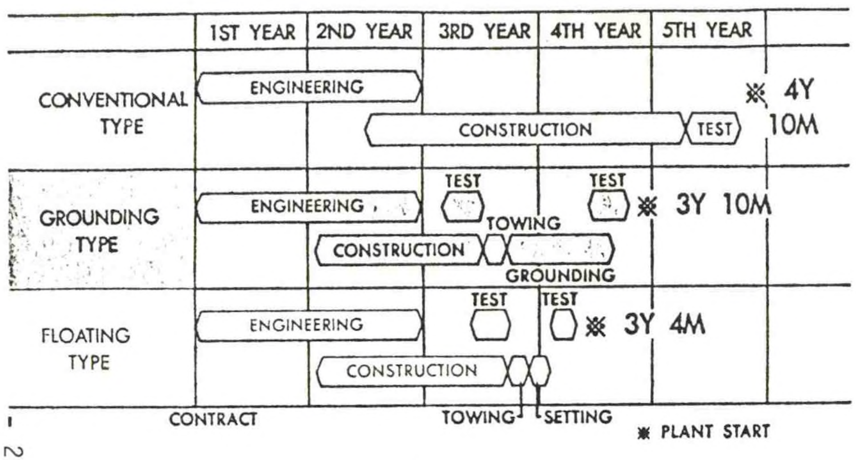

Fig. 1

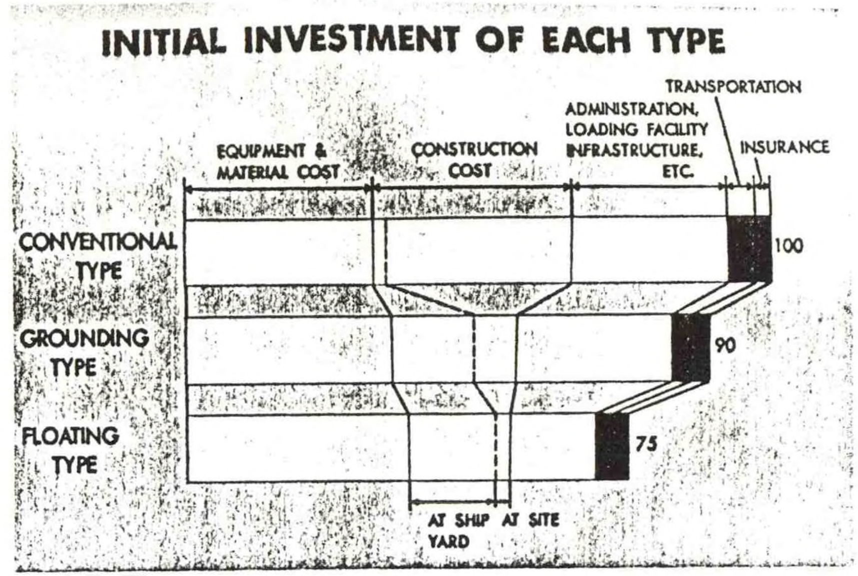

Fig. 2

IPS-CONSTRUCTION RECORD

(DEC., 1980)

Plant Name		Number (Built)	Installed in Developed / Under Developing Country / Country
Power	Elect. Power Plant	17	10 / 7
Process	Petrochemical Plant	6	0 / 6
	LPG Plant	1	0 / 1
	Oil Refining Plant	2	0 / 2
Others	Desalination Plant	3	0 / 3
	Pulp Plant	3	0 / 3
	Others (Oil Treatment Plant, etc.)	2	2 / 0
Total		34	12 / 22

Fig. 3

APPLICATIONS OF THE IP SYSTEM

PROCESS PLANTS	PULP AND PAPER, CEMENT. PETROLEUM REFINING. PETROCHEMICAL, METHANOL. AMMONIA AND UREA, SUGAR REFINING.
GAS PLANTS	LNG, LPG.
POWER PLANTS	THERMAL & NUCLEAR POWER.
OTHERS	STEEL-MAKING, DESALINATION. BATCHER, TIMBER AND SAW MILL. STORAGE TANKS.

Fig. 4

ON A FLAP-TYPE WAVE ENERGY CONVERTER AT THE COASTLINE

by

Masaaki Kuroi

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Introduction

Both pneumatic and floating type converters have been proposed for extracting wave energy, but the flap type has the following advantages: (1) It is simple in principle, (2) compact, and (3) the construction cost is low compared with other methods, if the device is installed in the existing breakwater.

Outline of the system

This device is a so-called flap-type wave energy converter fixed at a coastline, and installed in the slit caisson which has been newly built at the tip of the breakwater in Mashike Harbor. Figure 1 shows the overall arrangement of the system.

(1) The flapper is 3-m wide and 5.3-m high (2.9-m below the waterline and 2.4-m above it) and made of a stiffened steel plate. Its rotation angle is restricted to 15^{o} in each direction by means of stoppers made of rubber fender.

(2) Oil hydraulic pump. Four rams, whose diameter is 140 mm and stroke is 250 mm, are driven by the flapper. The relief valve would work in case the pressure exceeds the maximum working pressure of 170 kgf/cm^2.

(3) The generator is AC variable frequency and its rated voltage is 400 V. The maximum design output is 20 KW. It is driven by hydraulic motor. A flow control valve is installed in the hydraulic circuit and maintains the flow rate below 150ℓ /min to prevent the generator from its exceeding rotation. An accumulator is used to damp the oil pressure fluctuation.

(4) The controlling board functions as an automatic voltage regulator, and a distributor to electric water heaters. It has also an automatic on-off mechanism that stops the electric generation to reduce the consumption for excitation power when the rotation of the generator is slow in calm water. Then it checks the rotation in a constant interval and starts the electric generation again if the rotational speed is high enough to excite the generator.

(5) The electric water heater has four tanks whose capacity are 460ℓ each. The maximum power consumption is 5.4 KW each. The thermostat of the heater works when the water temperature is 85^{o}C.

Performance

The flapper is moved back and forth about the axis of its top by waves, and these movements drive four rams which yield hydraulic pressure. The hydraulic pressure drives the hydraulic motor which rotates the generator connected to the motor directly. An outline of the hydraulic circuit is shown in Figure 2.

Electricity is transmitted about 500 m and consumed by a electric water heater. The electric power output is affected by wave amplitude, wave period, and load applied to the generator. However, its mean value with 3-m width is expected to be about 5 KW in winter and its mean annual value about 2 KW, assuming a total efficiency of 30%.

The maximum theoretical efficiency is 100% in case of the absorption of regular waves whose period is equal to the natural period of the flappers. In a resonant condition an 80% peak efficiency was achieved in the model test conducted at Muroran Institute of Technology. The natural period of the flapper must be nearly equal to the period of incident waves, and the load to the generator must be proper to obtain a high efficiency. Putting the length behind the flapper L m, the natural period of the flapper becomes $1.6\sqrt{L}$ sec. In the case of the flap type, there is a characteristic that the efficiency drop is big for shorter waves, while it is small for longer waves. Consequently, it is possible to absorb wave energy efficiently in a wider range of wave periods, if the natural period of the flapper is designed for the waves of shorter period than those of peak energy.

It is desirable to fix the magnitude of the load and the maximum design power output of the generator based on the local wave data, so that the annual wave energy absorption becomes maximum. The maximum design output of the converter system in Mashike Harbor is 20 KW. When the energy of incident waves is higher, the relief valve and flow control valve protect the system from the extreme increase in pressure and the flow in the hydraulic circuit.

Acknowledgements

The wave-energy converter system in Mashike Harbor is jointly developed by the wave energy research group, directed by Professors Kondo and Watabe at Muroran Institute of Technology, and Hitachi Zosen Corporation. The author would like to acknowledge Mr. Takeda, chief of Harbor and Coastal Hydraulic Laboratory, Hokkaido Development Bureau and Mr. Mizuno, Rumoi Harbor Office, Hokkaido Development Bureau, for their guidance and help to install the system.

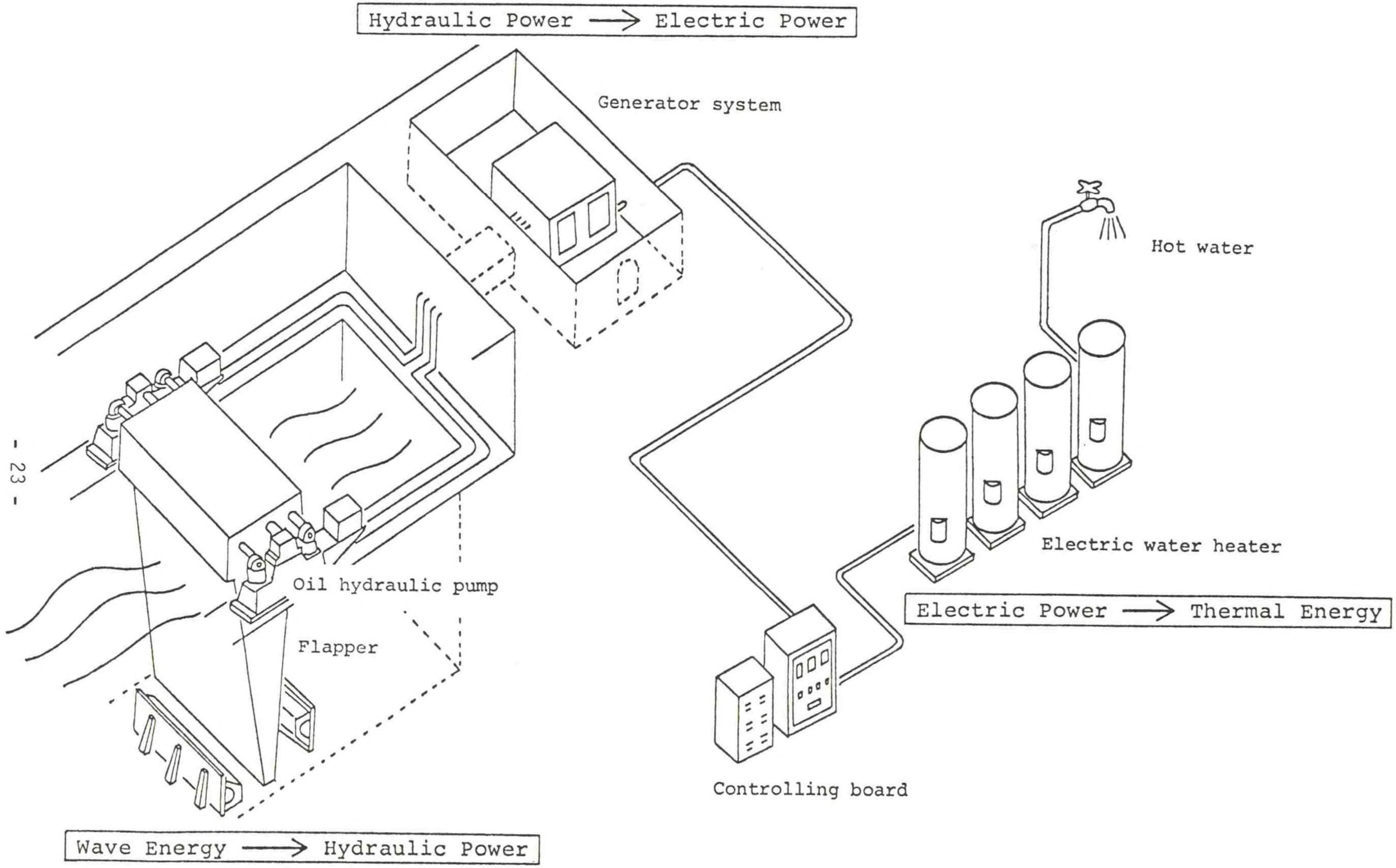

Fig. 1 Overall arrangement of the system

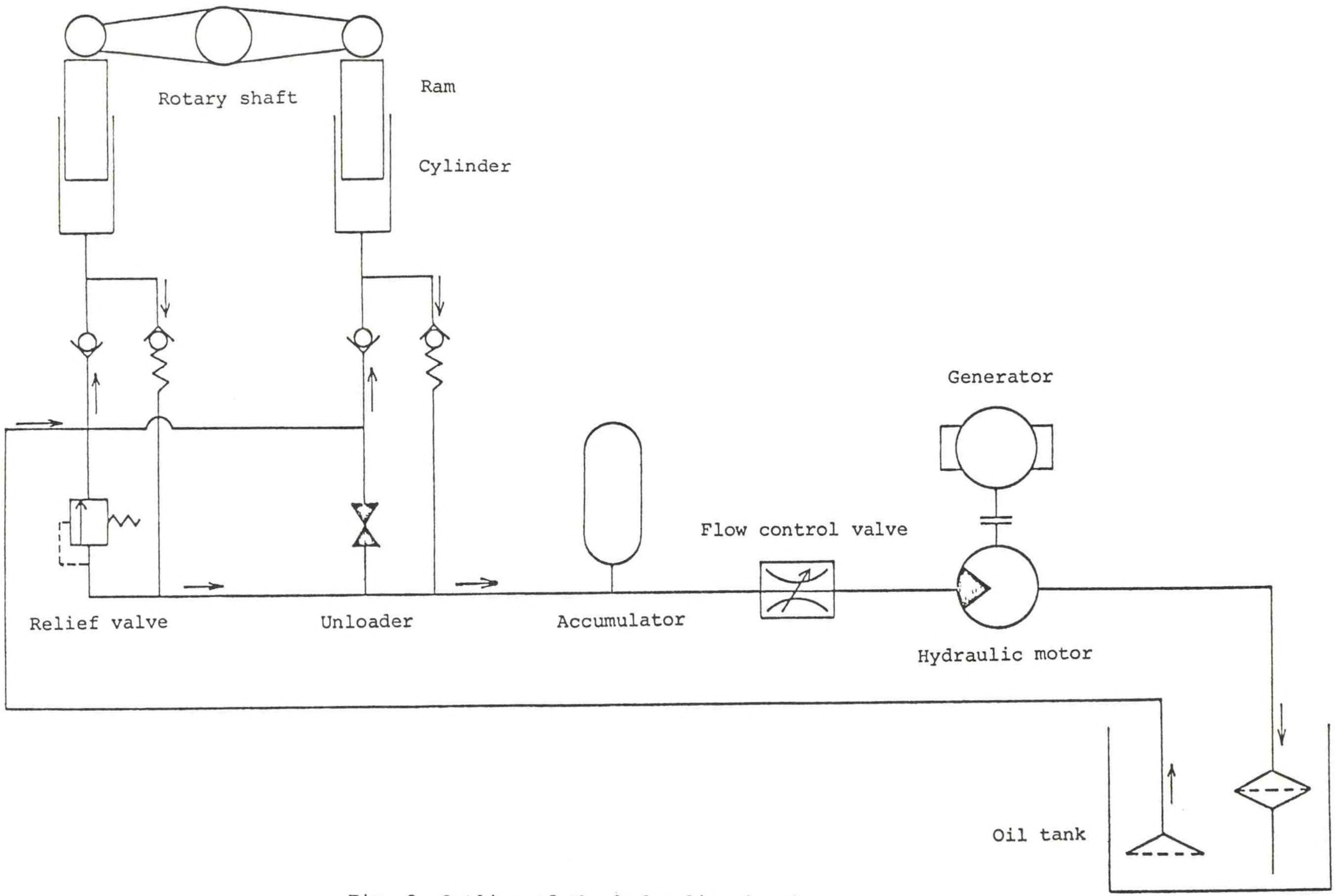

Fig. 2 Outline of the hydraulic circuit

AN OVERVIEW OF RECENT JAPANESE OTEC DEVELOPMENTS

by

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Toshiba Corporation

General Aspects

Ocean thermal energy conversion (OTEC) was first noticed in Japan in the beginning of the '70's. In March 1974, just after the first oil shock, the Sunshine Project started, which included the study of OTEC.

In November 1979, the Sunshine Project was revised, to accelerate the development of new energy, in which the basis program of OTEC research and development was authorized, by an advisory council to the Ministry of International Trade and Industry (MITI).

At present, the national program of development of OTEC seems to be somewhat behind the schedule mentioned above.

In the last fiscal year (April, '81 - March, '82), an oceanographic survey of the possible OTEC test plant site and simulation studies of mechanical problems of the ocean structure were undertaken by the Engineering Advancement Association of Japan (EAAJ).

A preliminary design of a 1-MWe OTEC test plant ship (binary cycle) was finished, in the Electrotechnical Laboratory (ETL) affiliated with MITI, by a task force consisting of OTEC specialists from government institutes, universities and industrial circles, under the chairmanship of Dr. T. Kajikawa of ETL. The results of their coordinated efforts appeared in a recent issue of the Journal of Solar Energy Engineering.[1] Also, other R & D items related to the binary cycle OTEC are being undertaken in ETL and several industrial companies.

A fundamental study on thermo-electric OTEC systems and elements is being done currently by EAAJ and ETL. They succeeded in getting an electrical output of 104 We, by an experimental heat loop, at the heat rate of 31,400 Wt (e/t conversion efficiency 0.33 %). In this experiment the incoming warm water and cold water temperatures are 29^{o}C and 9^{o}C respectively.

Fundamental experiments on biofouling and corrosion problems are underway in the Governmental Research Institute, Chugoku, affiliated with MITI.

Research and Development work on OTEC also is being done by a Saga University group, headed by Dr. H. Uehara. At present the main objectives of this group are to clear up the problems related to a 50 KWe experimental hybrid power plant to be built in Tokunoshima, an island south west of Kyushu, beginning this June. The sponsor of Tokunoshima project, Kyushu Electric

Power Company, is being subsidized by MITI. The hydrid system means its high temperature heat source is discharged waste heat from a diesel power station, and its cold heat sink is pumped-up deep sea water from off-shore of the island. The features of this power plant are that it uses NH_3 as the working fluid and titanium plate-type heat exchangers coupled with pellet type on-line biofouling cleaning systems.

Experimental OTEC power plant in Nauru Island

This 100 KWe OTEC power plant developed by Japan was completed in October, 1981, in Nauru, an island republic in the equatorial Pacific Ocean (0.5^o, S. Lat., 167^o, E. Long.). This project is sponsored by Tokyo Electric Power Company (TEPCO) and Tokyo Electric Power Service Company (TEPSCO) with subsidies from MITI. Civil engineering and construction work, including CWP deployment was undertaken by Shimizu Construction Company Ltd., and the power system engineering, manufacturing and system operation was undertaken by Toshiba Corporation.

In advance of the on-site construction work, an extended environmental measurement of not onlyΔT, but also wind, wave, tide level, and sea current was taken. The average surface current veolcity is about 0.5 knots, and its velocity decreases away from the surface, but its direction changes to an inverse direction.

The sea bed, where the CWP is to be settled, is a steep rugged coral reef, with a sharp incline of about 40 to 45 degrees to the sea surface.

The schematic diagram of the CWP deployment is shown in Figure 1. This deployment method was selected from three possible methods, considering the environmental condition around the plant site.

At first the unit polyethylene (75 cm, OD; 50 m,L) pipes were welded in sequence, using a heat welding machine, on the construction platform at the plant site beach. The resulting CWP was towed out by a tug boat after each section was welded until it reached the desired length, as shown by 1 in this figure. An auxiliary wire rope for the tug was attached to the CWP, with a number of auxiliary floats connected to the wire rope. A support-work boat pulled the wire rope at the middle from upsteam of the sea current to be sure that the CWP did not bend, over its designed limit.

In the next step, roughly shown by 2 , these floats were cut off and the CWP was gradually lowered, until it settled on the sea bed as shown in 3 . In this process, the configuration of the CWP could be estimated comparing the computer calculation results and the CWP position information from the three ultrasonic transponders attached to the CWP end and to two intermediate points of the CWP.

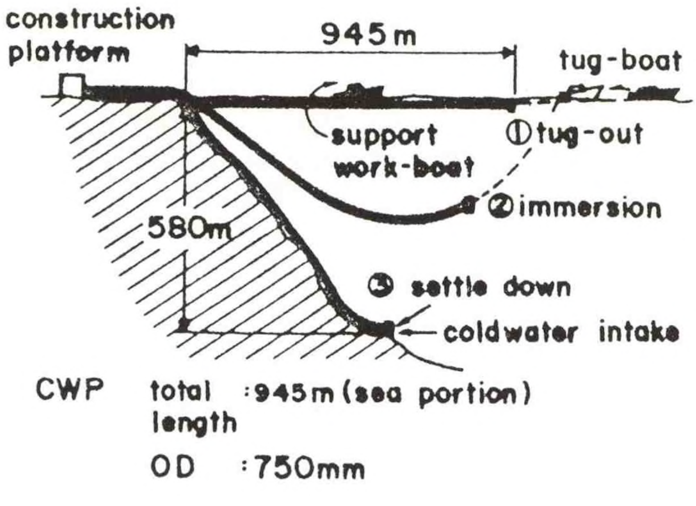

Figure 1 Deployment of the CWP

This plant is located on the shore in Nauru. The power loop consists of the evaporator, the turbine-generator, and the condenser. The working fluid of this loop is freon 22. The evaporator is a horizontal shell and tube type, with the outside of its tubes (Ti) coated with a thin copper layer to enhance evaporation. The condenser is a vertical shell and tube type, its tubes (Ti) having many vertical flutes on the outside to enhance condensing.

Warm sea water is taken from the surface layer near the shore. Cold sea water is taken off shore at the depth of 580 meters, using a polyethylene CWP (ID: 70 cm, L: 950 m) mentioned above.

The turbine-generator was rolled up initially on October third, and attained 100 KWe on October 11th. Excluding the inplant power (Mainly for water pumps) the net power was 15 KWe, which was supplied into the Nauru power grid. Since then, power generation experiments are being made under various conditions.

The maximum output of the plant was 120 KWe (net power output 31.5 KWe). Also, it was continuously operated at the level of 105 KWe (net power output 14.5 KWe) for 240 hours. The sponge ball on-line tube cleaning system, supplied by Taproge-Japan is coupled with both heat exchangers. It works so well, the heat transfer coefficient keeps the initial value, even now. This experiment is still underway successfully and is scheduled to be concluded at the end of September 1982.

[1] T. Kajikawa, Preliminary Design of a 1-MWe OTEC Test Plant, Jour. Solar Energy Engineering, Vol. 104, pp.3-8 (Feb. 1982).

ENHANCEMENT OF SEAWEED AND SEA URCHIN BY UTILIZATION OF WAVE ENERGY

by

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Introduction

To rear a marine organism, the existence of sea water is inevitable, however, its mere existence is not sufficient for the life of the organism. The sea water must have such a motion that results in an exchange of the sea water for feeding food or nutritious salts, supply of dissolved oxygen, or sewerage of biodeposition of the animals.

Energy such as tidal force, sea current, wind or, in some cases, motor power is needed to provide proper motion of the sea water. This paper deals with the utilization of wave energy to propel the sea water.

In deep water the motion of sea water is circular due to wave action. In a shallow sea, its orbital motion is deformed due to the friction of sea floor. As the wave nears the shore, its height becomes large and water particles are transported in the propagating direction (shoaling). Shoaling can be used to raise the mean water level and to induce the water flow.[1] The methods are,

1. to increase the flow resistance to backwash compared with overwash (see Fig. 1-a)

2. to heighten the water level by topping over an impermeable dyke (Fig. 1-b)

3. to increase the coefficient of discharge for inflow compared with outflow (Fig. 1-c,d)

4. to concentrate the wave energy by the configuration of inlet (contracting the cross-sectional area of inlet planely and vertically) (Fig. 2).

Adopting one of the methods or in combination, one can raise the mean water level and flow the water through the water course. Hereafter, the fourth method, the wave-energy concentration method, will be considered.

Concentrated by the configuration of intake work, a wave travels up the weir at the upper end of the slope and over the level beyond

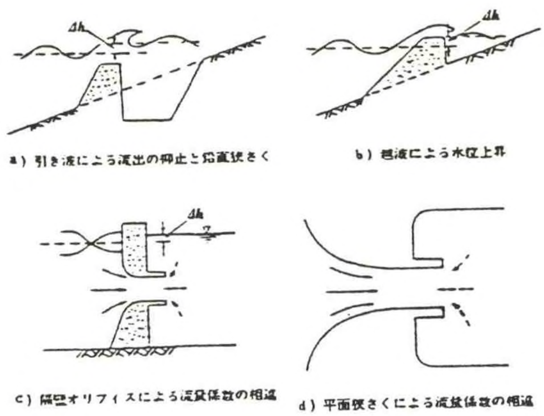

Fig. 1. 波浪エネルギー利用による水位上昇
Mean water level ups by wave energy

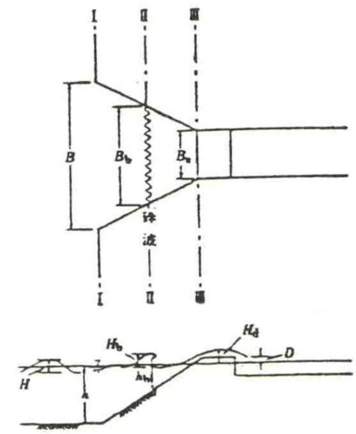

Fig. 2. 狭さくによるエネルギーの収束と砕波
Wave energy concentration and breaking of wave

the still water surface and flows. An estimate of the flow rate is proposed relating to the configuration of the inlet and the incident wave.

Design of Wave-Energy Concentration Method

The method aims to rear the marine organism all year by utilizing existing waves. The method has to be applied at a coast where waves or sea swell usually exist. The location of the inlet is set where the wave comes directly to shore and the water level is easily raised, for example, a V-shaped topography. Inversely, the outlet is selected at the place where the wave does not come directly such as the rear side of a rock.

The theory of the wave-energy concentration method is as follows. Assuming that, even in case of being contracted planely and vertically, the wave energy is kept by Green's theorem until the wave reaches the breaking point, that is, the wave energy at onset of the contraction equals to that of breaking point

$$\frac{w}{8} H^2 B C_G = \frac{w}{8} H_b^2 B_b C_{Gb} \qquad (1)$$

where, H, H_b : incident wave height and breaking wave height, respectively, C_G, C_{Gb} : energy transferring velocities of incident and breaking waves when shallowness h/L is small they can be expressed $C_G = \sqrt{gh}$, $C_{Gb} = \sqrt{gh_b}$, B, B_b : widths of inlet at onset of contracting point and breaking one, h, h_b :water depth of inlet at onset and the breaking, w: unit weight of sea water, g: gravitational acceleration.

The width of breaking is geometrically obtained by Equation 2

$$B_b = B_a\left(1 - \frac{h_b + D}{n + D}\right) + B\left(\frac{h_b + D}{n + D}\right) \tag{2}$$

where, B_a : width of inlet at the end of contraction, and D: dam up height. After being contracted, the kinematic energy at the breaking point becomes kinematic and potential energies of the weir.

$$\frac{u_b^2 (h_b + a H_b)}{2g(H_d - D)} \frac{B_b}{B_a} = H_d + \frac{u^2}{2g}$$

$$u_b = \sqrt{\alpha g H_b} \tag{3}$$

$$u = K\sqrt{g(H_d - D)}$$

where, H_d : overflow head beyond still water surface, a : factor of breaking wave crest height beyond still water per breaking wave height (= 0.5), u_b : flow velocity by breaking, u : flow velocity at the weir, α :coefficient of flow velocity by breaking (=0.6~0.75), K : coefficient of flow velocity of hydraulic bore (=1.7).

Replacing, $n = H_d/H_b$ and $\xi = D/H_b$, eq. (3) becomes,

$$\left(1 + \frac{K^2}{2}\right)\eta^2 - (K^2+1)\eta\xi^2 + \frac{K^2}{2}\xi^2 - \frac{\alpha}{2}\left(\frac{h_b}{H_b} + a\right)\frac{B_b}{B_a} = 0 \tag{4}$$

On the weir, water flows changing periodically its thickness from 0 to $(H_d - D)$,

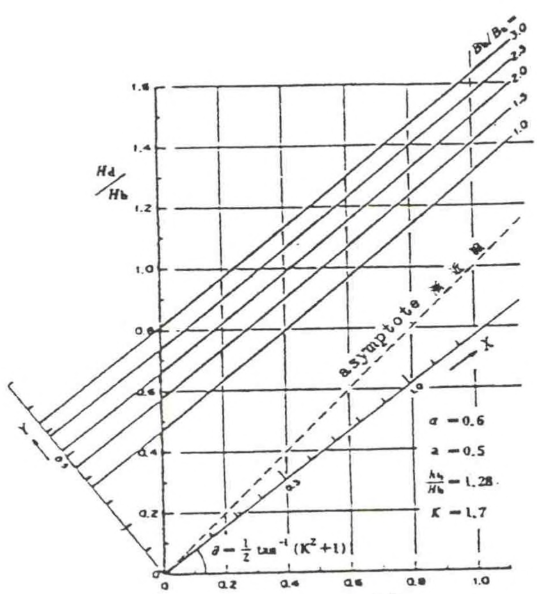

Fig. 3. 越流水位と堰上げ高

Relation between H_d/H_b and D/H_b

the flow rate, q_c , is expressed by,

$$q_c = \bar{u}\,(H_d - D)$$
$$\bar{u} = \beta K \sqrt{g(H_d - D)} \qquad (5)$$

where, $\bar{u}$: mean overflow velocity, and β:factor of mean overflow velocity against the maximum one.

$$\beta = \frac{1}{T}\int_0^T \frac{u}{u_{max}}\,dt \qquad (6)$$
$$u_{max} = K\sqrt{g(H_d - D)}$$

From eqs.(5) and (6)

$$q_c = \beta K \sqrt{g\,H_d - D^3} \qquad (7)$$

where, βK is empirical coefficient and obtained, βK = 0.29.

For application in situ, the calculation method of the inlet width that could supply the flow rate under the given incident wave condition is as follows. First, the sea water exchange rate, i.e., flow rate, is given by the requirement of the reared organism. The dimension of inlet is determined to let such a flow rate enter.

Dam up height, D

Dam up height is calculated as a product of hydraulic gradient and length of water course that can propel the required flow velocity from inlet to outlet.

$$D = \frac{n^2 v^2}{R^{4/3}}\,\ell + f$$
$$v = \frac{q_c}{A} \qquad (8)$$

where, n : Manning's roughness coefficient, v : required flow velocity, ℓ : length of water course, A : cross-sectional area of water flow, R : hydraulic radius, and f : loss head.

Overflow head, H

Having determined the required flow rate, q , and dam up height, overflow head, H_d, is calculated by

$$H_d = \sqrt[3]{\frac{1}{g}\left(\frac{q_c}{\beta K}\right)^2} + D \qquad (9)$$

Contraction ratio, B/B_a,

Once H_d and D are determined, the contraction ratio is estimated, defining $y = B/B_a$, by

$$y^7 - y^6 + C_1 y^5 + C_2 y^4 - C_3 = 0$$

$$C_1 = \frac{K_1^2 D}{H^4 h}, \qquad C_2 = \frac{K_1^2}{H^4} \tag{10}$$

$$C_3 = \frac{K_1^7 K_0^2 (h + D)}{H^{12} h^3}$$

$$K_1 = \frac{(H_d - D)\{2H_d + K^2(H_d - D)\}}{\alpha(K_0 + a)}$$

Performance at Taneichi[2)]

Taneichi, on the North East part of Honshu Island, has about 120 ha of wave-cut bench. The ground height of the bench is about +0.25 m beyond mean sea level. At this ground level seaweed hardly survives because of drought in summer and freezing in winter.

Some development works were attempted with a little success, such as rearing of seaweeds, *Gloiopeltis* and *Porphyra tenera*. Most parts of the area had been left without use. A new development project had been planned in 1973, to enhance the seaweed (wakame and kelp), sea urchin and abalone.

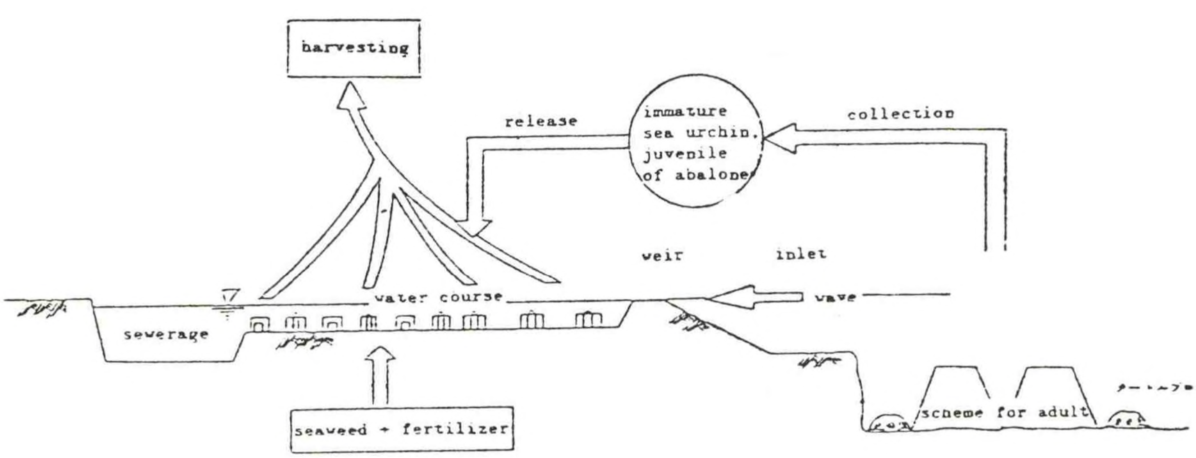

Fig. 4 Synoptic presentation of the farm

The project aims were;

1. to reduce the beach size to reduce drying in ebb tide, and
2. to propel the water most suitable for marine life.

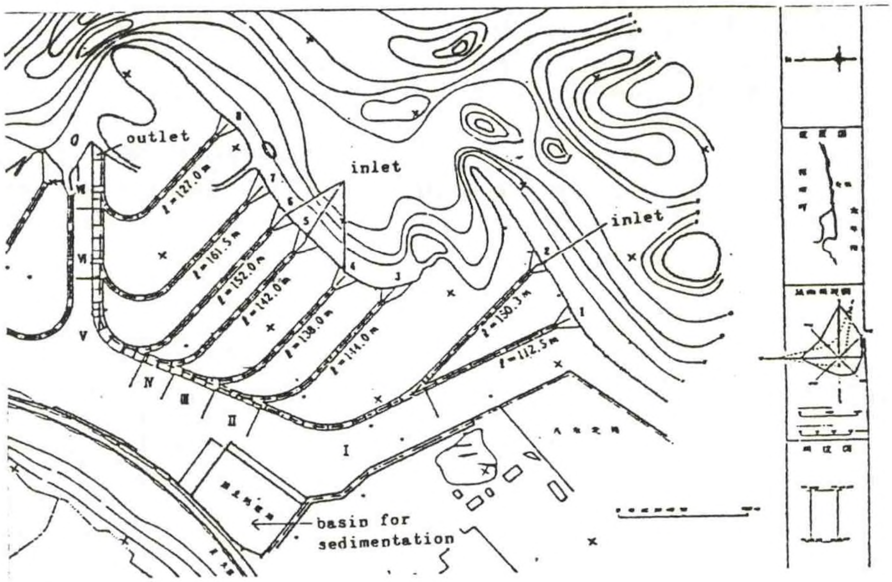

Fig. 5 Plan of the work at Ohama

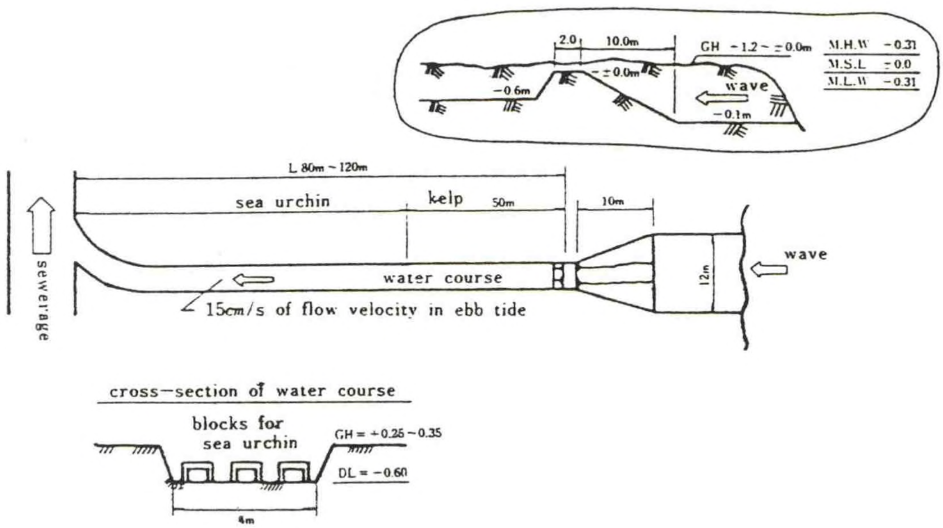

Fig. 6 Representation of the water course and the inlet

The designed flow velocity in the water course was determined by the requirement of growth of kelp, 10∼15 cm/s. The dimension of the water course, four m wide, 0.6 m deep were mainly determined by the harvesting and management works. (Manning's roughness coefficient was determined $n = 0.1$ from the observation at test water course where the kelp had flourished). The contraction ratio of inlet was determined to make flow of 0.36 m^3/s with usually existing waves; its height $H = 0.2$ m.

The bed materials of the beach are sandstone or mudstone with 54 kg/cm^2 of unconfined compression strength. The working method, such as blasting with dynamite, digging with backhoe, and ripping by underwater bulldozer were considered, and the last one was adopted. The construction period was 1975∼'79. The total reclaimed area was 51.9 ha, with 92 water courses, the construction cost was 1,073,747 ($x10^3$ yen).

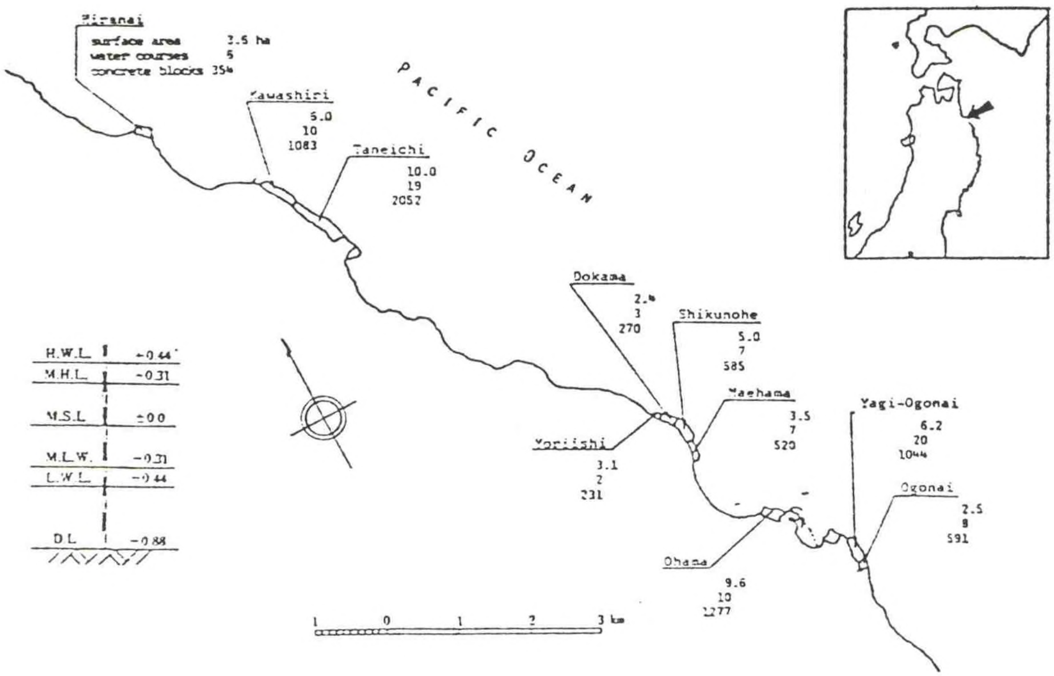

Fig. 7 Sites of the work

Results[3)]

Construction of the water courses has changed the sterile wave-cut beach into a "marine farm." For example, Table 1 shows the comparison of the production before and after construction. The figures of 1973∿'77 show the yearly mean production that was yielded off or on the beach. The data for 1980 show the production of the year. Sea urchin was harvested in the farm, and the other species were caught off or in the farm.

species / sites	wakame				kelp				sea urchin				abalone				total			
	1973～'77		1980		1973～'77		1980		1973～'77		1980		1973～'77		1980		1973～'77		1980	
	yield	profit	y	p	y	p	y	p	y	p	y	p	y	p	y	p	y	p	y	p
	t	**	t	**	t	**	t	**	t	**	t	**	t	**	t	**	t	**	t	**
Hiranai	169	1173	137	848	136	9123	157	19482	1.7	7665	09	6110	10	5867	30	14834	332	23828	333	41274
Kawashiri	71.2	4846	498	4321	50	2923	146	17753	16	7545	20	13573	08	2441	25	12550	786	17755	689	48197
Taneichi	105	6481	848	7728	28	2213	208	26587	13	5660	33	22576	22	5347	28	14604	1113	19701	1117	71495
Yoriishi	*		19	2437	*		21	2837	*		43	21833	*		21	13876	*		104	40983
Shikunohe	*		0	0	*		06	810	*		23	11594	*		31	19730	*		60	32134
Maehame	344	3215	24	3000	0.7	573	10	1351	05	2119	23	14806	0.7	1923	01	620	363	8130	58	19777
Ohama	862	3038	32	4000	1.7	1434	23	3107	13	6049	45	28644	18	4808	15	7569	910	20329	115	43320
Yagi	529	3999	561	4827	134	5193	39	5407	29	13693	12	20910	13	3862	25	13062	705	28747	757	44206
Ogonai	1519	12278	1656	16062	265	20238	274	36089	51	20779	64	41700	34	9906	54	28333	1909	53201	2048	122184
total	5215	40030	3875	42223	637	41697	884	113423	154	63810	292	181746	11.2	34154	230	125178	6118	179891	5281	463570

tonnage of wakame is almost dried weight, kelp dried, sea urchin net weight, and abalone weight with shell

y : yied(ton), p : profit(×10³yen)

* : included in Maehama

The work also changed fisherman to farmer, that is, before the work those who engaged in the fishing around the beach were fishermen at the prime of life. Today they are women or the aged.

The planned marine lives were wakame *(Undaria pinnatifida)* and kelp *(Laminari japonica)* as plants, and sea urchin *(Strongylocentrotus nudus)* and abalone *(Haliotis discus hannai)*. The results showed wakame is best suited for the water course because of its eurythermal properties, and abalone is not fit for the rearing species in the water course because as the animal becomes bigger, it moves to deeper water. Thus, the adult, commercial size, is not seen there. (As marine organisms can transit from one phase to another, it may be a little too early to say this, it is only 2∿3 years from the end of the work.)

The facts. Seaweed flourishes in the farm but it is not of proper quality for commerce, and there are so many starving sea urchin around and off the beach. Sea urchin became the main target in the farm. As seeds, the starving animals, with 4~7 % gonad index, are collected off the beach and released into the water course. They become mature with 20~25% gonad index in about a year (released in August~December, harvested in July~August of next year).

A water course with a specially designed inlet dug in the sterile wave-cut beach, becomes a marine farm. In order to be a marine farm, the water course has to be well managed like an inland farm, and that is possible.

ACKNOWLEDGEMENT

I am grateful to Mr. KOMATSU, Director General of Kuji Fisheries Bureau of Iwate Pref. who sent me the up-to-date documents and references.

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INFLUENCE OF WAVE DUE TO LARGE SHIP UPON SMALL SHIPS AND OCEAN STRUCTURES

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Introduction

In order to keep the safety of ships in a traffic congested sea route, we shall have to take more interest in the mutual interaction of ship-to-ship and ship-to-structure (in- and off-shore) in the traffic area. Many efforts have been made in the field of navigation, but studies in the naval hydro-dyamics seems to be remaining unsatisfactory.

If the problem is restricted, in a sense, to the traffic capacity in the congested sea area, a concept of the ship domain seems available for modelling of the behavior of a ship in the traffic area. The ship domain concept which was first introduced by Fujii (1) of the Electronic Navigation Laboratory of the Ministry of Transport, will be defined as a effective area around a ship where no other vessels can enter without bringing some dangerous effects on the ship.

In general, the area under the influence of sea-going ships is, however, not restricted only in the ship domain but is extended behind ships. It is not rare that severe influences arise from waves generated by large high-speed ships like car-ferries or container ships. One example of such influence is that in 1959 about 50 fishing boats and fishers suffered big damage by the swelling and breaking waves of the ship travelling near the beach (2). The ship, at that time, was passing two miles off the beach at Imabari in Ehime prefecture.

Taking an opportunity of the enactment of the Maritime Traffic Safety Law, since 1972 a study on the prevention of danger of small ships owing to waves generated by large ships has been performed. The purpose of this law is to ensure the safety of ship's traffic by prescribing the special modes of the navigation and by effecting the control for preventing danger in the traffic congested area. One sea area where this Law is applicable is at the entrance to the Tokyo Bay as shown in Fig. 1. In this area, any vessel cannot navigate at a speed exceeding 12 knots.

Around these prescribed traffic routes there is a number of small ships operating so that the above-mentioned new study has been proposed from the point of view of preventing public hazards. The cooperative study was organized by the Japan Association for Preventing Marine Accidents jointly with the Maritime Safety Agency and the Ship Research Institute (SRI), and others.

As another direction of the study in the similar field, the SRI have continued the experimental studies which relate the influence of ship waves to a small ship and ocean structures. The studies are intended to show the practical applications of the wave-making theory of ships to those problems. The results seem hopeful as shown in the following.

At the beginning of the studies, inquiries into the cause of accidents have been mainly pursued. After that the trend of studies shifted to preventing accidents or troubles. Following are some results of the studies mainly obtained at the SRI.

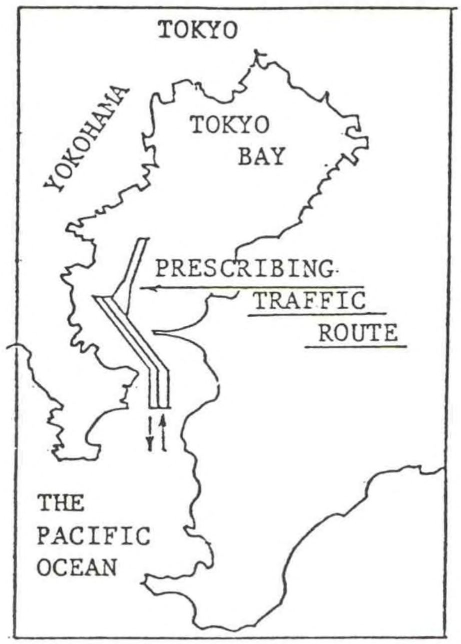

Fig. 1. Example of Presecribing Traffic Route (Uraga Suido and Naka-no-se Traffic Routes)

Properties of Ship Wave

One of the main features of ship wave is so-called Kelvin's wave pattern which is triangle-shaped with the ship's bow as the apex (fig. 2). The dominant waves are seen along the sides from the apex which is called the cusp line of the ship wave. The wave height along this line diminishes at $R^{-1/3}$ as the distance R from the bow increases.

Ship waves may affect environments. For instance, small leisure and fishing boats are turned over by the waves of a big ship which passes by. The structural components of ocean structures may be damaged by the wave forces in which ship waves are superimposed of the ocean waves. Moored ships at piers or yachts in marinas sometimes get crushed to a pier's wall or each other by the ship waves which have travelled from the traffic route.

Ship wave spectra has a different structure from ocean wave spectra. In the former, sharp peaks appear at a definitive frequency for a definitive ship speed, while the latter do not. An example of the energy spectrum of a ship wave for a container is given in Fig. 3, in which θ stands for wave frequency. The peaks appear at a fixed value for any ship at the same Froude number.

Near the cusp line, the steepness, of a ship wave is larger than the other part, which suggests that there is a concentration of wave energy. So it becomes indispensable to be able to estimate ship waves around the cusp line for the investigation of the ship wave effect on the environment. It is not difficult to get reliable wave data of a ship by only the calculation when the ship hull geometry is given.

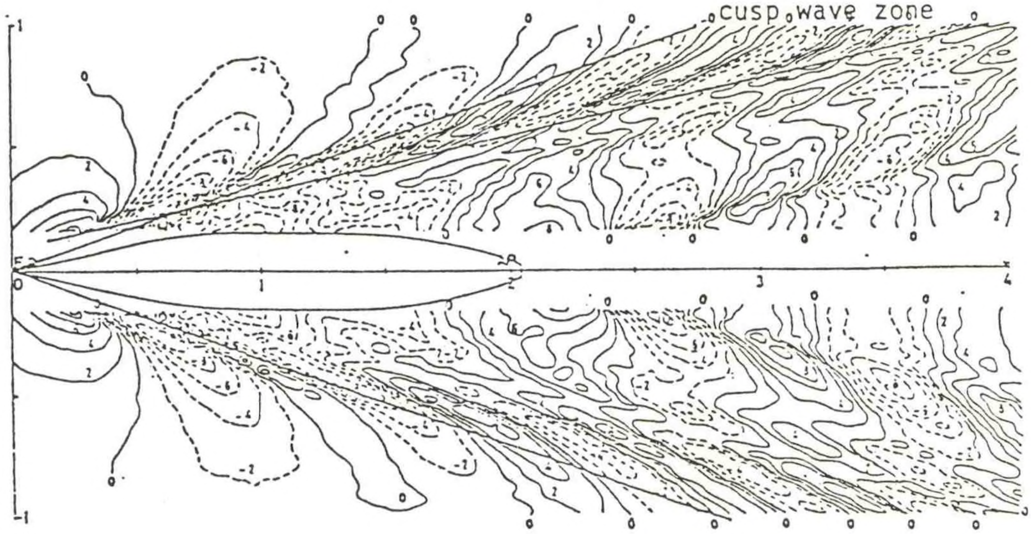

Fig. 2 Wave contour map of a container ship model at Fn=0.27. Model ship length L=10 m. Corresponding ship L=195m. Unit in figure 2ξ/L x 1000.

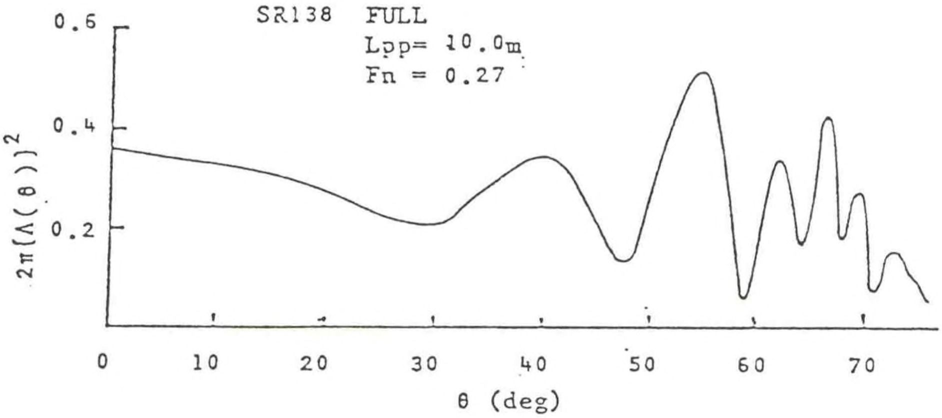

Fig. 3 Energy spectrum of waves of 10m container ship model at Fn=0.27. The integration of amplitude with respect to θ gives wave pattern resistance.

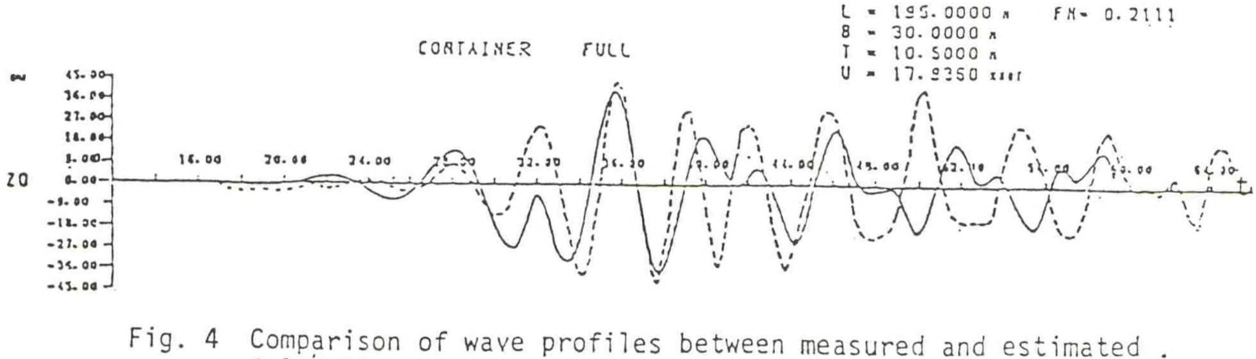

Fig. 4 Comparison of wave profiles between measured and estimated . Solid line; measured for 10m container ship model. Dotted line; estimated from linearized theory.

Estimation Method of Ship Wave

The usual method of the estimation of ship wave is to utilize the steady ship wave-making theory utilizing ship hull geometry and speed as input and ship wave or wave resistance as output. If detailed information about the ship waves are not needed, a simpler method is sufficient.

When the experimental ship wave data are available, the relatively accurate estimation of ship wave becomes possible. However, this case may not be general publication of ship wave data from the towing tank is useful for people who want to know the effect of ship wave on the environment. It is usually difficult to know the detailed hull geometry for an actual ship which might cause some influence on the environment. For such case, only estimated speed and the ship's name are needed. These make it possible to know the tonnage and the horse power and so forth from the register books. Then it becomes necessary to estimate her waves from such non-geometrical data.

To estimate waves for arbitrary ships, it may be practical to use a simple theoretical method and correct it by the experimental data. The correction factors are provided by the experiments for typical type ships. Under this consideration, a system for estimating ship wave has been developed in the SRI. The calculation by the linearized wave-making theory is corrected by the correction factor obtained from experiments in the towing tank. An example is shown in Fig. 4 for a container ship. This treatment is sufficient to know the wave heights and wave length around the cusp line.

When lines of ships cannot be obtained, an estimation of wave height is made by the following formula[3]:

$$H=(L/100)^{1/3}\ (EHPs/2.2*L*Vk)^{1/2}$$

Where L=ship length (m), VK=ship speed (knot), EHPw=0.65*SHP-EHPf, $EHPf-1/2P S V^2 CfV/75$, $S=2.5(\Delta L)^{1/2}$, Δ=displacement (m^3), V=0.514VK and $Cf=0.075/(\log(VL/1.2x10^6)-2)^{1/2}$.

H stands for the maximum wave height at the parallel line 100 m apart from the ships route. With H and the data of the type ship, wave data on the cusp line will be approximated only knowing ship length, displacement, and shaft horse power.

Interaction of Ship Wave with Small Boat from View Point of Safety

The safety of small boats such as a one-man leisure boat is affected by the presence of big waves which propagate away from the ship's track. It is not an easy task to establish the measure for the assessment of the safety of a small boat. First of all, the motion of the boat responding to the incident wave has to be estimated. Usually a small ship makes motion of large amplitude, so that it becomes difficult to make use of linearized ship motion theory. And, moreover, the motion characteristics of the combination of small ship and man is easy to change.

The steepness of waves and the relative position of the small boat are thought to be the simplest and practical standard for the measure of safety. Among the modes of motion of a small ship, the rolling mode may be the most critical for the turnover of a ship. Then, the safety standards for both rolling motion at resonance and absolute wave height are expected to be practical ones.

The resonant motion of a small ship, the absolute wave height of ship wave and the inclination of wave slope calculated from the wave data at two points of the small ship hull define the danger limit for the small ship. When the absolute wave height exceeds a certain limit for a given small ship, the danger limit hits high score. And as the natural rolling period of a small ship is near to the period of ship wave, the danger limit becomes high score too.

A computer program has been developed to assess the danger limit after the above-mentioned criteria for small ships around the traffic routes of large ships. As an example, calculations for a 5 m length small ship affected by waves of a large container ship are shown in Figs. 5 and 6 and Table 1. Wave heights at the ends and both sides of the small ship are printed out together with the wave slope which is calculated from wave height at the four points. And the period of waves passing by the small ship are calculated to know whether the small ship has resonance. From this information the danger limit for the safety of the small ship can be estimated. The determination of the danger limit is not definitive. However, this program may be useful to understand the effect of ship waves on small ships.

Influence of Ship Waves on Ocean Structures

The ocean structures influenced by ship waves are fishery facilities, oceanographical devices, structural components of piers and marinas, and artifical floating platforms in the sea. For these ocean structures, the effect of the ocean wave is main and the ship wave is secondary. However, the ship wave effect may become important in such a case that the pre-tension is imposed by ocean current of the structure.

Forces Exerted on Ocean Structure

There are many shapes for ocean structures. However, the elemental components are usually composed of a circular cylinder, flat plate, and things like that. Therefore, it seems useful to investigate the basic behavior of such elemental components when exposed to the influence of ship waves. In the SRI a preliminary experimental system in the towing tank and an analysis system for the experiment have been developed. The brief introduction for the system is shown in the following.

Since the towing tank at the SRI has 18 m width and 400 m length, a relatively large ship model, up to about 14 m in length, is available to generate ship waves as the incident wave to elemental components. And since the maximum speed of the towing carriage is 15 m/s, the waves of small high-speed crafts are also available.

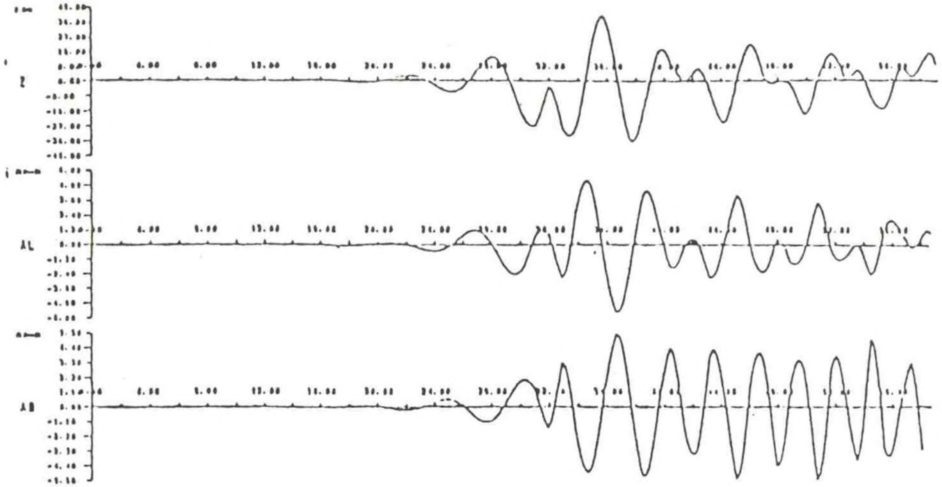

Fig. 6 Output example of the computer program for the safety standards. Wave height, lengthwise wave slope and beamwise wave slope at a small ship.

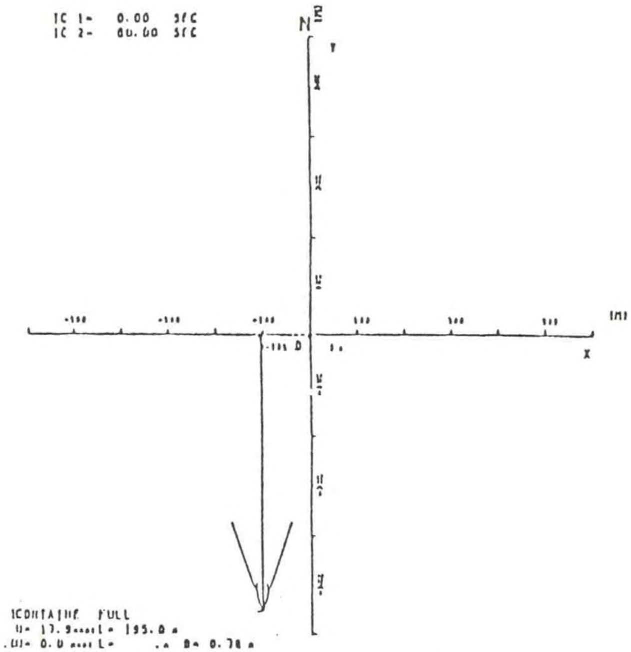

Fig. 5 Relative position of a large ship and a small ship. Small ship is at the origin.

Large Ship
L=195.0 m
B= 30.0 m
T= 10.5 m
U= 18 knot

DANGER ZONE OF WAVE

TIME1	TIME2	ONE-CYCLE TIME	WAVE HEIGHT	DANGER(1)	DANGER(2)	DANGER-SOGO
1.883	5.649	7.532	0.001	0	0	0
5.649	9.415	7.532	0.002	0	0	0
33.895	35.778	3.766	0.697	3	0	3
35.778	37.662	3.766	0.764	3	0	3
37.662	39.545	3.766	0.528	3	0	3
39.545	41.428	3.766	0.174	3	0	3
41.428	42.369	1.883	0.072	0	0	0

Table 1 Output example of the computer program for the safety standards. Danger zones and value of danger limit.

In Fig. 7 the typical setting up of the experimental system is shown. The force components and the pressure distributions on the elemental components are measured together with wave records.

The impact of ship wave on the structural components is similar to that due to the transient solitary wave. Only the wave near the cusp line of the ship wave is large both in amplitude and steepness. The cusp wave which is composed of diverging waves from the ship bow has a strong dependency in the direction of propagation.

In most cases, the maximum forces are conserved as the result of the interaction of waves with structures. As the typical structural components, circular cylinder and flat plat are considered, the maximum X and Y direction forces and pressures are determined as shown in Fig. 8. The results for a circular cylinder shows that when the ship speed increases the force also becomes larger almost proportionally to the maximum wave height. This tendency is also true for the case of a flat plate. However, as shown in Fig. 9, forces change in magnitude as the relative direction of the flat plate changes. The maximum force is at an angle of about 30 degrees at which the cusp wave hits head-on the flat plate. The distribution of the maximum pressure is useful when precise structural analysis is required. For circular cylinders and flat plates, typical pressure distributions are shown in Fig. 10 and 11.

The above-mentioned are mere results of a sample measurement. The data obtained in such experiments are utilized as input to a sophisticated computer analysis system for ocean structures.

Conclusions

Owing to the effect of the traffic routes prescribed under the Maritime Traffic Safety Law, the small ships damaged by ship-forming waves recently seems to be gradually decreasing. The importance of the study in this field, however, has not changed in the past decade because the potentiality of big accidents increases with increasing traffic area congestion and increasing number of ocean structures.

Continuous endeavours to prevent accidents and troubles due to ship waves are underway in the SRI. Through this study, the authors would like to contribute to the systems development on the safety assessment for small ship operations such as fishing and dredging around traffic sea routes, and to contribute to the safe design of ocean structures. The results will be helpful in sustaining the policy of safety in traffic areas.

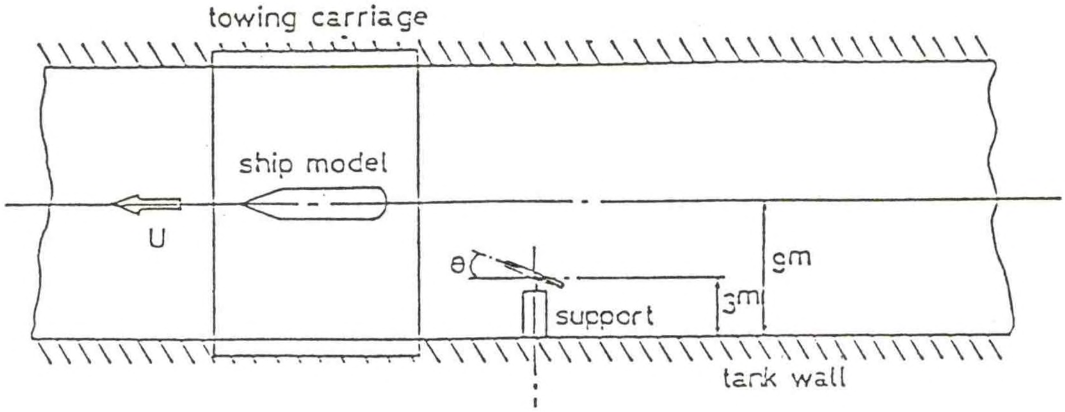

Fig. 7 Test geometry in SRI 400m towing tank. Elemental component of ocean structure is fixed to the support.

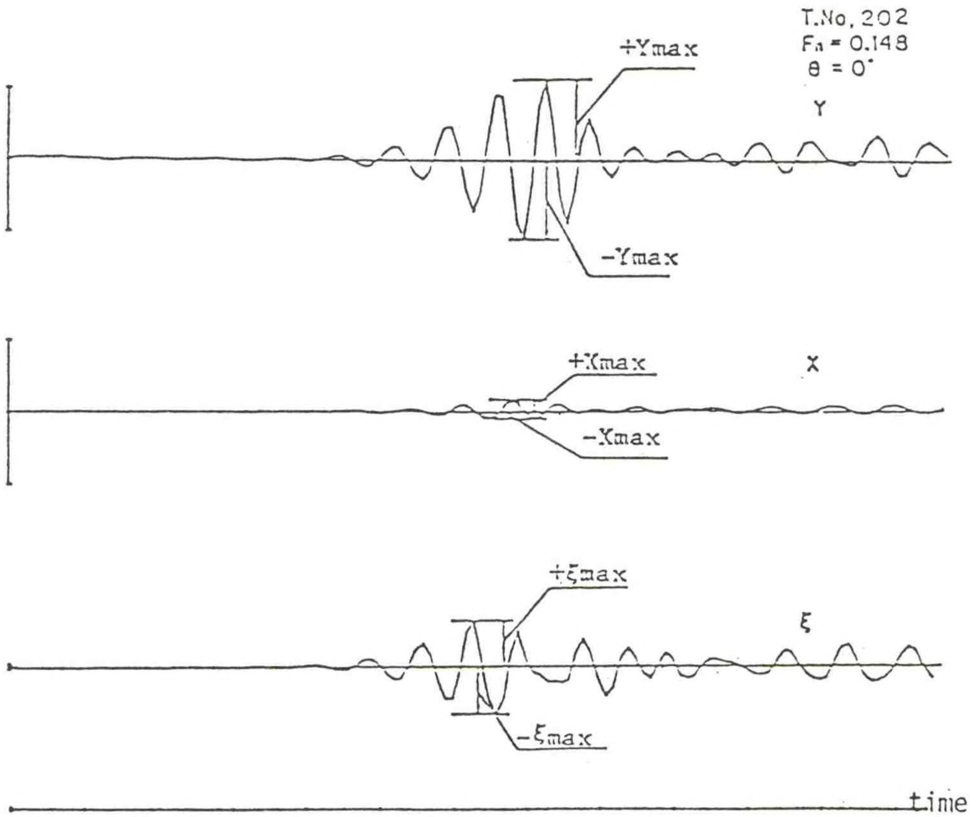

Fig. 8 Plotter output of experiment for the flat plate. Incident wave is from 10m container ship model. Y and X forces and wave height at the plate.

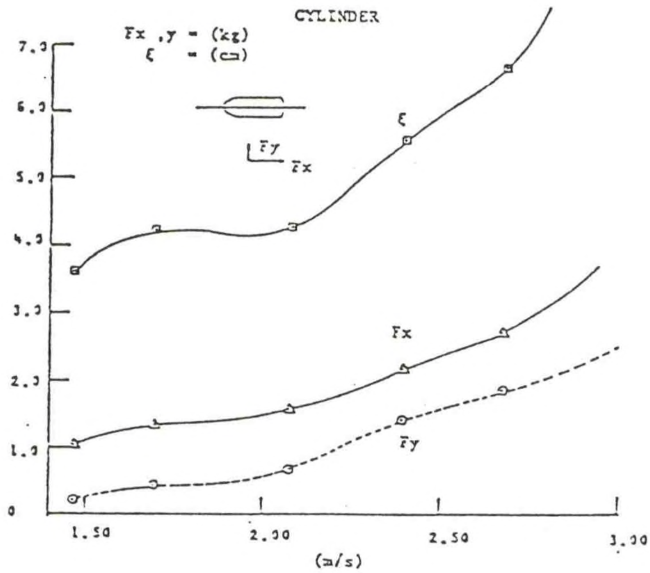

Fig. 9a Measured forces of a circular cylinder of radius 0.1m and depth 1.0m.

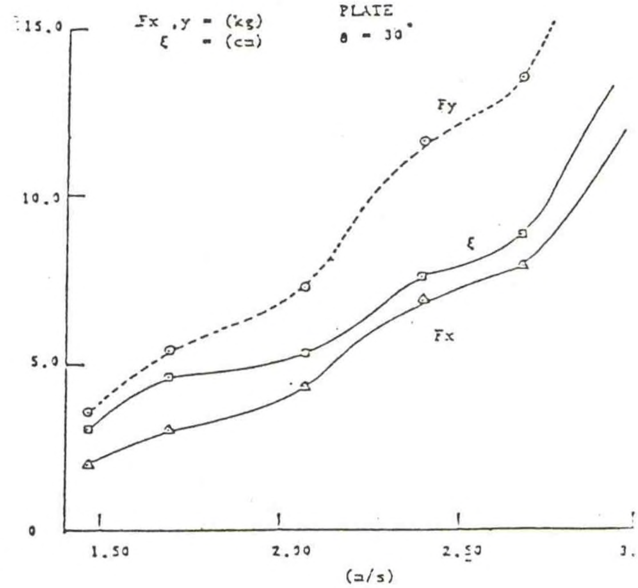

Fig. 9b Measured forces of a flat plate length 0.5m and depth 1.0m at angle θ=30°.

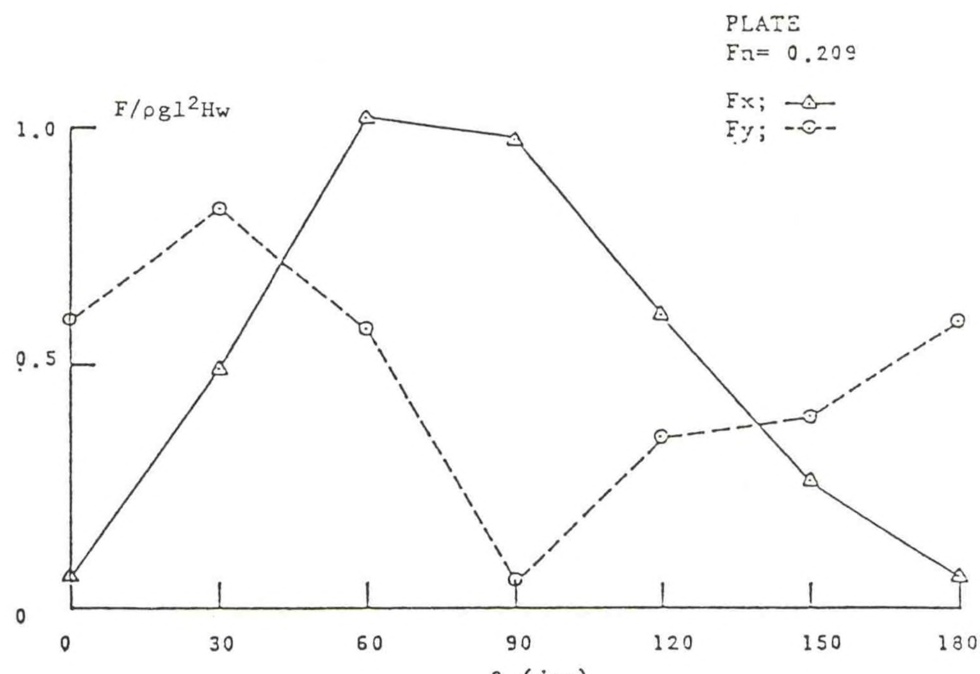

Fig. 9c Dependacy of forces on the direction of ship waves. Flat plate at the speed of 10m container ship model Fn=0.209.

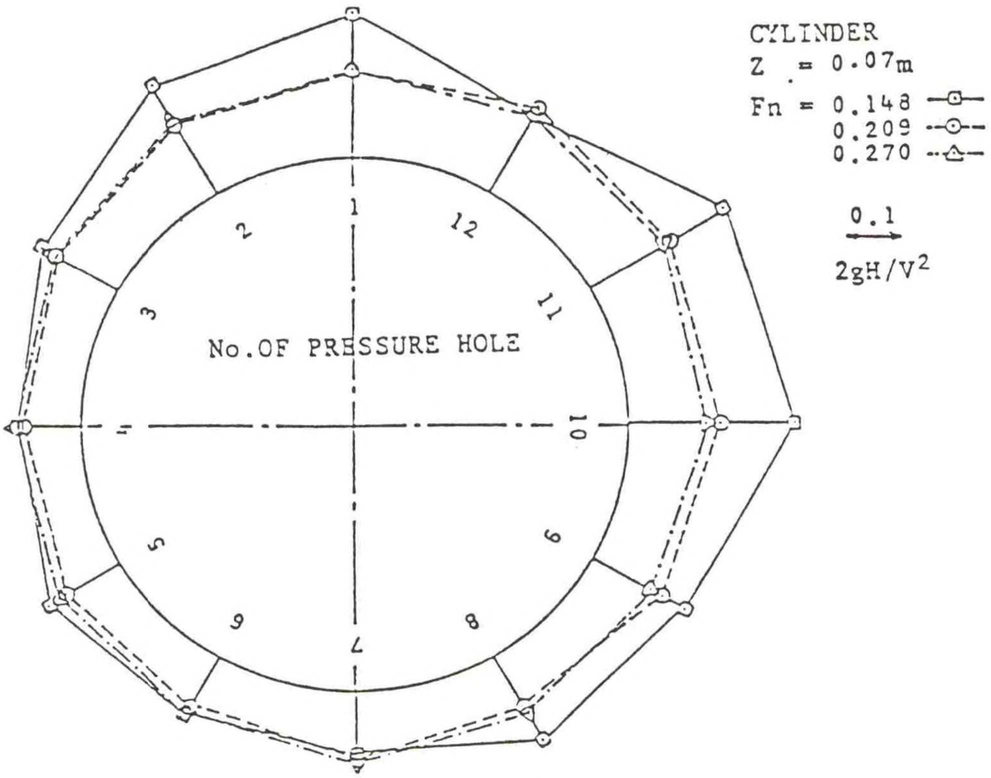

Fig. 10 Pressures of the maximum amplitude for a circular cylinder r=0.1m. Pressure hole No.1 is at angle θ=90° (see Fig.7). Fn is the Froude number of 10m container ship model.

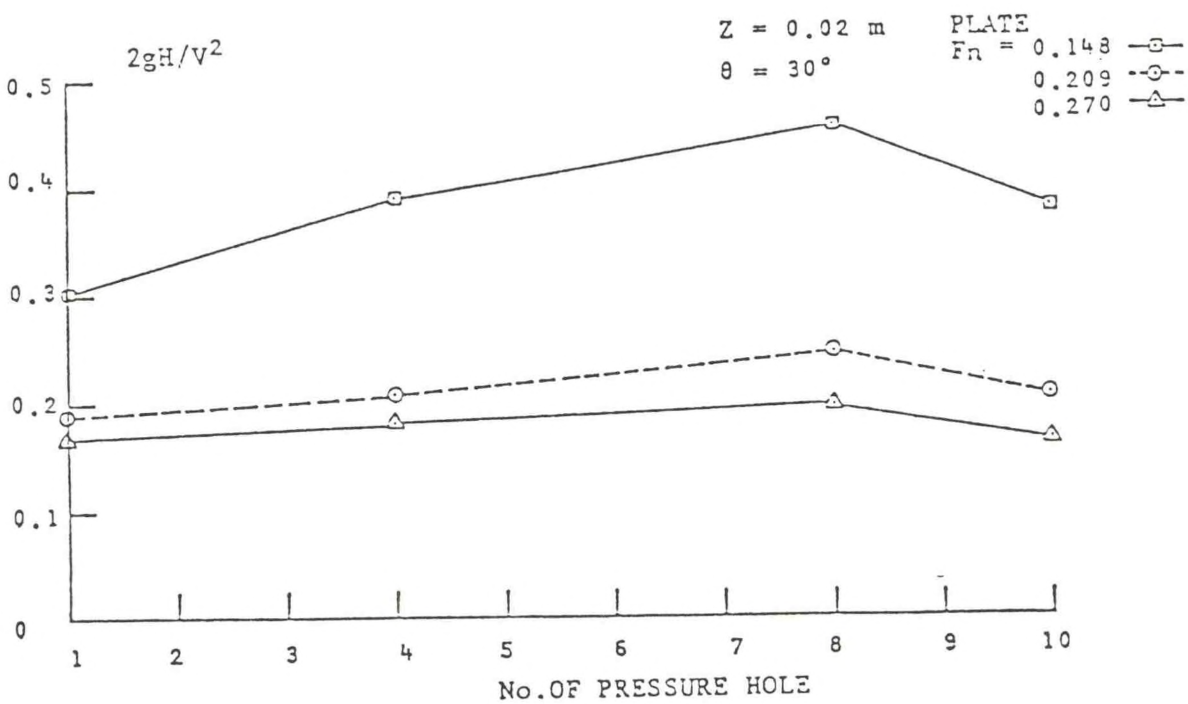

Fig. 11 Pressures of the maximum amplitude for a flat plate.

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(2) Takenouchi, Y. and Nanasawa, K.; About "GUNKAN-NAMI" (warship wave) which Reaches on the Imabari Beach as Significant Breakers, J. of the Oceanographical Society of Japan, Vol. 17, No. 2, (1961) (Japanese)

(3) Ship Waves Committee; Investigation into the Fundamental Problems on Safety at Traffic Sea Area (Part 3), Study on Influences of Ship Waves on Small Ships, The Japan Association for Preventing Marine Accidents (1974), (Japanese)

ARCTIC SHIP RESEARCH IN JAPAN

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In recent years, the exploration of natural resources is being rapidly promoted in the Arctic regions such as Prudhoe Bay, Beaufort Sea, and the Arctic Islands; but, as a conventional means of transportation cannot be used in these regions, a new type of transportation system is required to carry the huge amount of natural resources to the consumption areas.

In Japan, the Ministry of Transport has conducted for six years a preliminary study of the natural environment, the structure of the ice breaker, navigation through the ice seas, and other studies concerning the ice breakers. Based on the study, the Shipbuilding Research Association of Japan made conceptional designs for several types of ice breaking tankers (the profile and principal dimensions of a 200,000 DWT self-propulsive ice breaking tanker is shown in Fig. 1), and identified the following technological problems to be overcome with priority.

(1) Research on ice, ice sea, and meteorological conditions in the Arctic region.
(2) Research on hull forms of ice breakers and resistance of ice breakers in the ice-breaking mode.
(3) Maneuverability in ice sea.
(4) Compact propulsion plant with high efficiency.
(5) Hull structure.
(6) Fittings.
(7) Navigation technology. Training and qualification for crew.

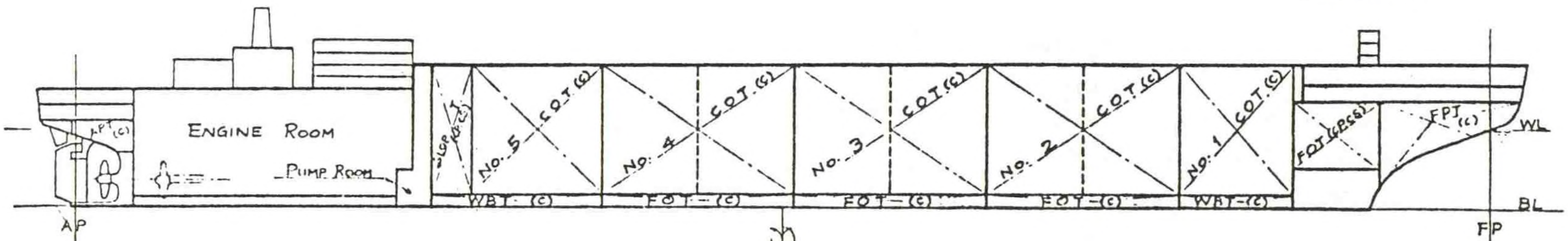
Since our country has no ice sea around its land, the experiment of the ice breakers in the actual ice water is rather difficult. However we are able to study the propulsion performance and the ship forms with less ice-breaking resistance through model tests. So, the Ministry of Transport is promoting such studies and experiments in the ice model basin of the Ship Research Institute of the Ministry of Transport. Figs. 2 and 3 show the outline of the basin.

The project to develop ice-sea-going ships has been carried out since 1981 in cooperation with the Shipbuilding Research Association of Japan. On the other hand, the Japan Foundation for Shipbuilding Advancement is studying artic marine oilspill prevention devices. The former association is scheduled to draw up a basic design of a 200,000 DWT ice-breaking tanker. The latter, on the other hand, is expected to develop an oil dispersant and an oil skimmer for ships to navigate through the ice sea.

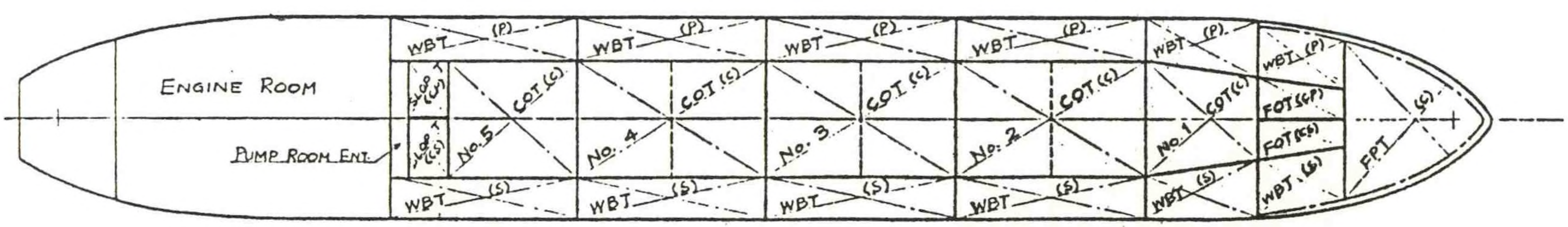
Fig. 1

200,000 DWT	Ice Breaking Tanker	
Lpp	360 m	
Bm	52 m	
Dm	37 m	
d	20 m	
Main Engine		Gasturbine-Electric
		227,400 PS, 3 shafts
Speed		15 Knots (open sea)
		3 Knots (ice sea)
Ice Class		10

Profile



Plan



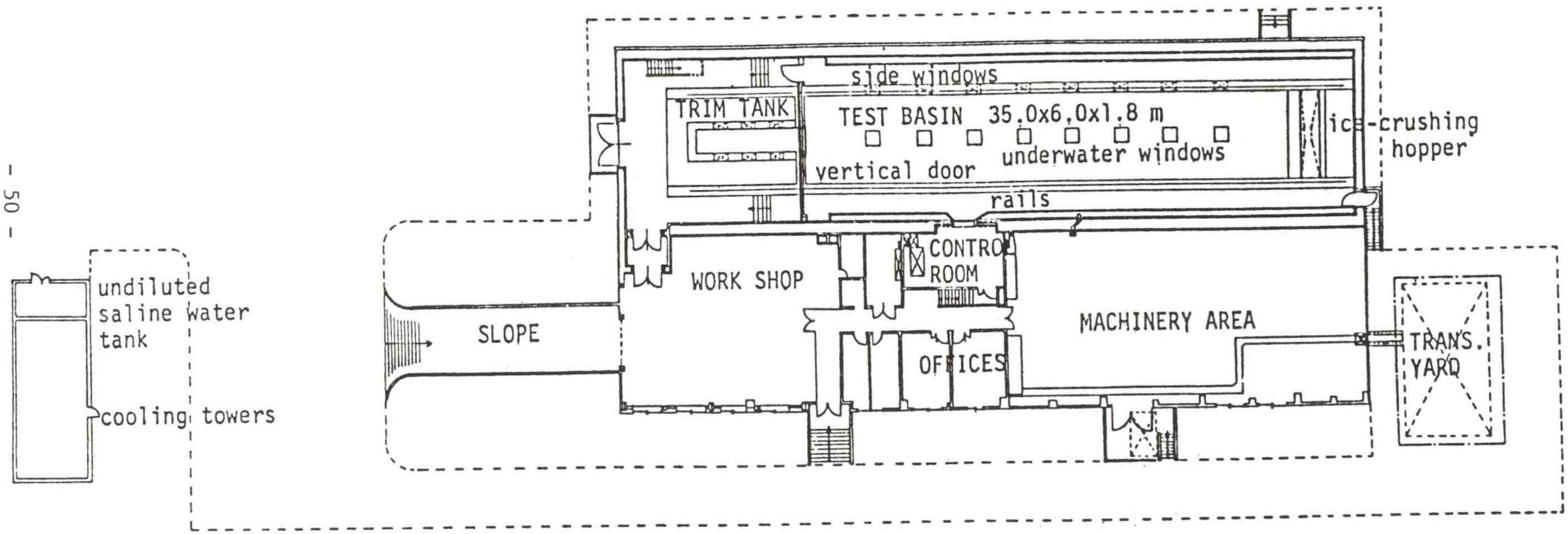


Fig. 2 Floor Plan of Ice Model Basin

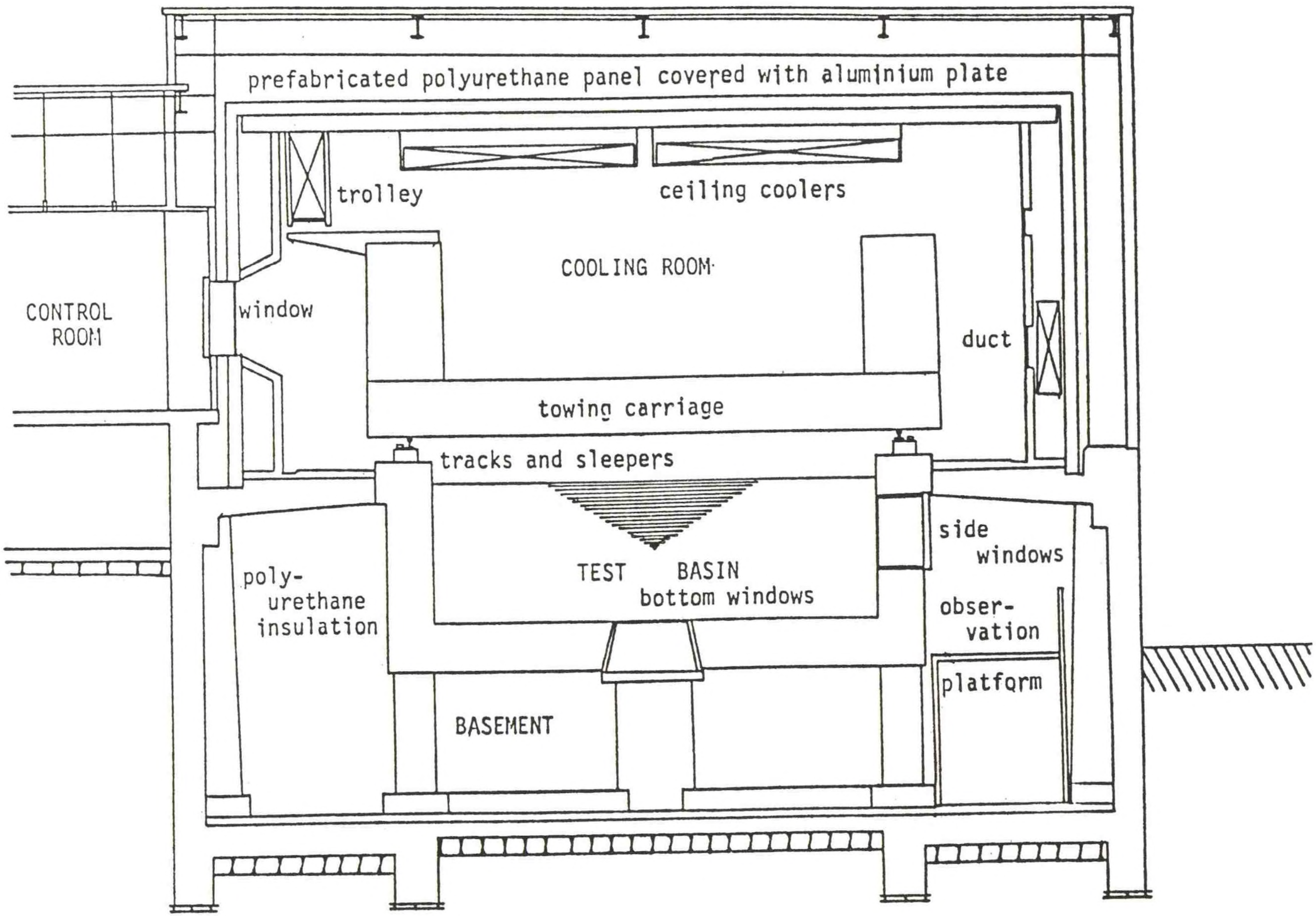


Fig. 3 Construction of Test Basin

ENERGY SAVING PROPULSION PLANT

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The price of oil has jumped to about 220 dollars per kiloliter, ten times as high as 20 dollars per kiloliter before the oil crisis, and fuel cost amounts to 50% or more of ship operation cost. Economy of the fuel oil consumption is now the most important sales point for the ship building company.

For this reason, energy saving policy such as the reduction in rate of fuel consumption of a main deisel engine, collecting and utilization of waste energy from a main engine, and rational utilization of auxiliary machinery are being positively pushed and is showing fruitful results.

1. Main Diesel Engine

In the field of low-speed diesel engine, the long-stroke diesel engines with bore-stroke ratio of two or more have been developed in order to use a slow-turning propeller which can offer improved propulsion efficiency and reduce fuel consumption at sea.

Some improvements of optimum fuel consumption have been introduced into fuel injection systems referred to as "De-Rating" and "Economy-Rating." The specific fuel consumption of 129~132 g/PS.h of s.f.c is expected.

On the other hand, relating to reduction of fuel consumption of the middle speed engine, with improvement of fuel injection system such as De-Rating and electronic control of governor, technological improvement has proceeded rapidly, and fuel consumption rate was reduced from 140's g/PS.h of a few years ago to 130's g/PS.

2. Exhaust Gas Economizer and Shaft Motor System

Exhaust gas has been collected as steam and used as a heat source or steam for various uses, but recently efficiency of the exhaust-gas economizer has improved rapidly and a part of the electricity supply in ships is offered by exhaust-gas turbo-generator.

3. Shaft Generator

The main diesel engine, which has high thermal efficiency and is able to burn low-cost and low-quality heavy-fuel oil, is used to drive the generator which supplies electric power for inboard use in navigation and consumption of high-cost diesel oil is being reduced.

With not only the difference of thermal efficiency of diesel engines but also the cost difference between diesel oil and fuel oil, the main engine generator has an energy saving effect which is expected to amount to 40% of fuel oil consumption of the generator.

4. Controllable-Volume Cooling Water Pump, etc.

A cooling sea water pump used to be operated at a fixed speed and had no relation to sea water temperature or output of a diesel engine. However, water volume for cooling a diesel engine depends on its output, so it is rational that the pump's output volume be changed in accordance with the situation.

Therefore, controling the output of the sea water pump in accordance with the change of engine output can realize an energy saving.

Proper control of auxiliary machineries like this is also effective to other pumps or blower, etc., and the reduction of fuel consumption by such energy saving techniques is a basis for utilizing the turbo-generating system.

SEMI-SUBMERSIBLE CATAMARAN-TYPE SUPPORT SHIP (FOR UNDERWATER EXPERIMENTAL WORKS)

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Abstract

Japan Marine Science and Technology Center (JAMSTEC) conducted the feasibility studies on new construction of a semi-submersible catamaran-type underwater experimental work-support ship (SSC support ship) in FY 1979, and did basic planning during 1980-1981.

Extensive studies were carried by JAMSTEC and discussed with the committee organized of professors, shipbuilders, and ship operators. As a result of the study, the committee concluded that a semi-submersible catamaran (SSC) was most suitable for conducting experimental underwater work in the open sea. Construction will be done in FY 1982-1985.

This paper presents a comparison of ship motion between a conventional mono-hull ship and SSC, and an outline of a SSC support ship. Also, saturated diving units already completed are briefly discussed.

Introduction

JAMSTEC has promoted the development and progress of Japan's marine science and technology under the cooperation of government, academic, and private circles since its establishment in 1971.

Recent research and development required many experiments such as saturated deep ocean floor survey, etc. Concerning deep diving technology, SEATOPIA projects which were named for the saturated diving experiments down to 100 m water depth, were successfully completed in 1975; and the 31 ATA saturated deep diving simulation was conducted with attendants from France, U.S.A., and West Germany at JAMSTEC's simulator in 1979. Much fruitful data of diving physiology and technology was obtained from these diving experiments.

JAMSTEC has already completed the construction of SDC-DDC units for R&D on 300 m deep diving technology in April, 1981.

As it is very important that experimental diving works in the field be conducted to confirm the performance of SDC-DDC units and to improve the system and technology, the Japanese government included in the budget the construction cost of a SSC support ship capable of accommodating SDC-DDC units, in FY 1982-1985.

Mission and Required Performance

JAMSTEC promotes various kinds of R&D of marine science and technology of Japan with the cooperation of the public, academic, and private circles. Almost all of these studies need large scale experiments in the open sea.

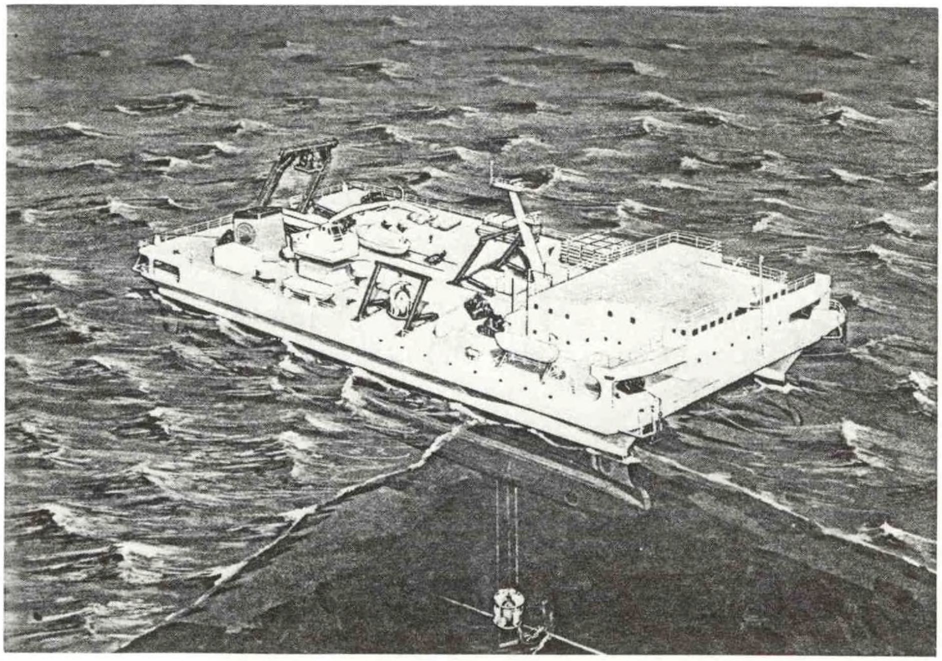


Fig. 1 SSC support ship

The missions of SSC support ship are as follows;

- o R&D of manned underwater work technology down to 300 m water depth
- o R&D of deep ocean floor survey and very fine-scale investigation of deep-water space.
- o R&D of data aquisition and monitoring system
- o Preparatory hydrographic survey for the manned deep submergence research vehicle "Shinkai 2000"
- o Training and education on board

The required performances to carry out the above missions are as follows;

Endurance

Thirty (30) days underwater work in addition to thirty (30) days voyage.

Speed

Stable at low speed for observation of ocean floor and moderate speed enough to avoid a sudden weather change.

Motion in waves

Stable to such extent as to secure good working conditions and accuracy of measurement as well as higher operating efficiency.

Maneuvability

Turning ability at the spot and course-keeping ability at low speed for ocean measurement.

Noise

Noise to an acceptable level for under-water communication and acoustic position reference.

Station keeping

Accurate station keeping for long-period experiments especially in case of deep underwater work experiment.

Accommodation

Large and comfortable quarter space enough for many staff personnel, researchers, and crew who may be required to engage in long-term projects.

Working deck area

Wide deck spaces used for installation of equipment and for safety of work.

Hull Motion in Waves (Model Test)

A theoretical calculation was made to estimate hull motion in waves for mono-hull and SSC, and a confirmation test was also conducted at the model basin.

Table 1 shows principal particulars of models and actual ships. Photograph of models used for tank test are shown on Fig. 2 and Fig. 3.

Model tests are carried out in the fully-loaded condition in both regular waves and irregular waves.

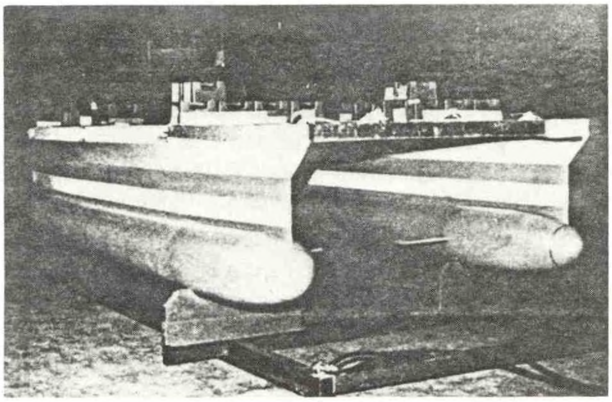


Fig. 2 Model of SSC

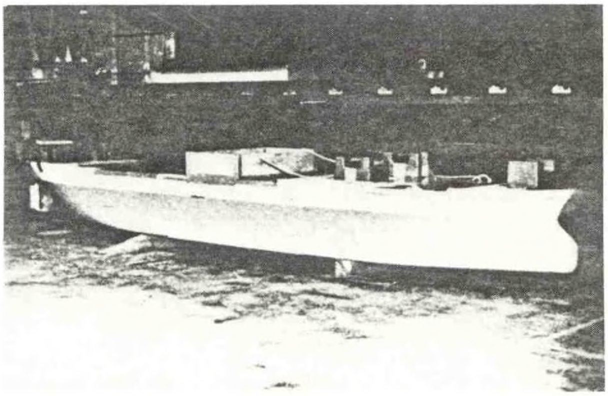


Fig. 3 Model of mono-hull

Fig. 4 through Fig. 9 show heave, pitch, roll, and relative distance between wave and hull bottom for each head sea and beam sea in irregular waves.

For example, in case of sea state 3, while heave and pitch are very small for both types of ship, roll of mono-hull is very large. From these model tests, SSC is confirmed to be very stable and suitable for under-water work operation in a rough sea.

Outline of SSC Type Underwater Experimental Work Support Ship

JAMSTEC decided to adop a semi-submersible catamaran type as the support ship, and key plans were extensively discussed by many specialists. General arrangement plans are shown on Fig. 10. A centerwell is so arranged to hoist and lower a SDC easily. Two sets of A frame cranes are provided near the well and the starboard on upper deck, respectiviely. Umbilical winches are also arranged near the centerwell in such a way that no passing of SDC disturbs the winch operation. A mooring winch is located at each corner on the upper deck and an articulated crane is porvided aft of upper deck for miscellaneous use. Quarter space is arranged on the fore part of upper deck and main deck. Unitized diving command room and D.P. control room is arranged aft of navigation room. DDC units are provided slightly aft of the center well on the main deck. Monitoring and communication can be done by central control panel. Four generator engines are arranged aft of main deck to reduce transmission of vibration and radiation of noise into underwater. Each CPP propeller is provided for each lower hull and driven by two sets of propulsion motors through a reduction gear. Eight controllable pitch-type side thrusters are located at the lower hull. Principal particulars are described in table 2.

TYPE / DIMENSION	SSC		MONO-HULL	
	MODEL (MN 1122)	SHIP	MODEL (MN 1004)	SHIP
LENGTH (M)	2.650	53.00	3.000	70.20
BREADTH (M)	1.400	28.00	0.493	11.50
DEPTH (M)	0.675	13.50	0.279	6.50
DRAFT (M)	0.315	6.30	0.194	4.50
DISPLACEMENT (TON)	0.394	3,150	0.242	3,100

Table 1 Particulars of model and ship

Test results show clearly the large difference in motion between SSC and mono-hull.

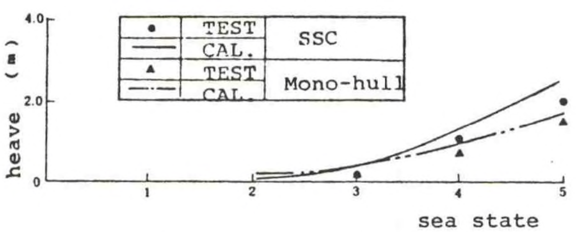


Fig. 4 Heave on head sea

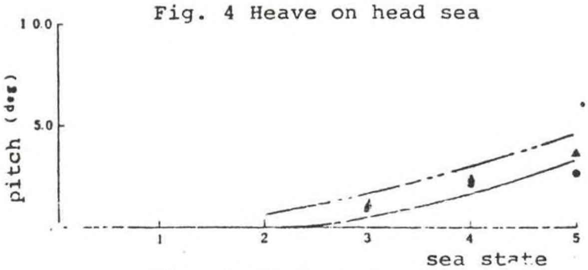


Fig. 5 Pitch on head sea

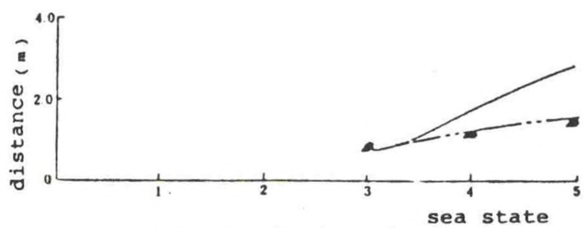


Fig. 6 Relative distance on head sea

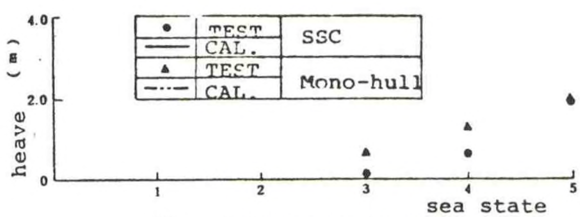


Fig. 7 Heave on beam sea

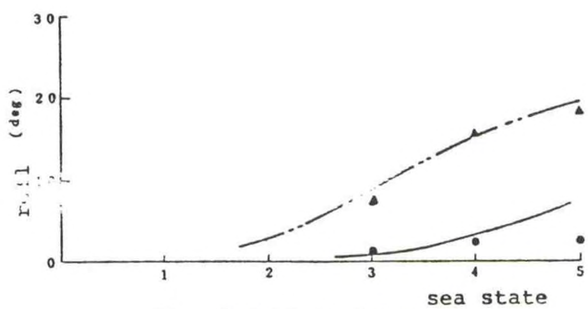


Fig. 8 Roll on beam sea

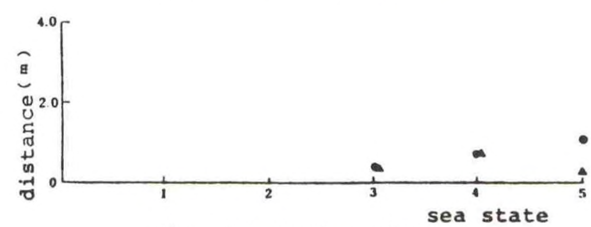


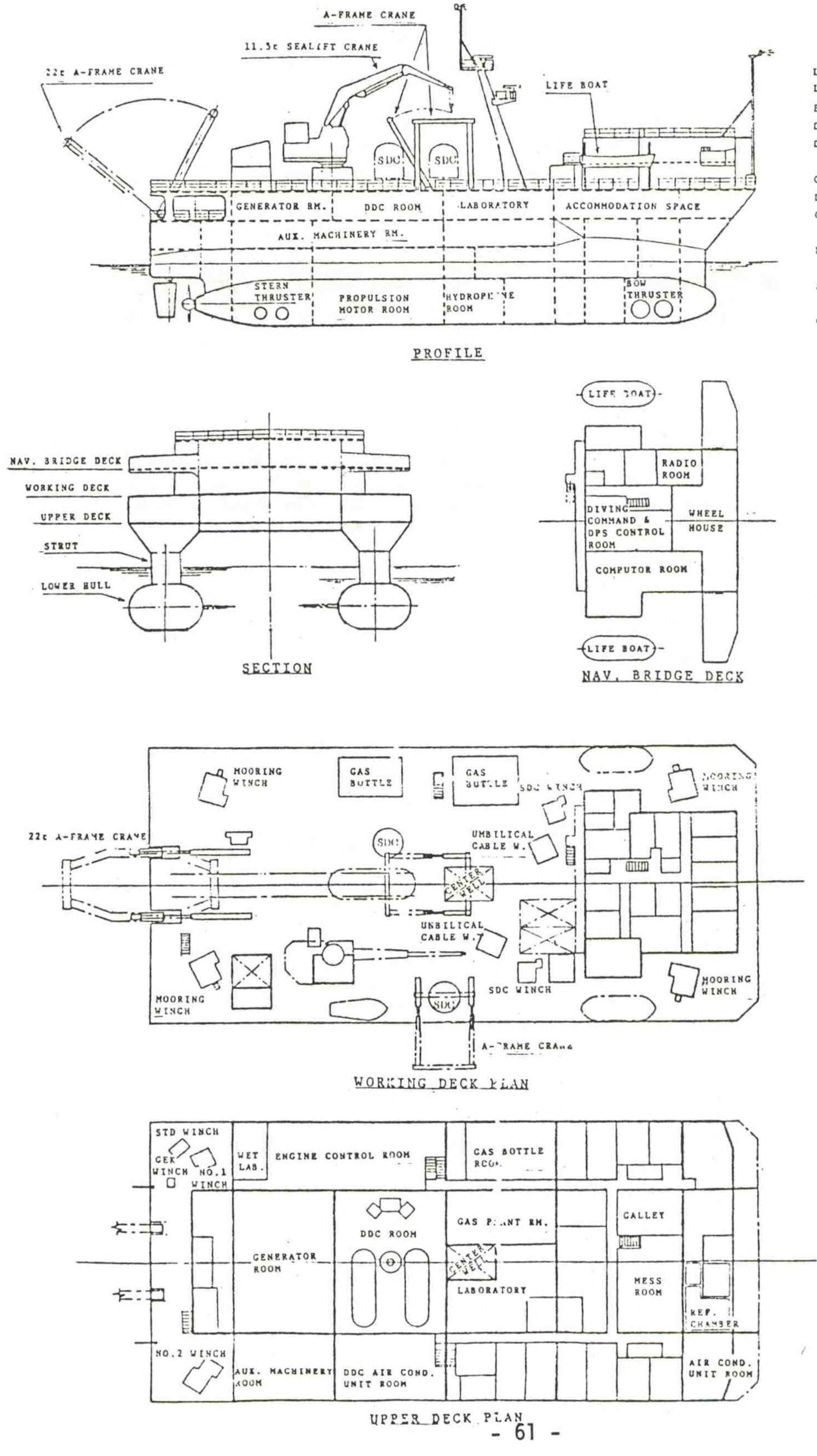
Fig. 9 Relative distance on beam sea

Table 2 Principal Particulars of SSC Support Ship

1. Principal Dimensions	
Length (o. a)	60.00 m
Length (p. p)	53.00 m
Breadth(mld)	28.00 m
Depth main deck (mld)	10.60 m
Draft (mld)	5.00/6.30 m
Dead weight	abt 860 ton at draft of 6.30 m
Gross Tonnage	abt 2800 T.
2. Class	NK (NS* MNS*)
3. Speed and Endurance	
Speed	abt 12.0 knots
Endurance	abt 4600 nautical miles
4. Complement	
Crew	29 persons
Project team	40 persons
5. Machinery	
Main generator	1250 kw x 4 sets
Propulsion motor	760 kw x 4 sets
Propeller	2 sets
6. Deck Machinery	
Crane	Sealift crane 10 T x 1 set
	Stern A frame crane 22 T x 1 set
Four point mooring winch	Electro-Hydraulic type x 4 sets
Steering gear	Electro-Hydraulic type x 2 sets
7. Dynamic Positioning System	
Thruster	CPP type side thruster x 8 sets
	CPP type main propeller x 2 sets
Controller	Dynamic positioning control system
	Joistic control system

8. Navigation and Radio Equipment	
Gyro compass	1 set
Echo sounder	1 set
Magnetic log	1 set
Radio telegraph	1 set
VHF telephne	1 set
Radio direction finder	1 set
Radar	2 sets
Weather facsimile	1 set
9. Integrated Navigation System	
Acoustic navigation :	Long base line
	Super short base line
	Vertical reference unit
Radio navigation :	NNSS
	LORANC
	Microwave
	Decca
10. Saturate Deep Diving System	
Deck decompression chamber	2 sets
Submersible decompression chamber	2 sets
11. Deep ocean floor survey program and very fine scale inverstigation of deep water space program	
Deeply towed vehicle	1 set
Remotely controlled viewer	1 set
12. New Ocean Surveying System	
Towed vehicle	1 set
13. Others	
Multi narrow beam hydrographic survey system	

Fig. 10. General Arrangement Plan

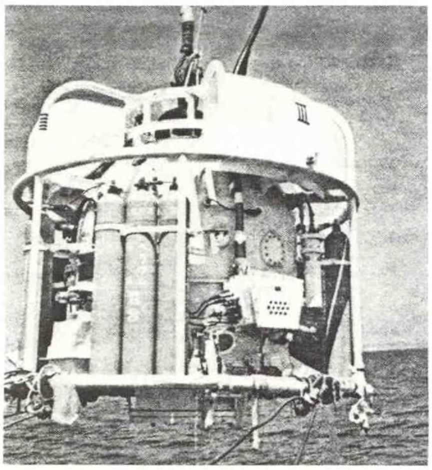


PRINCIPAL PARTICULARS

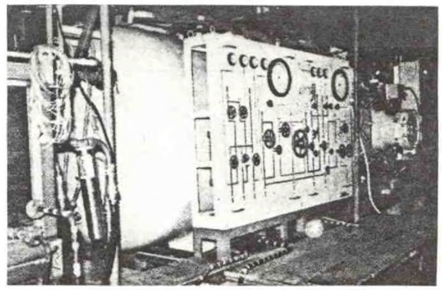
LENGTH O.A.	ABT.60.00 M
LENGTH B.P.	53.00 M
BREADTH MLD.	28.00 M
DEPTH MLD.	10.60 M
DRAFT	6.30 M
CLASS	NK
DEADWEIGHT	870 MT
GROSS TONNAGE	ABT.2800 TON
MAIN PROPULSION MOTOR	760 KW x 4 SETS
SPEED	ABT.12 KNOTS
COMPLEMENT	69 P.

Diving Equipment

Diving equipment consists of two SDC units (spherical-type and cylinder-type), two DDC units, and a transfer lock. The cylindical SDC is mainly used for lockout diving down to 300 m depth, while the spherical SDC is used for deeper observation research down to 500 m depth under atmospheric environment. Picture and main particulars of the SDC-DDC units are shown on Fig. 11 and table 3, respectively. The chamber arrangement is determined so that a wide variety of research programs can be conducted with complete safety.



• **Submersible decompression chamber (SDC)**



• **Deck decompression chamber (DDC)**

Fig. 11 Picture of SDC-DDC

SDC	TYPE, NUMBER	SPHERICAL (1 set)	CYLINDRICAL (1set)
	MAX. WATER DEPTH	500m (external press.) 300m (internal press.)	300m (external and) (internal press.)
	CAPACITY DIMENSION	3 persons abt.2.2m (inner dia.)	3 persons abt.1.9m (inner dia.) x 2.3m (inner height)
DDC	TYPE, NUMBER	MAIN, SUB CHAMBER (2 sets) TRANSFER LOCK (1 set)	
	MAX. WATER DEPTH	300m (inner press.)	
	CAPACITY DIMENSION	6 persons per each MAIN, SUB CHAMBER:abt.2.1m x 7.5m (inner length) TRANSFER LOCK :abt.2.1m x 2.4m (inner height)	

Table 3 Main Particulars of SDC and DDC

Environmental control can be automatically or manually done from central control panel. The TV camera is fitted on each DDC and transfer lock for monitoring inside of chamber.

STATION KEEPING

SSC support ship has two methods of station keeping system. Where shallow water less than 100m, four points mooring winch system is used. Where deep water, dynamic positioning system can hold the ship on station within a radius about the 5 percent of operating water or 10m, whichever is greater.

In order to know ship's characteristics, wind tunnel test, hydrodynamic test and wave induced motion test were conducted. Also dynamic simulation was confirmed to satisfy the required holding capability.

CONSTRUCTION SCHEDULE

SSC support ship is expected to go into voyage by the middle of 1985. The construction schedule is shown on Fig. 12.

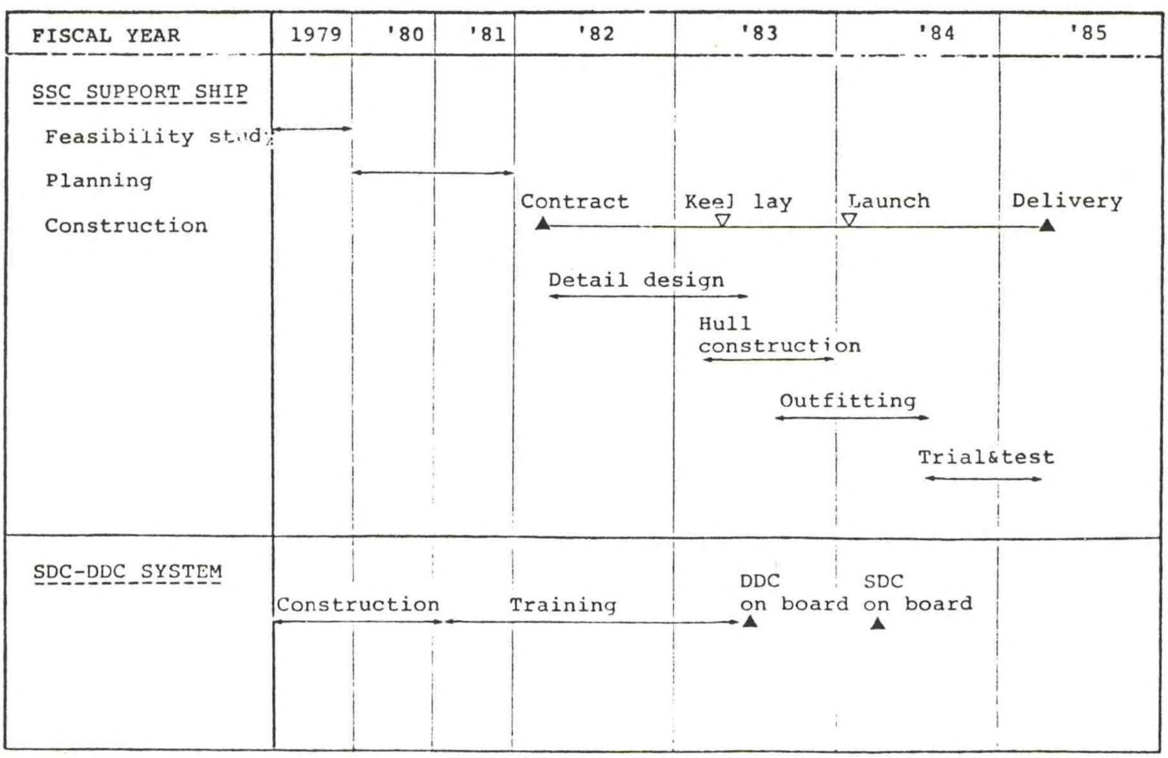


Fig. 12 Construction schedule

DEVELOPMENT OF ARCHIDEDIAN TRACTOR

M. Kohmoto
Mitsui Engineering and Shipbuilding Co., Ltd.

Mr. Kohmoto presented an excellent movie showing the Archimedian Tractor in action in the Arctic. Excertps from a brochure are shown below and on pages that follow.

Currently, various projects are underway to develop oil in continental shelves under such ice-covered seas, where the surface is frozen or covered with pack ice, as arctic seas in Alaska and Canada, the Po-Hai Bay of China, and the offshore of Sakhalin.

The success of such oil development projects depends on a number of factors, of which one of the most important is the availability of the means of transport and supply of equipment between the offshore operation base and supporting base on land. However, the existing vessels have so far been inadequate, and the demand for some amphibian vehicle that can travel both on ice fields and water has became pressing in the arctic oil development and related circles.

Developed in reply to such a demand "MITSUI-AST" (Archimedean Screw Tractor) is a totally new type of vehicle for amphibian operation in and around ice-covered seas. It features a pair of cylindrical screw rotors attached to the bottom of the body. Movements from sea to ice surface and vice versa are no problem, and the vehicle also prossesses a remarkable ice-breaking capability.

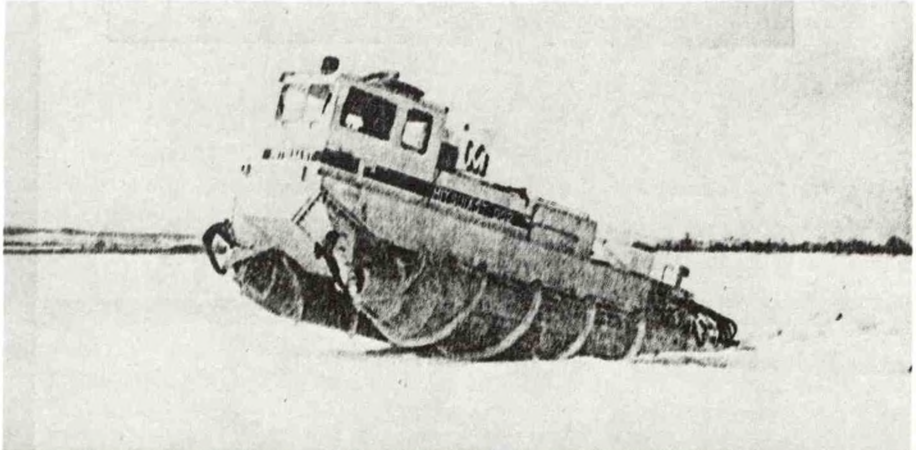
When the AST travels on water, its buoyancy is provided by the two cylindrical screw rotors. For propulsion, there is an inboard engine which rotates the rotors whose spirally arranged blades act as propellers.

When travelling on ice surface, these spiral blades dig into the surface. As the rotors rotate, the screw action of these blades causes the AST to move forwards.

Moving on from water to ice surface is quite simple. Once the foremost parts of the rotors are over the ice surface, the screw action of the blades enables the AST to crawl steadily onto the surface. If the ice is not thick enough to bear the AST's weight, the vehicle will continue to move on by breaking the ice, by rotating the rotors. Incidentally, MITSUI-AST's ice-breaking ability is far greater than that of any conventional ice-breaking vessel having equivalent horsepower. This has been confirmed by repeated tests in ice-covered seas.

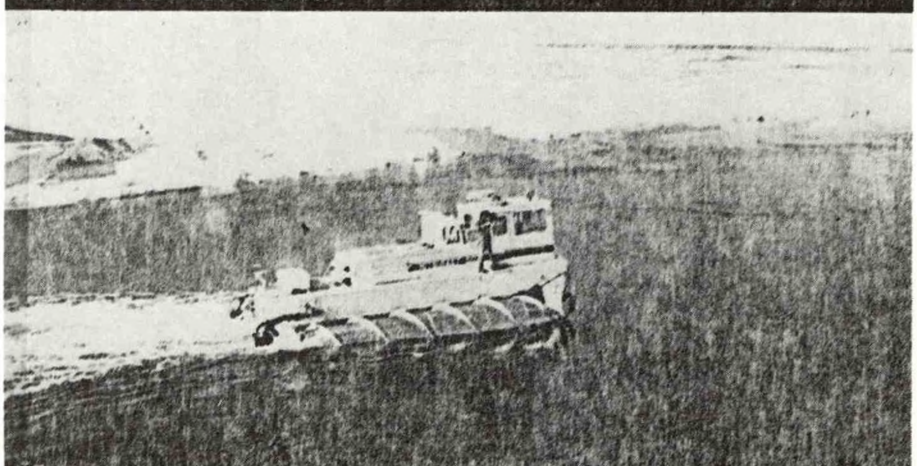
MITSUI-AST is also quite simple to operate, requiring no more than control of the revolution of the two rotors. It is safe and reliable, as it maintains good stability on water, even if floated on the buoyancy of only one rotor.

Mitsui started the development of MITSUI-AST in 1976. The first trial model, the AST-001, was completed in 1978 on the basis of various data obtained by the model tests in ice tank simulating arctic environment and in actual ice-covered seas. In the following year, a larger prototype, the AST-002, was completed. This prototype was put to various stringent trial runs and ice-breaking

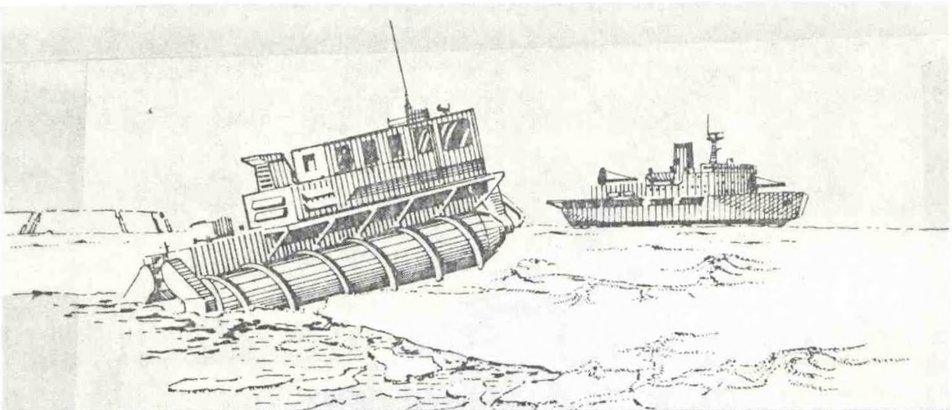


砕氷中の AST-002　AST-002 Breaking Ice

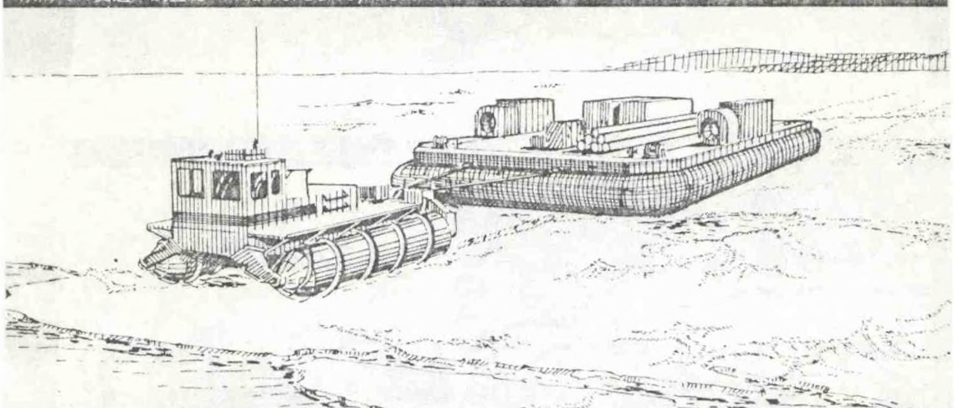
氷上のAST-002　AST-002 on Ice



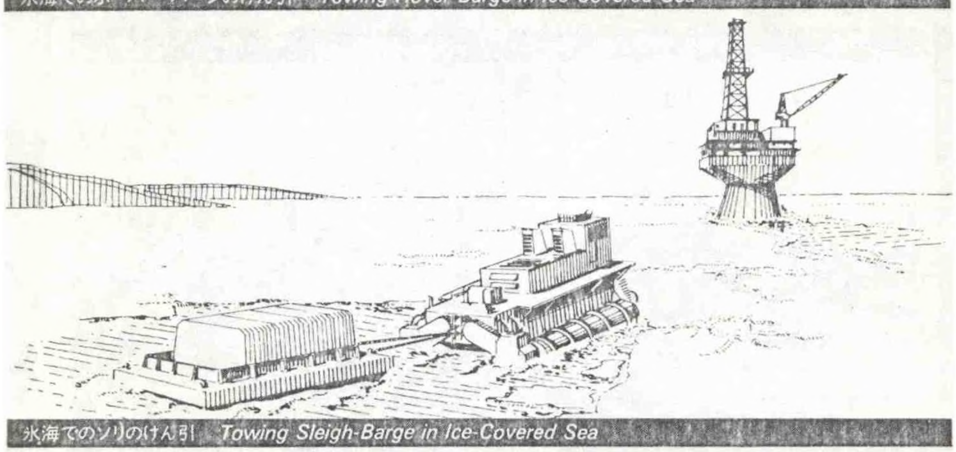
氷海航行中のAST-002　AST-002 Cruising in Ice-Covered Sea



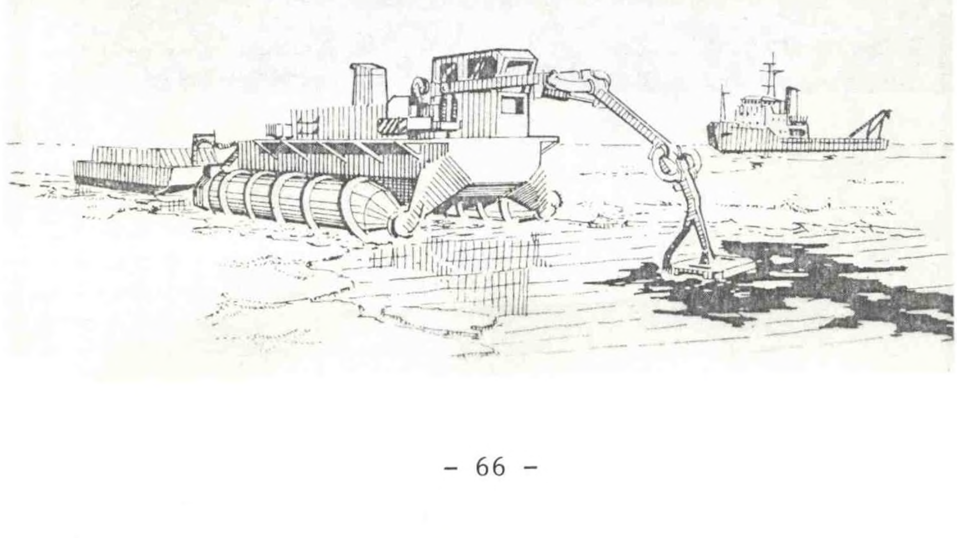
氷海での交通／調査艇　*Traffic/Survey Boat in Ice-Covered Sea*



氷海でのホーバー・バージのけん引　*Towing Hover-Barge in Ice-Covered Sea*



氷海でのソリのけん引　*Towing Sleigh-Barge in Ice-Covered Sea*

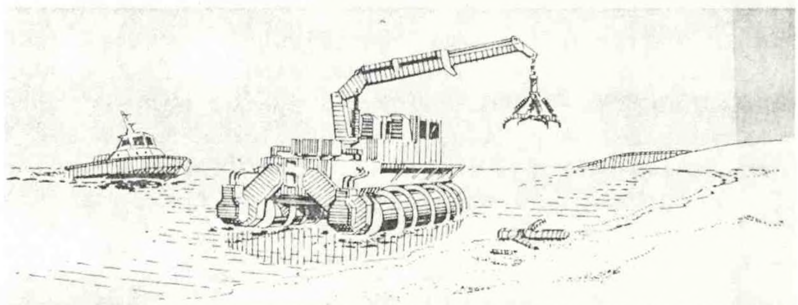


三井－ASTは湿地帯、泥ねい地においてもすぐれた走行性能、作業能力を発揮します。従来の作業車が近づけないようなぬかるみにも、ASTは難なく入って行くことができ、各種アタッチメントを装備することによって、作業の用途に応じた三井－ASTが考えられます。

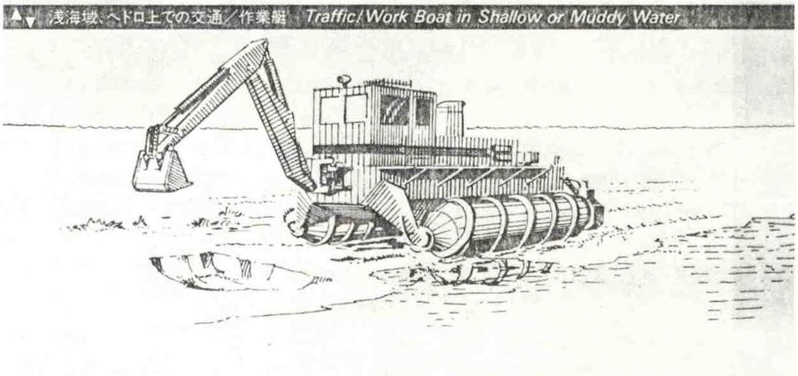
MITSUI－AST, moreover, gives excellent running and operating performances on swampy and muddy grounds. It has no problem in travelling in mires where all other conventional work vehicles fail to function. By providing it with suitable attachments, MITSUI－AST can be put to a wide range of uses.

AST-001の泥ねい地走行
AST-001 Running on Soft Mud

AST-001の湿原地走行
AST-001 Running on Marsh Land



▲▼ 浅海域、ヘドロ上での交通／作業艇 *Traffic/Work Boat in Shallow or Muddy Water*



主要目 Principal Particulars

		AST-001	AST-002
乗員 Number of Crew		2	5
重量 Weight (Tons)		1.6	10.8
構造材料 Material		耐食アルミニウム合金 Alminum	
寸法 Dimension (m) 全長L ×全幅B ×全高H		3.69 x 2.47 x 1.80	8.85 x 4.86 x 3.73
吃水 Draft in Water (m)		0.48	0.80
速力 Speed (Knots)	氷上 On Ice	Max. 4.8	Max. 6.0
	水上 On Water	Max. 3.1	Max. 4.3
ホラード牽引力 Bollard Pull (Tons)	氷上 On Ice	Max. 1.8	Max. 10.0
	水上 On Water	Max. 0.3	Max. 1.0
砕氷能力 Ice Breaking Capability	氷厚 Ice Thickness (cm)	15 (Sea Ice)	40 (Sea Ice)
	速力 Speed (Knots)	2	3
エンジン Engine		空冷2気筒4サイクルガソリンエンジン Air-Cooled, 2-Cylinder 4-Stroke, Gasoline Engine	空冷12気筒4サイクルV型ディーゼルエンジン Air-Cooled, 12-Cylinder 4-Stroke, V-Type Diesel Engine
		20 ps x 2 sets	305 ps x 1 set
トランスミッション Transmission		油圧及びチェーン Hydrostatic Transmission and Chain	油圧 Hydrostatic Transmission

PROGRESS FOR MANNED SUBMERSIBLE (DSV-2K SYSTEM)

Shinichi Takagawa
Deep Sea Technology Department
Japan Marine Science and Technology Center

Introduction

JAMSTEC has developed a 2,000 m deep submergence research vehicle "SHINKAI 2000" system. The construction including the sea-trials accomplished at the end of October 1981. Now by the use of this system, the training of the crew is being carried out. The mission diving will begin from 1983.

The SHINKAI 2000 system, the first integrated system for Japan, consists of three systems, i.e., the submersible SHINKAI 2000 constructed by Mitsubishi Heavy Industries Ltd., Kobe Shipyard, her support ship NATSUSHIMA constructed by Kawasaki Heavy Industries Ltd. Kobe Work, and the shoreside base. Its main activity areas is the research for geophysics, oceanography, mineral/ bio-resources, and the inspection of the underwater artificial structures.

Outlines of Shinkai 2000 System

Main features of this system are as follow;

1) This system is an integrated system having its own surface support ship.

2) The maintenance/supply system is well equipped on NATSUSHIMA so that NATSUSHIMA functions as a base on the sea. Therefore, SHINKAI 2000 can dive to 2000 m depth day by day during one cruise.

3) SHINKAI 2000 has good maneuverability.

4) The lower space in the pressure hull is designed to be so clear that even a non-trained observer can be in this hull for long hours without being tired by varying his/her attitudes.

5) The launch/retrieval system is so specially designed that the operations can be executed even at sea state 4.

6) This system has an integrated navigation system utilizing radio wave, satelite, and underwater acoustics effectively so that locating both the support ship and the submersible can be done precisely.

7) SHINKAI 2000 and NATSUSHIMA are designed to be very quite vessels so that the underwater acoustic support system works well.

General arrangements, photos, and principal characteristics of SHINKAI 2000 and NATSUSHIMA are shown in Fig. 1. and Fig. 2., Photo. 1. and Photo. 2. and Table 1. and Table 2. respectively. The construction of the shoreside base is now underway in front of the headquarters of JAMSTEC. The wharf for NATSUSHIMA will be completed in August 1982.

Schedule of the Sea-Trials of Shinkai 2000 System

After completion of construction, the submersible and the support ship were tested in dock or on the sea, respectively.

Dock tests of the submersible were carried out for the purpose of precise measurements such as velocity and acoustic signal or noise levels, etc. Sea-trials of the support ship were carried out for the purpose of the tests and the training of the launch/ retrieval operation using a dummy submersible, and for the purpose of precise measurement of noise emission. Of course, usual sea-trials as a surface ship were included.

Then, since May 1981, sea-trials of the total system were carried out following the schedule shown in Table 3. in order to ensure the performances of SHINKAI 2000 in deep water. The sea-trials were divided into five periods, each becoming deeper and deeper to 2000 m.

Items of the Sea-Trials

Items of the sea-trials can be divided into two tests. One is the matching test between the submersible and the support ship, and the other is the performance test of the submersible in deep under the support of NATSUSHIMA. In Table 4. the items of the sea-trials are shown. The sea-trials were finished in 15 October 1981 and the construction of this system was accomplished on 30 October 1981 by the delivery of this system to us JAMSTEC.

Results of the Sea-Trials

The sea-trials showed this system to have good performances. Especially the launch/retrieval system worked well even in sea state of 4. The noise reduction was very effective; the acoustic navigation system worked so well that communication by the underwater telephone was very clear, and the location measurement was very accurate.

The maneuverability of the submersible was fairly good and the atmospheric condition in the pressure hull and the attitudes of the crew were satisfactory.

In this sea-trial, the rescue buoy system was tested only for the releasing of the buoy and the retrieval in very shallow water. After the delivery, the test of the rescue buoy system was executed in water to a depth of 500 m showing very good performance. This test will be continued to 2000 m soon.

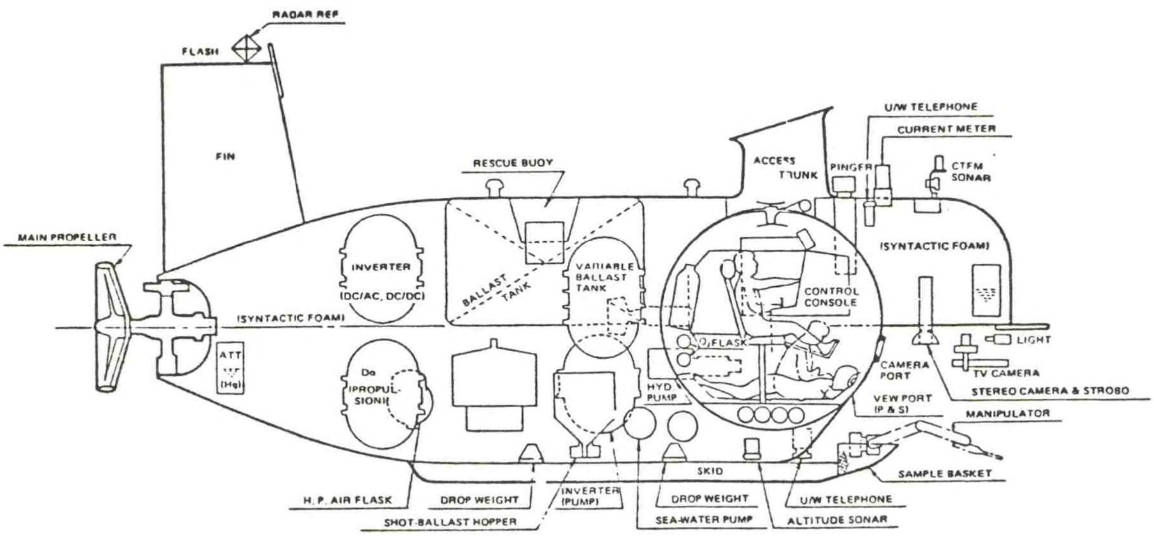


FIG. 1. GENERAL ARRANGEMENT OF SHINKAI 2000

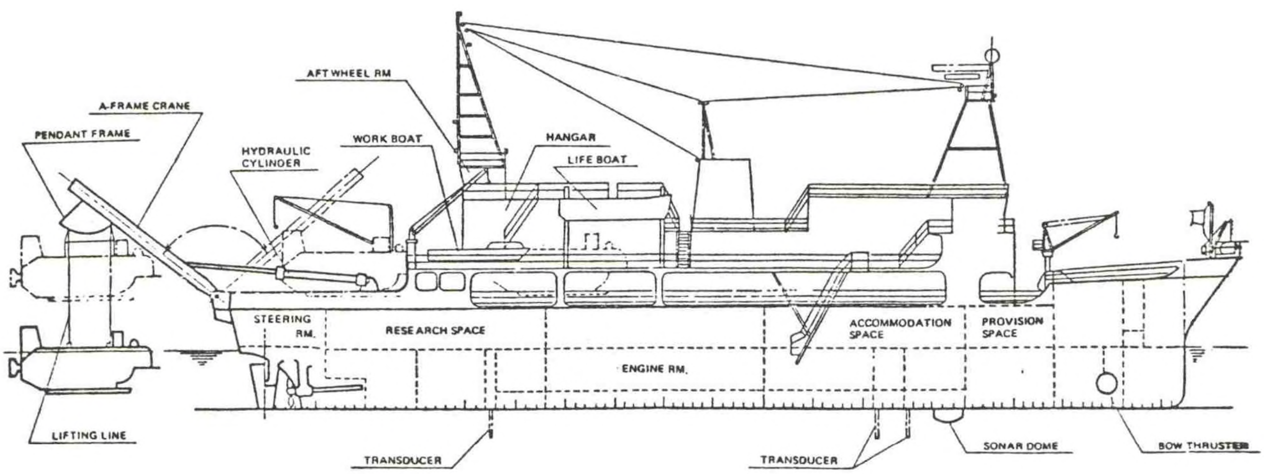


FIG. 2. GENERAL ARRANGEMENT OF NATSUSHIMA

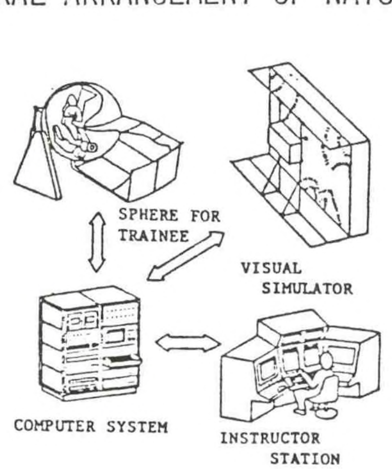


FIG. 3. OUTLINE OF TRAINING SIMULATOR OF SHINAKI 2000

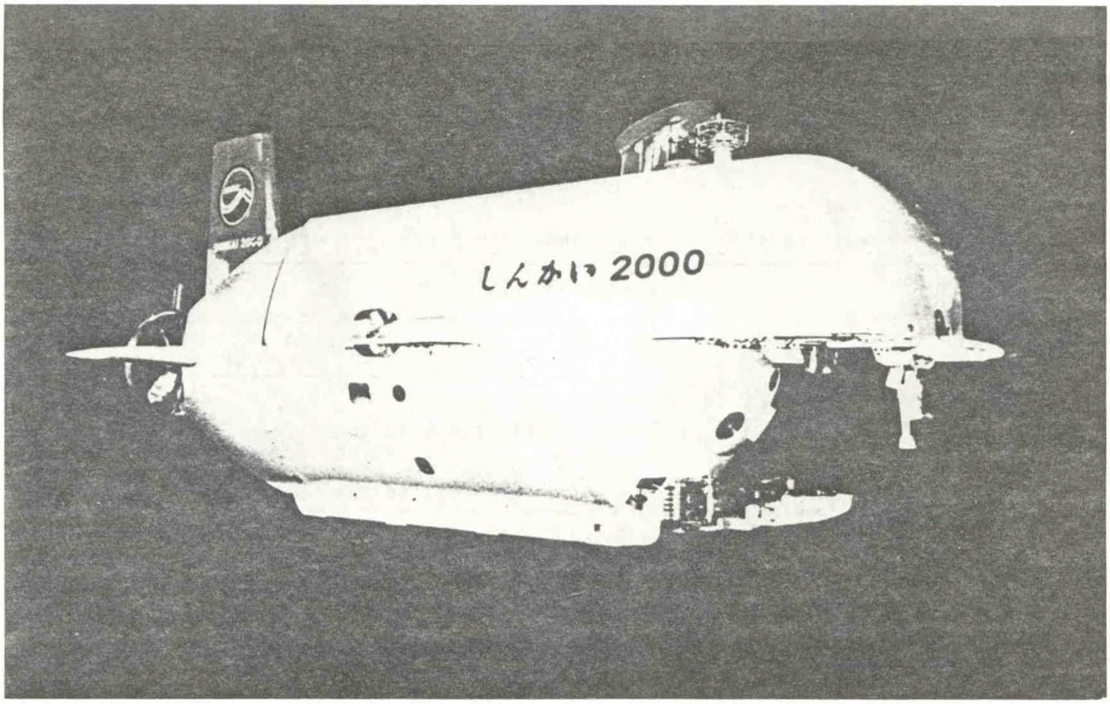


PHOTO. 1. SHINKAI 2000

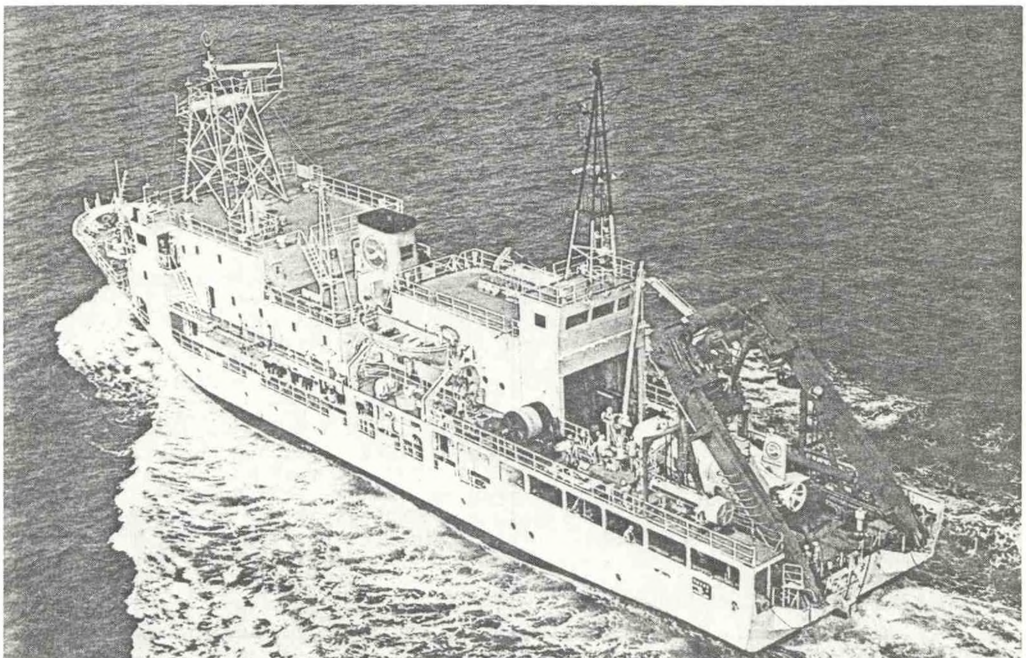


PHOTO. 2. NATSUSHIMA

TABLE 1. PRINCIPAL CHARACTERISTICS OF DEEP SUBMERGENCE RESEARCH VEHICLE "SHINKAI 2000"

PRINCIPAL PARTICULARS

Length (OA):	9.3m	Speed:	1kt (cruise)
Breadth (MLD):	3.0m		2.8kt (max.)
Depth (MLD):	2.9m	Crew:	2 Pilots
Draught:	2.5m		1 Observer
Weight (dry):	23.3t	Life	80hrs for
Operating Depth:	2000m	Support:	3 men
Collapse Depth:	3300m	Payload:	100 kg

POWER SOURCE

Main Battery:	Ag-Zn Oil-immersed Battery 108Vx570AH (1.5Vx285AHunit Cell x 72cells in seriesx 2 groups) at the 75th cycle of charge/discharge of this battery
Distributor:	Oil-immersed Pressure-compensated Type
Inverter:	6-settled in 3 pressure vessels (Ti-6Al-4V) for General Use (AC 115V, DC28V)/Propulsion (Main & Aux.)/Pump (Seawater Pump & Hydraulic Pump)

VIEWING

Dimension of Viewing:	ø120mmIDx2 for Viewport ;90°Cone ø80mmIDx1 for Cameraport;90°Cone
Television:	Black & White, Pan & Tilt x1
External Lighting:	500W Halogen Lampx6sets

EQUIPMENT

Manipulator (6 degree-of-freedom)/Still Camera/ Stereo Camera/ Current Meter/ STD

PRESSURE HULL

Material:	High Strength Quenched and Tempered Steel named NS90 ($\sigma_{y0.2\%}$= 90kg/mm²)
Dimension:	2.2mIDx30mmthickness sphere

PROPULSION

Main:	1x4kW AC Induction motor trainable ±60° horiz. at the end of the vehicle
Aux.:	2x1.5kW AC Induction motor trainable 90° vert. at the both side of midship

BALLAST/TRIM

Main Ballast System (Flood-in &	: 1.4m³x2
Air-Blow)/Compressed Air	: 225kg/cm²x43ℓ
Shot Ballast System	: 700kg (dry weight)
Dump Speed	: ab 5kg/sec
Variable Ballast System (Volume)	: 350ℓ
Seawater Pump	: 210kg/cm²x6ℓ/min
Trimming System	: ±10° (15'/min)
Trimming Pump	: 12kg/cm²x12ℓ/min

NAVIGATION & COMMUNICATION

Transponder/Pinger/Gyro Compass/Depth Gauge/CTFM Sonar/A-D Sonar/ B-D Sonar/Underwater Telephonex2 /VHF Radio/ Transceiver

EMERGENCY FEATURE

Jettisonable Weight (Drop Weight; 300kg, Manipulator, Basket, Hopper: Total 800kg)/Emergency Battery (Ni-Cd Enclosed Type, Settled in the Hull)/Rescue Buoy

TABLE 2. PRINCIPAL CHARACTERISTICS OF SUPPORT SHIP "NATSUSHIMA"

PRINCIPAL PARTICULARS

Class:	NK	Gross Tonnage:	1553t
Length (Lpp):	60.0m	Cruising Speed:	12kt
Breadth (MLD):	13.0m	Endurance:	8400miles
Depth (MLD):	6.3m	Accommodation:	30 (Ship's Crew)
Draught:	3.75m		25 (Ops. Pers.)
Propulsion:	Two CPP and two rudder/Bow Thruster		

INTEGRATED NAVIGATION SYSTEM

Surface Navigation:	NNSS/Loran-C/Doppler Sonar/E-M log and their hybrid navigation System
Submersible Tracking:	Long/Short/Super Short Base Line Underwater Acoustic Navigation System
Communication:	Underwater Telephone x2
Observation:	Side Scan Sonar/Echo Sounder/ STDV/XBT

LAUNCH/RETRIEVAL

Type:	Stern A-Frame Crane with Pendant Frame
Lifting Points:	2
Lifting capacity:	20tonx18m/min each
Lifting Rope:	ø85mmTetlon-Nylon Double Braided
Performance:	Normal/Emergency Sea State 3/4

SUBMERSIBLE MAINTENANCE & STORAGE SYSTEM

Maintenance System:	Battery Charger/Compressor/Hydraulic Test Unit/Electric-Electronic Check-out System
Power Supply:	AC115V 60Hz 1ø, DC28V
Storage System:	Hanger (13mLx10mBx7mH)/Trolley System/ Electric Hoist System

TABLE 3. SCHEDULE OF THE SEA-TRIALS OF SHINKAI 2000 SYSTEM

PERIOD	DATE	DEPTH	REMARKS
I	13～21 May 1981	25m ～ 100m	5 divings
II	1 ～ 9 June 1981	100m ～ 250m	6 divings
III	23 June ～ 2 July 1981	500m ～1250m	6 divings
IV	14 ～ 25 July 1981	1500m	4 divings
V	7 ～ 15 Oct. 1981	1500m～2000m	3 divings

TABLE 4. ITEMS OF THE SEA-TRIALS OF SHINKAI 2000 SYSTEM

TEST	CONTENTS
MATCHING TEST	o Launch/Retrieval System o Transponder & Pinger of SHINKAI 2000 o Locating by Acoustic Navigation System o Underwater Telephone o Minimum Detection Range by Radar o Tranceiver
SUBMERSIBLE PERFORMANCE TEST	o Ballast/Trim System * Ballast Tank Flood-in/Blow-out * Sea Water Pump System * Trim Adjust System * Shot Ballast System o Velocity and Maneuverability * Propulsion and Maneuvering * Forward Velocity * Forward/Backward Inertia * Up/Down Velocity * Up/Down Inertia * Turning o Navigation System * Forward Obstacle Avoidance Sonar(CTFM Sonar) * Acoustic Bearing Detection Sonar * A/D Sonar * Fathometer o Observation/Measurement System * STD * Current Meter * Manipulator * Light * TV Camera * Stereo Camera o Rescue Buoy Release Test o Noise Measurement o Test Diving to the Maximum Operation Depth

Trainings

After delivery of the submersible system, training of the launch/retrieval operation was carried out by the crew of NATSUSHIMA and SHINKAI 2000 using the dummy submersible. In parallel with this training, the crew of SHINKAI 2000 were trained for maneuvering by using the the newly developed simulator. Fig. 2 shows the outline of this simulator.

From April 1982, by the use of this submersible system, training of the crew is being carried out on the sea by making the depth deeper and deeper following the schedule shown in Table 5.

Unmanned Vehicle for the Rescue Operation

Safety is the most important factor for the manned submersible system. A rescue buoy system can be applied to the unexpected weight increase of the submersible SHINKAI 2000; however, it cannot be applied to the entaglement accident with the ropes or fishing nets. In order to cope with such a situation the development of an unmanned vehicle which can be applied to the rescue operation is programmed. Construction will start in 1983.

Conclusions and Prospect to 6,000 Vehicle

This system is a first integrated deep-submergence research vehicle system for Japan. Many research workers place their expectations on the operations of this system. We at JAMSTEC will reply to the expectations with much fruitful results.

By the success of the development of this 2000 m vehicle system, we could obtain techniques, knowledge, and experience through design, construction, and operation of this system. Now we at JAMSTEC are planning to develop the 6,000 m deep submergence research vehicle system using the above mentioned techniques.

TABLE 5. FY1982 SCHEDULE ON TRAINING DIVE OF SHINKAI 2000

	Voyage	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1982 APR	50 ~ 130 m SAGAMI BAY (5–16); 130 ~ 340 m SAGAMI BAY (21–28)						#1	#2		#3		#4		#5	#6								#7	#8			#9	#10				×
MAY	300 m SAGAMI BAY (20–31)																					T	#1		#2		#3		#4		#5	
JUN	(1–3); 500 m SAGAMI BAY (10–22); (30)		#6								#7		#8		#9		#10		#11			#12									#13	×
JUL	500 m SAGAMI BAY (1–8)		#14			#15		#16																								
AUG	500 m SAGAMI BAY (1–20)			T	#1		#2		#3		#4		#5		#6		#7		#8													
SEP	1400 m SAGAMI BAY (1–15); 2000 m SURUGA BAY (24–30)			#9			#10		#11		#12	#13		#14														#15		#16		×
OCT	ANNUAL INSPECTION (7–30)																															
NOV	ANNUAL INSPECTION (7–30)																															×
DEC	ANNUAL INSPECTION (7–30)																															
1983 JAN	100 m ~ SAGAMI BAY (11–22)											#1	#2		#3	#4		#5		#6		#7										
FEB	600 m ~ 1000 m SAGAMI BAY (7–25)									T	#1		#2		#3		#4		#5		#6		#7		#8					×	×	×
MAR	600 m ~ 1000 m SAGAMI BAY (1–17)		#9		#10		#11		#12		#13		#14		#15		#16															

REMARKS #N IS THE NUMBER OF TRAINING DIVE IN ONE VOYAGE, T IS THE TEST DIVE.

RESEARCH AND DEVELOPMENT OF A 5,000 m DEEP OCEAN FLOOR SURVEY SYSTEM

Hiroshi Hotta, H. Momma, K. Ohtsuka,
T. Tsuchiya, and T. Nakanishi
Japan Marine Science and Technology Center

Abstract

Since 1977, JAMSTEC has been developing a Deep Ocean Floor Survey System (DOFSS, JAMSTEC/Deep Tow) under a contract with the Science and Technology Agency for the radioactive waste dumping program.

The system consists of four subsystems; an acoustic investigation subsystem, and optical observation subsystem, an acoustic transponder navigation subsystem, and a towing gear subsystem. The system has been tuned up to successfully obtain information on the deep sea floor micro-topography and sub-bottom microstructure for five years.

We had many troubles in the system during the development period. One of the most serious troubles was in failure to recover deeply moored transponders. However, we succeeded in retrieving one of them by deep trawling, hooking it up, and determining the cause of trouble.

Recently, the system was applied to a research program of tectonic activity in the northernmost part of the Phillippine Sea Plate because it has a capability to survey very fine-scale topography of the deep-sea floor and sub-bottom structure beneath the floor.

Introduction

The Japanese Government has a plan to dump the low-level radioactive wastes into the deep waters in the Northwestern Pacific Basin. In order to promote the plan, it was recognized that some surveillance system should be developed to confirm the distribution and condition of dumped canisters at the site. JAMSTEC had a contract to research and develop such a system with STA in 1977.

Outline of the System

The detailed search for artificial targets on the deep ocean floor was carried out by towing a frame which is equipped with side-scan sonar, sub-bottom profiling sonar, TV, still cameras with lights and strobes, and a submergence relay transponder. The towed frame is lowered close to the sea floor about 100 m or less in height by double-armored coaxial cable 8,000 m long and

17.2 mm in diameter. Electric power and command signals are sent down to the subsurface instruments through the cable. Information on the sea floor is sent back to the surface also through the cable. The positions of the towed frame and the towing vessel are accurately fixed by the acoustic-transponder navigation system. MPL/Deep Tow of Scripps Institutions of Oceanography is apparently referred to the conceptual design of this system.

Construction of the System

1. Acoustic Investigation Subsystem

A. Side-Scan Sonar specifications

Frequency	100 KHz
Pulse Width	0.1 ms
Horizontal Beamwidth	0.5^{o} or 1.0^{o}/alternative
Vertical Beamwidth	35^{o} or 55^{o}/alternative
Source Level	129 dB p-p (re 1 ubar at 1 m)
Recorder	Graphic recorder of dry paper type/Magnetic analogue data recorder

Dip angle of the transducers are remotely controlled from the deck unit.

B. Sub-bottom Profiling Sonar specifications

Frequency	3.5, 4.5, 5.5, 7.0 KHz/Selective
Power Output	0-10 kw/adjustable
Beamwidth	55^{o} at 2.5 KHz
	48^{o} at 4.5 KHz
Beamwidth	38^{o} at 5.5 KHz
	30^{o} at 7.0 KHz
Pulse Width	0.1 ms
Source Level at 10 kw	Up to 111 dB p-p

C. Depth and Altitude Detector

The depth of the towed frame is detected by the electro-statical capacitor transducer and the altitude is measured by detecting the first echo of the sub-bottom profiling sonar from the sea floor. These data are also sent to the deck unit in real time and recorded on a magnetic data recorder.

D. CTD

Conductivity, temperature, and depth of the survey area area are measured by the CTD Sensor. These data are sent to the processor on the deck unit by frequency-division multiplexing and used to calculate average vertical velocity of sound.

2. Optical Observation Subsystem

This subsystem consists of a black and white TV camera, a 25 mm still camera, and a 70 mm still camera.

A. Deep Sea TV Camera

A Newvicon image tube is used for the camera. The fast scan video signal is sent to the deck monitor in real time, so, the sonar subsystem is switched off when the cameras are used. Resolution of a monitor display is about 220 lines through a coaxial cable of 8,000 m length. Two 250 w thallium-iodide lights are used for illumination. The light sensitivity of the camera is about 0.5 lux.

B. 35 mm still camera

About 750 photographs can be taken at one load. A 100 wsec strobe light is used for the camera.

Both cameras are actuated remotely from the surface.

3. Acoustic Transponder Navigation Subsystem

A transponder navigation system is used for precise short-range navigation using underwater transponders as the bench-marks. Three transponders are usually deployed in the survey area. The transponders reply with a unique signal which is received at the ship for a common interrogate signal transmitted from the ship or submergence relay transponder. The return signal is fed into a precessor/plotter which converts the raw data into a position fix and graphically plots the tracks of the ship and towed frame on a X-Y recorder.

4. Towing Gear Subsystem

A sheave suspended in the gimbals was designed and built in order to reduce abrasion or breakage of the towing cable, especially during a quick change in course. The mechanism makes the sheave easier to follow the cable motion than the conventional one by rotating around tri-axes. Two guide arms also help the sheave follow the cable motion. Accurate measurement of tension is made by means of a shear-pin-type of load cell on the sheave and angle sensors. The sheave is attached to an A-frame crane which is electro-hydraulically driven. One of the most important keys to success in retrieving a troubled transponder from 6,2000 m was in this towing gear subsystem.

Examples of Results

A. First preliminary trial at sea

The first trial at sea was carried out in the shallow waters off Atami city. Fig. 4 shows an example of a sonar record of an outcrop of basalt surrounding sandy sediments off Hatsu-shima inlet.

Sonars were towed at a constant depth of about 10 m from a small boat. Weak effects of yawing were sometimes recognized on the other records.

B. Second preliminary trial at sea

In 1979 the second trial of the system was completed in waters approximately 1,500 m deep in the Sagaminada. On the western gentle slope toward the Sagami Trough some round shaped hummocky outcrops were recorded (Fig. 5). The rocks inferred volcanic extrusion along the fissures.

C. Second trial in the Northwestern Pacific Basin

We tried to make the first trial in waters of 6,200 m depth in 1980. However, many serious troubles occurred in the underwater connectors, pressure housings, electronic circuitries, and so on. Moreover, we were forced to leave the area for a few days by a typhoon. Very poor results were obtained at this trial because of the loss of many days for those reasons. Three transponders did not come up.

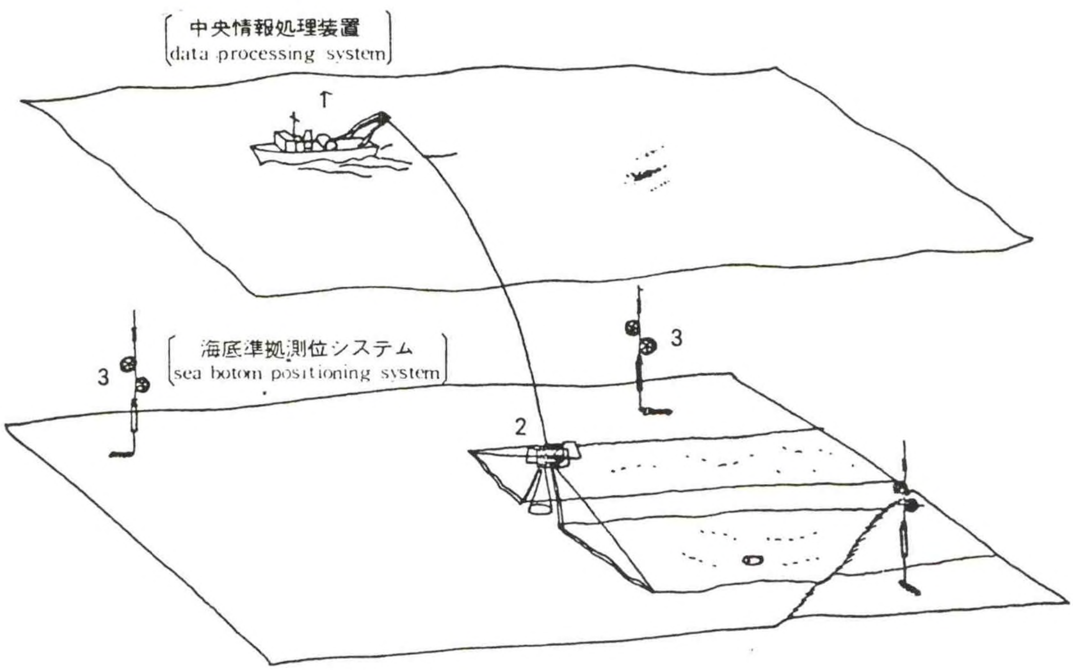
In 1981 the second trial was carried out. Almost all subsystems worked fairly well with less troubles, although typhoons attacked us twice. At the end of this trial we tried to retreive one of three transponders which was alive by deep trawling and fortunately succeeded to hook it. The reason for the trouble was identified as a malfunction in the release mechanism.

D. Detailed survey of the micro-topography and geological structure

The first applied program for the earth sciences of the system was proposed by STA in 1980. It is convinced that a big earthquake will occur in the Tokai district as a result of interaction between the Asian Plate and the Philippines Sea Plate. In order to promote the study on earthquake prediction, STA started a joint research program on the tectonic activities in the northern most part of the Philippine Sea Plate entitled the forthcoming "Tokao Earthquake."

A very fine-scale topographic and structural survey by the system is adopted as one of the items of the program, and the results will be used for the site selection to dive a manned submersible," Shinkai 2000," in the near future.

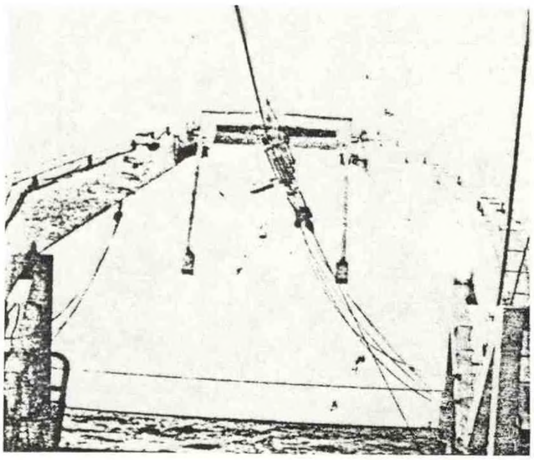
Examples of the sonographs and photographs in the Suruga Bay which is part of the Philippine Sea Plate are shown in Fig. 7 through 10.

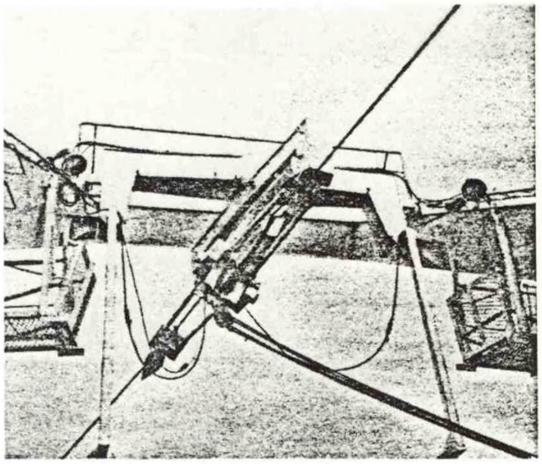


1. 曳航装置（船）　towing gean on the ship
2. 曳　航　体　towing frame with sonars and cameras
3. トランスポンダ　transponder

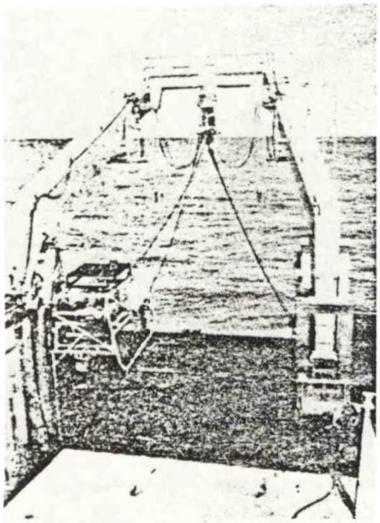
図1　深海底探索調査システムの概念図

Fig.1 Schematic illustration of the Deep Ocean Floor Survey System

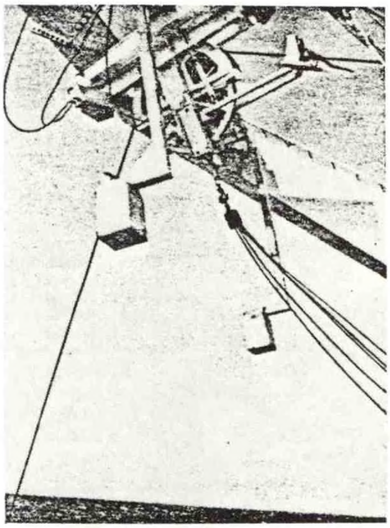




(3) 船の回頭中（左；昭54，右；昭55）
（シーブとケーブル面とがよく一致している）
Sheave coincide well with cable plane
(left 1979, right 1980)



(1) 曳航装置の全景（昭55）
A-frame crane and sheave.



(2) ジンバル式シーブ（昭54）
Gimbal suspended sheave
with guide arm (1979)

写真3 曳航装置の海洋実験（その1）
Fig.2 Sea trial of the towing system (part 1)

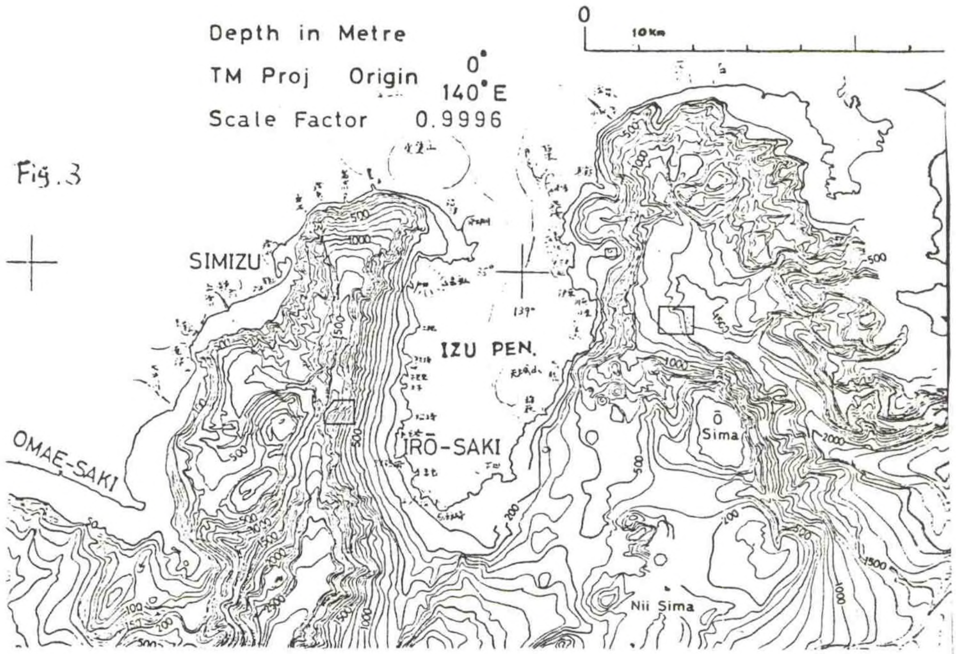
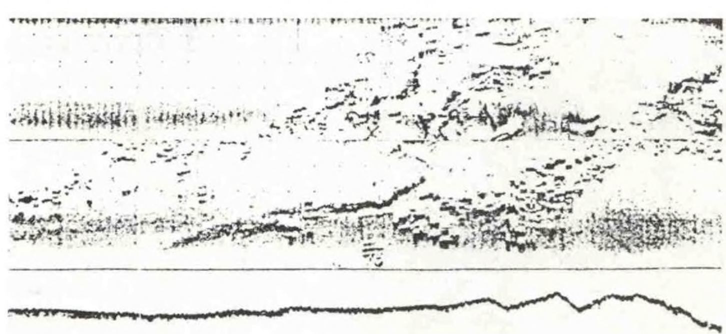


Fig.3

曳航体の進行方向は左から右である。
サイドスキャンソーナーのレンジは両舷 150 m，サブボトムプロファイラのレンジは 75 m
右舷は白黒反転させて記録した。
Vehicle was towed from left to night. Range for side sean sonar display is 150 m per side and range for Sub-Buttom Profiler is 75 m. The gray scale of the starboard image was inverted.

写真10　初島沖のサイドスキャンソーナーおよびサブボトムプロファイラによる記録例

Fig.4 Example of side scan sonar and Sub-Bottom Profiler imager off Hatsushima island.



写真の中央に段差がはっきり認められる
It can be seen clearly that there is a difference in level at starboarol side

写真12　写真11の右舷の記録の白黒反転写真

Fig 5 Inverted images of the starboard in photo. 11

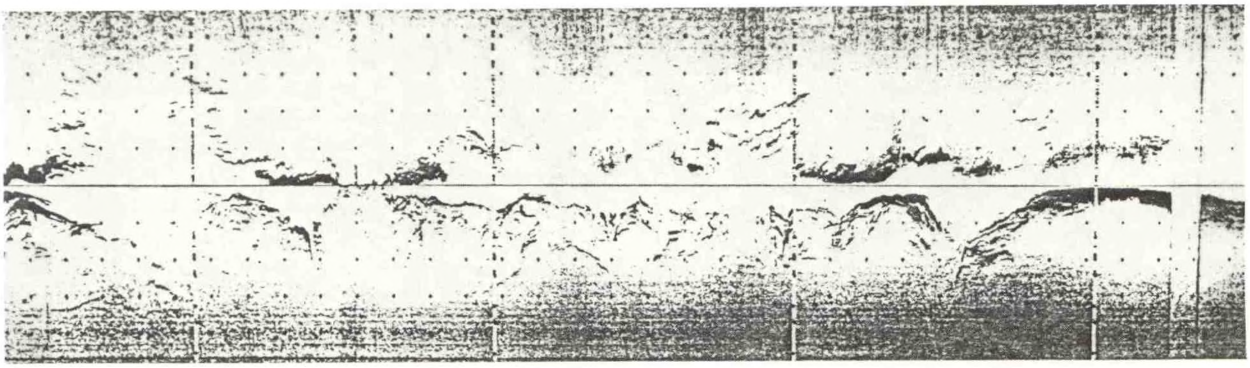


Fig. 7

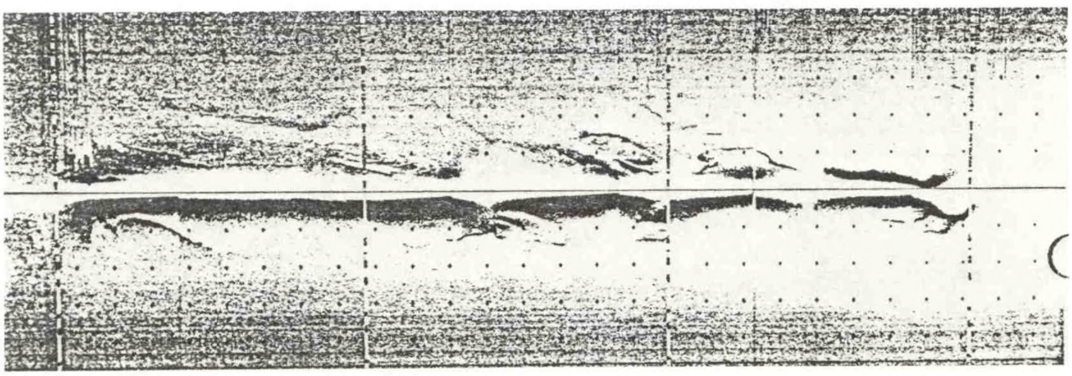


Fig. 8

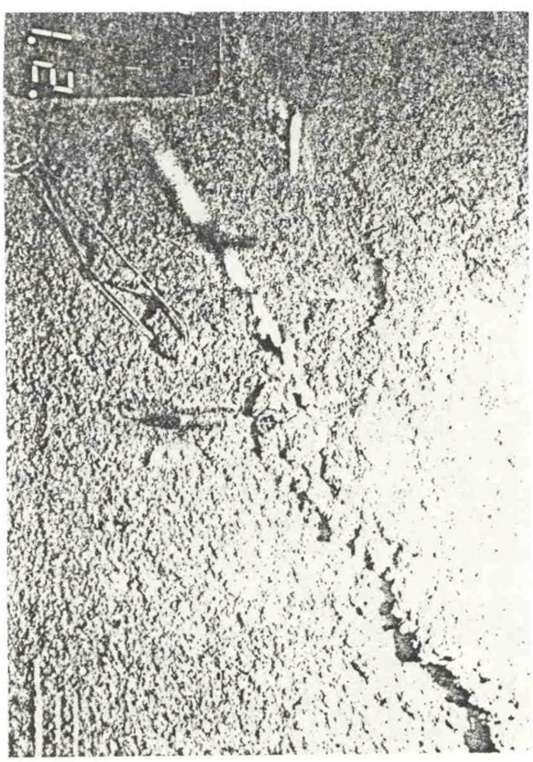


Fig. 9

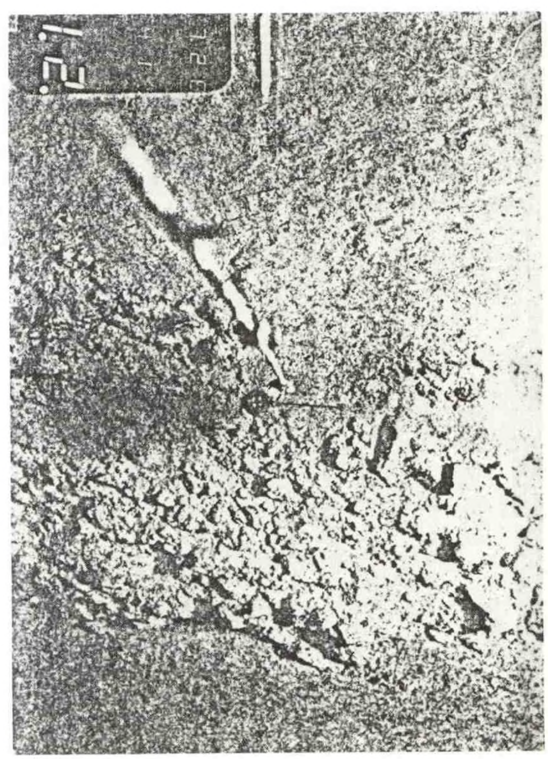


Fig. 10

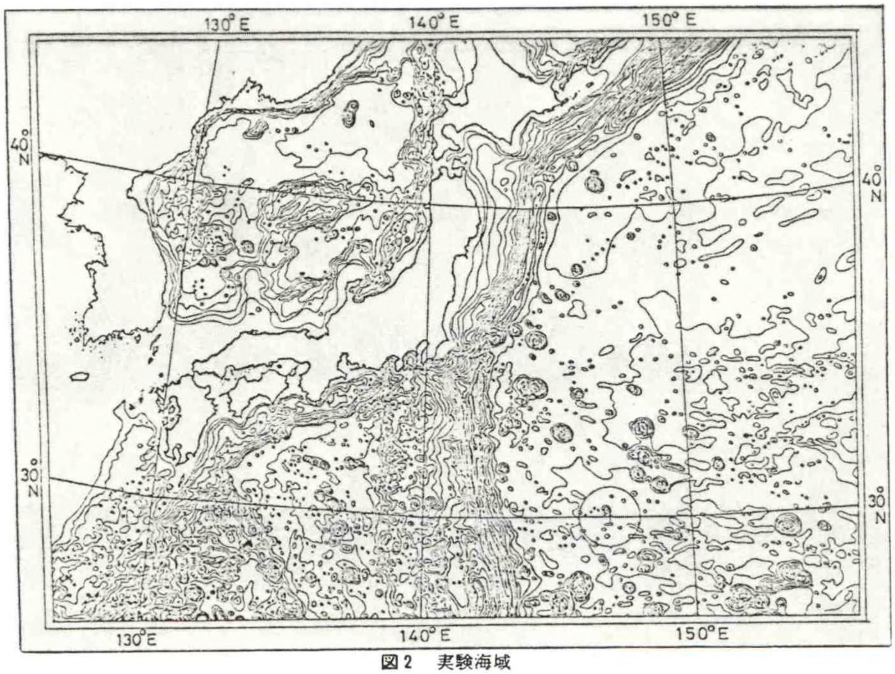
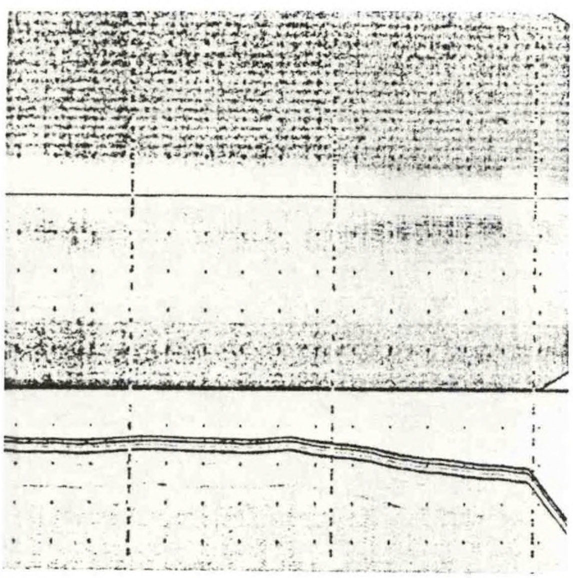
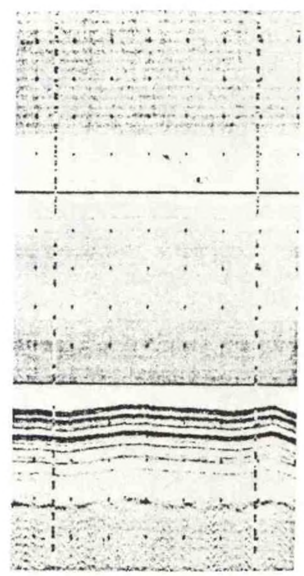


図2　実験海域

Experiment area in the bathymetric chart (J.H.O. No. 6901)



(a)　サイドスキャンソーナーのレンジは両舷 600 m
サブボトムプロファイラのレンジは 300 m
range for side scan sonar display is 600 m
range for sub-bottom profiler display is 300 m



(b)　サイドスキャンソーナーのレンジは両舷 600 m
サブボトムプロファイラのレンジは 150 m
サブボトムプロファイラのオフセットは 60 m
range for side scan sonar display is 600 m
range for sub-bottom profiler display is 150 m
and offset is 60 m

測定日，data ; 1981年7月26日， 26. July 1981

写真14　北西太平洋の水深約 6,200 m の海域のサイドスキャンソーナーおよびサブボトムプロファイラの記録例

Fig.6 Examples of side scan sonar and sub-bottom profiler images at the site of 6,200 m depth sea trial (N 30°, E 147°)

OPERATION OF MURS-300

I. Mutoh
Mitsui Ocean Development and
Engineering Co. Ltd.

The MURS-300 (MODEC Unmanned Remote-Controlled Submersible for 300 m water depth) system consists of the following major modules (see Fig. 1):

1. Submersible with a CTFM sonar, color and monochrome TV cameras, and a manipulator system (see Fig. 2, and photo 1).

A. Size	:	2.73 m(L) x 2.06 m(W) x 1.85 m(H)
B. Weight	:	2,600 kgw(in air), 10 kgw(in water)
C. Maximum operating Depth	:	300 m
D. Maximum speed	:	about 3 KTS on surface

2. Control Van with a two-man operated control console and a power supply panel (see Fig. 3, and photo 2).

A. Size	:	5.2 m(L) x 2.4 m(W) x 2.4 m (H)
B. Weight	:	3,500 kg

3. Cable winch with 500 m tether cable (photo 3).

A. Size	:	3.6 m(L) x 1.8 m(W) x 2.48 m(H)
B. Weight	:	3,500 kg
C. Type	:	Electoro-hydraulic drive
D. Tether cable	:	28 m/m x 500 m Kevlar armoured composite cable

Operation results (Ref. Fig. 4)

Development of MURS-300 started in April 1977 and was completed in April 1979 with temporary buoyant material. The first sea trial was carried out in August 1979 to check its system function, and was finished satisfactorily up to 68 m depth. (This was introduced at the last UJNR meeting at Tokyo in 1979, photo 4.) After that, some demonstration work and a 300 m depth test dive were done. In September 1980, the buoyant material was changed to syntactic foam with specific gravity of 0.32.

The first actual job was a survey of sea bottom cable in 2,000 m length at a maximum water depth of 60 m at Seto Inland Sea in September 1980. (photo 5,6). The second job was a survey of a dam wall and water intake mouth at a maximum depth of 90 m in March 1981. From this job, a new cable winch with power sheave

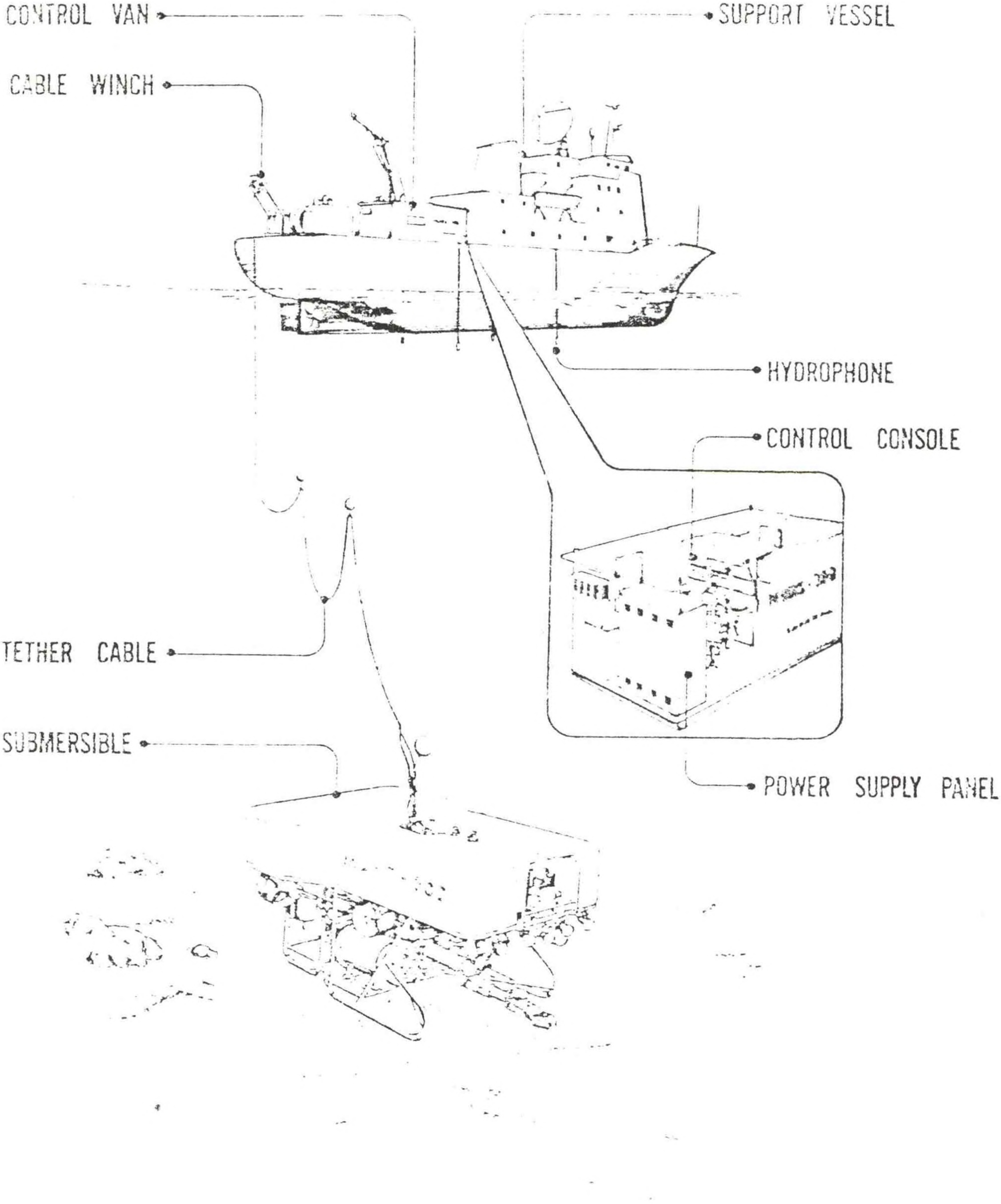


FIG.1 SYSTEM CONFIGURATION

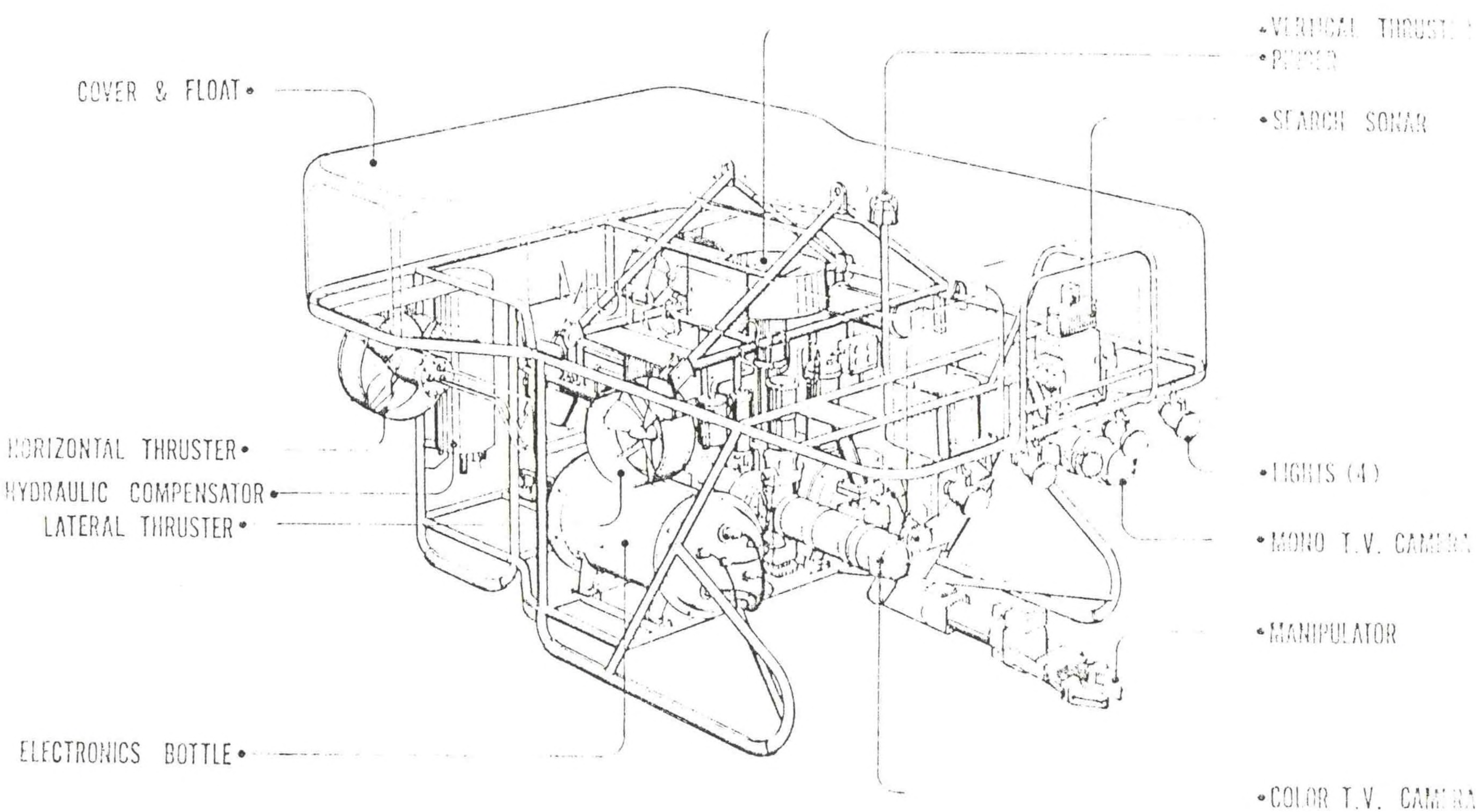


FIG. 2 SUBMERSIBLE

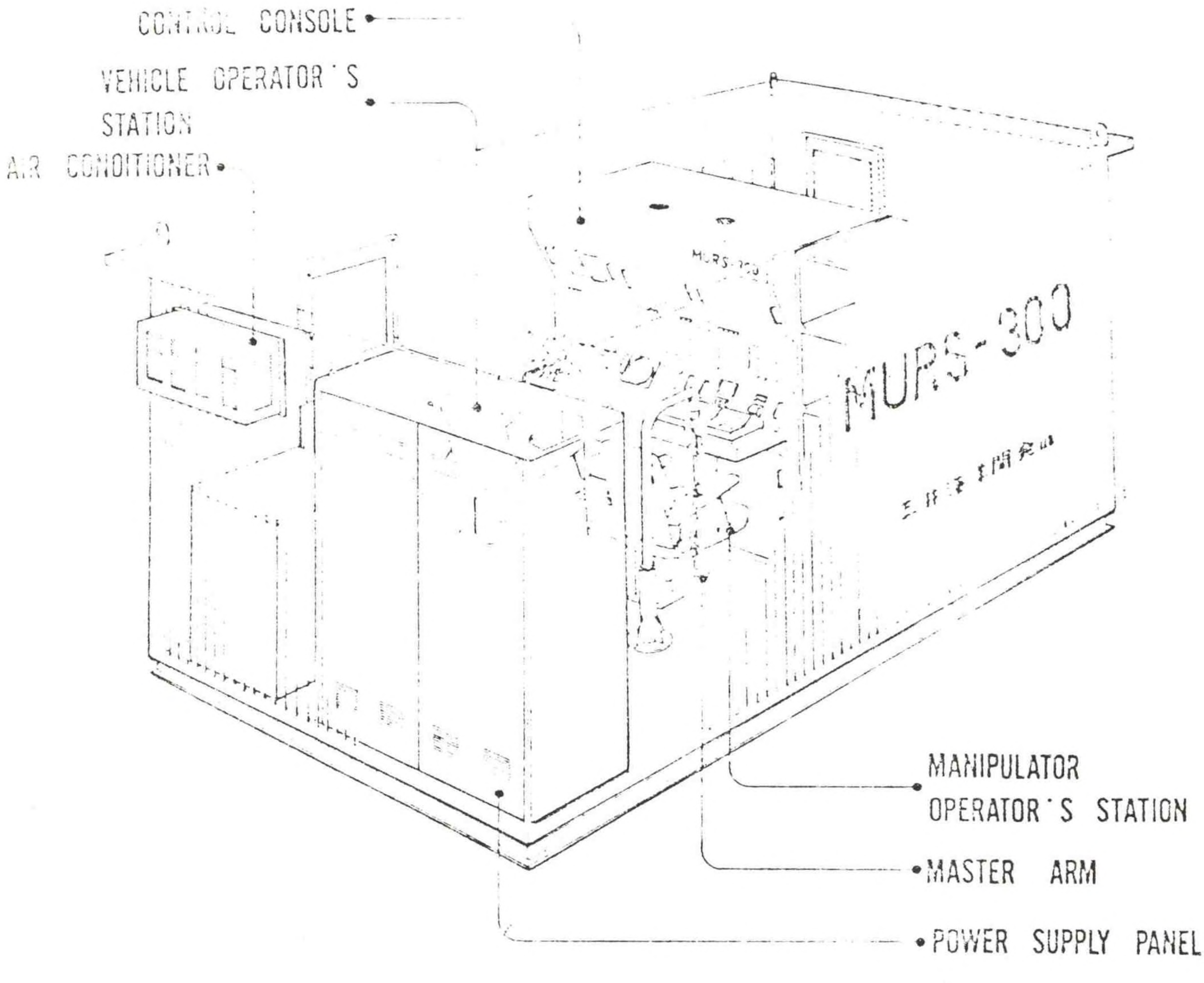


FIG.3 CONTROL VAN

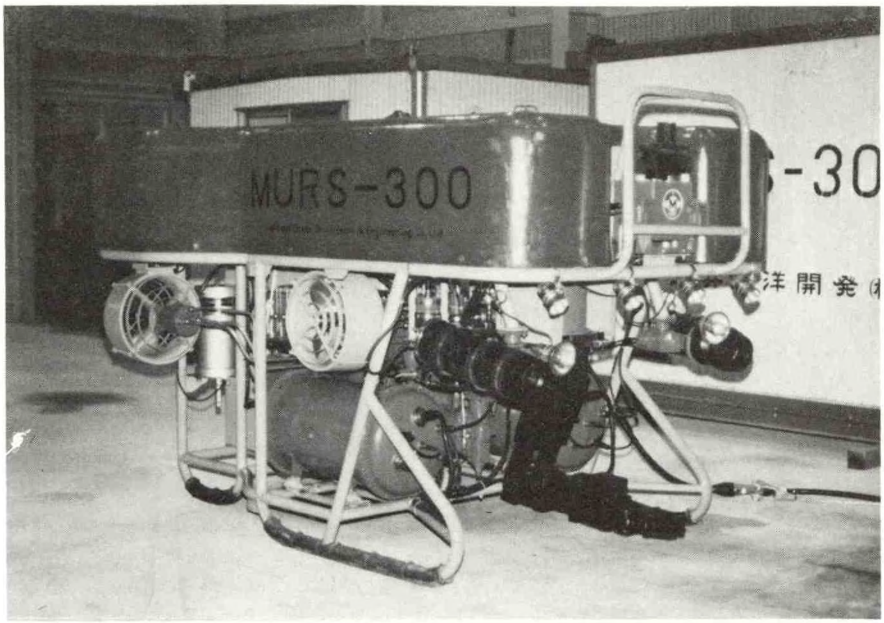


Photo 1. MURS-300

Photo 2. Control Console

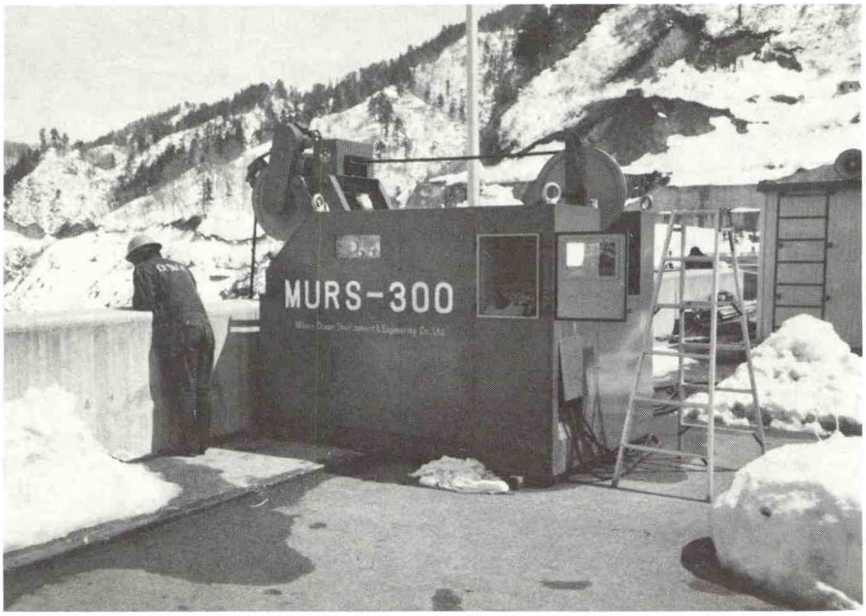


Photo 3. Cable winch

Photo 4. (Job No.1)

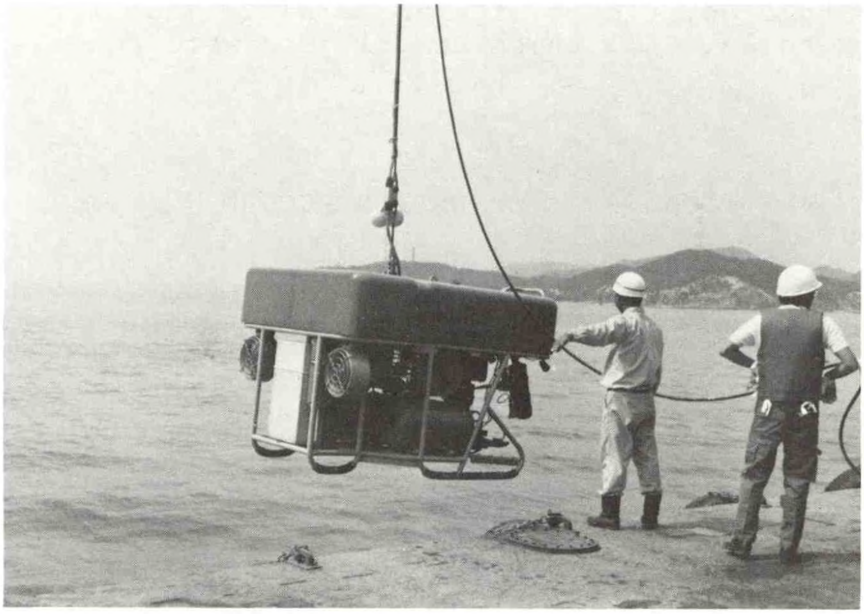


Photo 5. (Job No.7)

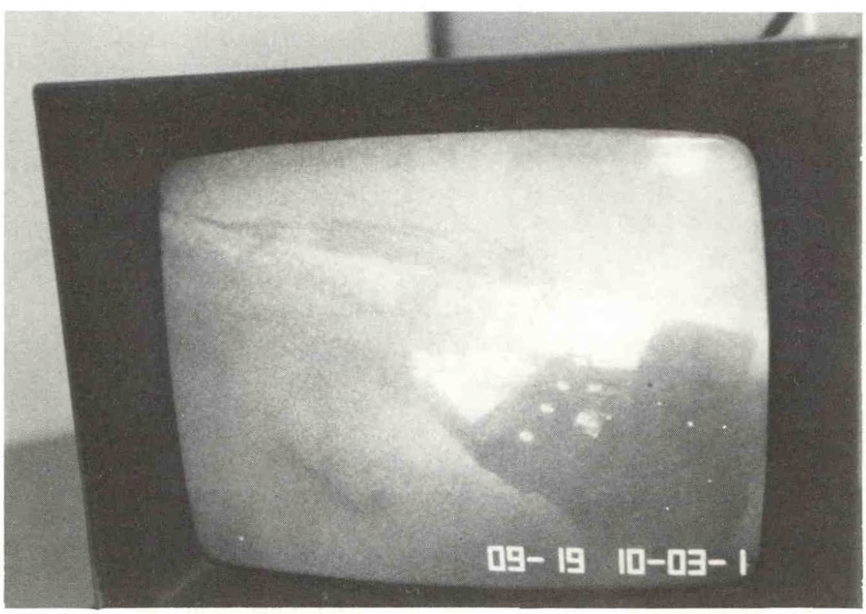


Photo 6. (Job No.7)

was equipped. The third job was an inspection of a water intake mouth of a dam at a maximum water depth of 60 m in April 1982 (photo 7). In this case the maneuvering system of thrusters was modified to a single joystick system and a newly made water resistant tether cable. All these actual jobs were done very successfully.

FIG. 4 MURS-300 OPERATION RECORD

No.	Date	Area	Depth (m)	Diving Time(h)	Object	Remarks
1	1979.8	Sagami Bay in Shizuoka Pref.	68	7.5	Test dive	Temporary buoyant material
2	1979.9	Niigata Port in Niigata Pref.	16	11	Demonstration and bottom survey	"
3	1979.11	Nagoya Port in Aichi Pref.	10.5	4	"	"
4	1980.2	Sagami Bay in Snizuoka Pref.	309	2.5	Test dive	"
5	1980.3	Seto Inland in Kagawa Pref.	35	4	Demonstration and bottom survey	"
6	1980.9	Tokyo Bay	9	1	Test dive	Syntactic foam material
7	1980.9	Seto Inland in Okayama Pref.	61	14	Cable survey	
8	1981.3	Lake AZUSA in Nagano Pref.	90	5.5	Dam survey	Cable winch
9	1982.4	Lake OKUTONE in Gunma Pref.	60	8.3	Inspection of dam water intake mouth	Joystick handling, new tether cable

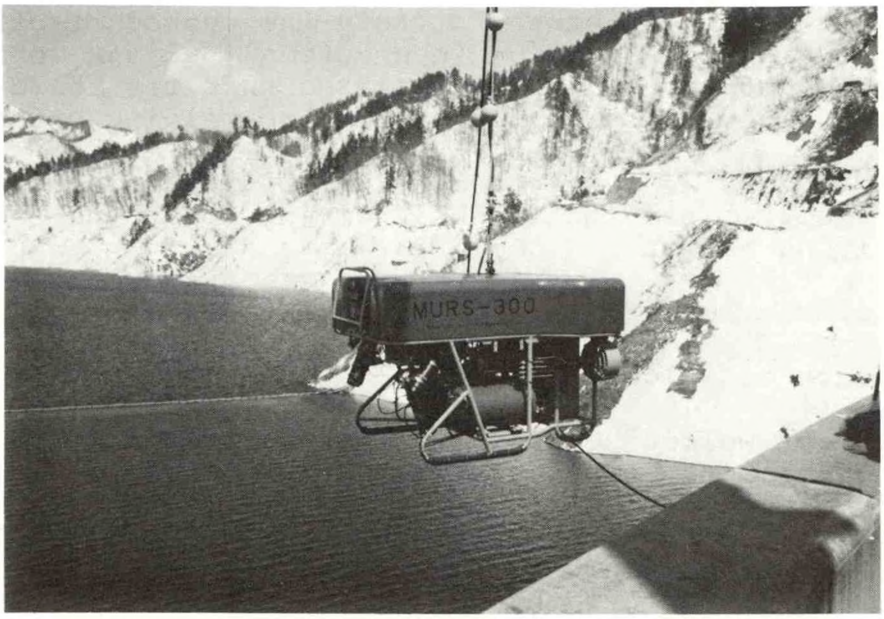


Photo 7. (Job No.9)

UNDERWATER WELDING IN PRACTICAL SALVAGE WORK

Yasumasa Kawahara
Nippon Salvage Co. Ltd.

It is said that the history of welding in Japan dates back to the period of World War II but it is not certain. In 1958 we, the Nippon Salvage Co. Ltd., began to study the method of utilizing underwater welding for adoption in practical salvage work. At the early stage of our study, we realized that the following problems must be solved to perform electric arc welding underwater.

1. Electric shock (as it may arise) which divers may be exposed to and electric erosion to their diving apparatus; especially their diving helmet.

2. Anti-electric leakage type of equipment (welding holder, etc.)

3. Kind/nature of welding electrode.

4. Intensity of welded section and extreme fragility caused by sudden cooling.

Although all of the above problems appear to have been clarified and looked upon as common knowledge today, we had tried in the past to solve each of them through repetition of trial and error after obtaining some know-how from relevant domestic and foreign documents. We have finally succeeded in putting underwater welding into practical use in 1965. Since then, we have endeavoured to acquire more advanced technical skill and improved equipment, and we now today have great confidence in performing high class underwater welding any place where divers could possibly work.

We shall hereunder report the course of our successful achievements and shall display some of our slides showing what we have actually performed in this respect.

Underwater Welding

With regard to the technique of underwater cutting by oxy-arc method, we have had it mastered and put into practical use since 1946. It is our understanding from experience that, if it is diving work, at least with helmet-type equipment, the problem of electric shock to divers or electric erosion to diver's equipment which may occur in the water could be practically solved with use of low voltage direct current. We, therefore, carefully studied the reaction of the divers while working, and we found that there is no appreciable problem at present in this respect.

One of the most important issues was how to maintain a certain percentage of intensity in strength of the welded section under abrupt cooling by sea water as compared to that of welding on shore under a normal atmosphere. It was readily assumed that the question of unavoidable defects such as blowhole and undercut caused by abrupt coldness at the welding section combined with the inconvenient posture in which divers would usually have to work underwater, would remain. One possible way of solving the above problem basically, is to install a watertight chamber in way of the section to be welded and by means of which welders can carry out welding as they do ashore. Another countermeasure would be "Gas sealing" of the spark section which is assumed to generat- a blowhole when the portion of melting pool contacts the sea water directly. It is our understanding that the method is already put into practical use as a result of several experiments by other concerns.

However, it is our view that in a case where an emergent salvage attendance is required which calls for underwater welding by divers, it is necessary that the following requirements be met:

a. Gear/equipment to be used should be readily available in view of the nature of the emergent service.

b. Gear/equipment to be used should be light in weight and easily transported.

c. In comparison with the result of welding ashore, decrease in intensity of welded section underwater could not be helped, but it is our aim to maintain 99 percent watertightness as well as 90 percent intensity in strength of welded section effected.

d. Maintenance of safe working condition for divers is indispensable.

e. Studies have begun with regard to type and kind of gear/ equipment which could be easily used by divers at an intricate structure of vessel and/or object.

Bearing the above in mind, we have continued studying.

Experimental Training

As study of welding electrodes to be used on shore progressed, various kinds of insulating material have appeared on the market in the 1960's. We have so far tested about 20 kinds of welding electrodes; and, in the course of testing, we found insulation material soaked in water for a few hours peeled off when charged with electricity. To prevent this we, therefore, tested many kinds of paint as coatings and also used cellophane tape which could be procurred and which were wrapped directly around the electrode insulation.

With a view to produce a welding holder which could also be used as a underwater gas-arc cutter, we have studied the design and tested the quality of a few kinds of holder; having regard to their strength, weight, easiness of handling, and safety.

When underwater welding is actually to be performed the most important problem was selection of the welder. After deliberation, we came to the conclusion that first, he must be a diver who must be well trained to weld on shore, and then he must undergo training of underwater welding as a next step. He must simultaneously carry on constant study of various gear/equipment and, in about six months, he applies for the qualification tests sponsored by the Nippon Kaiji Kyokai, an organization of shipping surveyors, and JIS Welding Technical Academy which consist of such courses as overhead position welding including flat position welding and horizontal position welding. Eight of our divers qualified in these tests, and they have obtained the 1st and 2nd degrees of Class B licenses from the above organization. For underwater training and experiment, we have devised a sea water circulating tank (about 40 tons in capacity) fitted with a glass window to observe from outside and wherein divers can do training at depths of three meters and keep in communication with instructors outside of the tank by means of diver's telephone. At the beginning they failed many times due to improper setting of the electric current and to the hard insulating material of the electrode, but they began to pick up self-confidence in the practical use of their technique from 1963.

Distinction of Welding Electrode

At the time of selection for use of the mild steel electrodes being sold on the market, attention should be paid to three standard points, as stated hereunder, and a test made to choose one which will fit the particular operation.

a. Characteristic of each kind of welding electrode in practical use. The characteristic of a welding electrode shows more remarkably when used underwater than on shore, and, therefore, it is hard for us to make an objective judgment of the quality of each welding electrode because each diver differs in degree of technique, habit, experience, and choice, but in general, the following may be said:

    1) Efficient work can be achieved with the use of a welding electrode of ilminite, lime-titanium, and titanium-type welding electrode.

    2) Good external appearance after welding can be obtained with titanium-type welding electrode.

3) Good melting and penetration can be obtained with ilminite-type welding electrode.

4) Efficient work can not be achieved with high cellulose and low hydrogen-type welding electrode, and they are not good for use.

5) Efficient work can be done hy using iron-powder titanium type which is preferable to multi-layer welding.

b. Availability of welding electrode

Ilminite-type welding electrode seems to be readily available.

c. Intensity

As a result of tensile tests regarding fillet weld, there was no difference among ilminite, lime-titanium, iron-powder titanium type of welding electrode but ilminite and high hydro-titanium welding electrode were better than others in bending test. In impact test, ilminite and high hydro-titanium type of welding electrode indicated the same result as is obtained on shore.

Mechanical Test of Joint Section

Test of intensity of welded section is being made time and again by staff of the public test organization as well as the research department of the shipbuilding companies.

An example of the result of the test is as follows:

a. By testing the welded pieces affected under flat position welding, only one test piece broke at the base metal whereas the others all broke in way of the penetration zone due to either undercut or blowhole. We achieved a 94 percent average in respect to joint efficiency which we had expected. The rate of tensile is from 8 to 13 percent which is half or one third when compared with the figure at shore.

b. Bending test

Although a test piece welded in the flat position did not break at a bending angle of 180 degrees, others welded in a different welding position broke due to blow hole and to undercut at an angle between 28 to 70 degrees.

c. Charpy impact test

Despite many defects like blowhole, etc., fracture rate appears to be very good. We understand that the generation of many blowholes is unavoidable in underwater welding because gas can not escape from the melting pool due to sudden cooling. Undercut which does not occur so frequently in flat position welding occurs in horizontal and vertical position welding, but we consider this problem could be technically minimized by means of proper electric current adjustment and training. A better counter measure may be to pay careful attention to the welding plan so that divers can work mostly in flat position welding.

Actual Example on Practical Salvage (Projection of Slide on Screen)

We successfully completed watertightening of an extensive "V" shape fracture on the shell plate of a L.P.G. carrier which collided with another vessel. Since then we have utilized this technique in welding eye pads at time of hoisting a sunken vessel with a floating crane, and water-tightening/reinforcing operation of a grounded vessel. The practical and basic application of this technique have changed the form of salvage operations of olden days to a great extent. Thirty divers of our company have applied with confidence this technique (NSC method) to more than 100 cases and especially the method "NIPPON PATCH" by which a punctured section is made watertight with reinforced steel has been highly appraised in the maritime circle. Contrary to the cox gun method, "NIPPON PATCH" can shut out incoming water perfectly and also serves as structural reinforcement to some extent as well as saving of working days as compared to watertightening operation by means of wooden patchwork.

Following are several examples out of many.

1) Nikkosan Maru

This vessel collided with another ship at the entrance to Tokyo Bay in 1969, and our company made the large fracture water-tight with a steel patch plate welded under-water. The special feature of this job was that the steel patch plate was curved by heating to fit neatly over the fracture which existed on the curvature of bilge strake. The job was completed in seven days.

2) Azov Sea

This vessel collided with another ship, and the former voluntarily beached herself at the entrance to Tokyo Bay in 1976. We made the big gash water-tight with a steel patch plate welded underwater. Divers experienced much difficulty in the diving work because the location of the casualty was exposed to the unsheltered sea.

3) Chi Star

This vessel, while on voyage in the Pacific Ocean from the west coast of U. S. Mainland, sustained large fractures on her shell plates at both side of Fore Peak Tank. We towed the vessel into Apra Harbour, Guam, where the fractures were made water-tight by our salvage team by welding steel patch plates which were reinforced with steel H-beams. The salvage team also reinforced the patched section from inside after the water was pumped out from the flooded compartment. The vessel was able to proceed to Japan on her own power after completion of the above repair work which took 25 days.

4) Ogden Congo

This vessel (20, 711 G/T) had been on a voyage with a full cargo of anthracite from the U. S. A. to South Korea when she was in collision with the Korean containership (11,452 G/T) on July 13, 1981. The latter vessel's bulbous bow pierced the vessel's starboard shell plating in way of the bulkhead between Nos. 3 and 4 holds, causing a large hole and indentation 13 m. long by 14 m. high, 95 percent of which being below sea level. The large damaged fracture area was sealed with eight reinforced steel plates each 12.5 m. long, placed vertically side by side and each side welded together underwater. Thereafter, the ends were sealed to the ship's side by carefully shaped plates which were welded into position.

Owing to the deformation aft of the steel patch and because of the need to prevent the weak section in way of the patch from further fracturing as the vessel's sagging condition decreased, the slender wedge-like opening at the aft between the vessel's shell plating and the steel patch was sealed with a U-shaped steel channel bar, and the plate was shaped to fit the opening and welded to both the patch and the vessel's shell plating. After pumping out Holds Nos. 3 and 4 further internal stiffening was fitted. The work was completed in 25 days, and after inspection of the completed work, the Bureau Veritas classification surveyor expressed great satisfaction with our workmanship.

Future Prospect

One aspect of the disadvantage of our method of welding is that we must depend too much upon the diver's technique which requires considerable training and time before he is able to attain a high level of welding technique. It is also true to say that welding intensity differs according to and depends upon each diver's technique.

With an aim to obtain equal welding intensity and to reduce labour work, one subject which we think we should study in the future is the utilization of automatic welding, which is already used practically on shore, in underwater operation. Meanwhile, further studies will be made to solve the defective problems of blowhole and undercut.

Result of Mechanical Test of Joint Section

Item / Posture of welding		Tensile Test				Bending Test		Charpy Impact Test (3)	
		σ_B (kg/mm^2)	El (%)	Joint efficiency (%) (1)	Place of breaking	Toward surface side Angle (θ) (2)	Toward reverse side Angle (θ) (2)	vEo (kg/cm^2) (4)	Ratio of brittle fracture (%) (4)
Welding test done at off Hakodate Depth of water (3.5 m)	Flat position	47.3	12.5	101.7	Welded penetration zone	180/62.5	180/45	7.40	12.0
	Horizontal position	44.9	12.2	96.6	"	40/34	49/56.5	5.84	13.5
	Vertical position	38.8	8.1	83.4	"	64/43	38.5/44.5	5.93	34.5
Welding test done at off Moji Depth of water (4.0 m)	Flat position	(33.0)	---	(71.0)	Base metal	180/	180/	4.73	51.0
	Horizontal position	46.5	17.6	100.0	Welded penetration zone	59/42.5	59.5/34	5.11	24.5
	Vertical position	41.2	10.3	88.6	"	68/77.5	28/38	4.91	40.0

Remarks:
(1) Ratio to breaking intensity of base metal
(2) Degree of angle when broken
(3) The fourth test piece (7.5 m/m in breadth)
(4) Average description of 3 test pieces

Ship Repair

Successful underwater job carried out by Japanese company

SINCE its foundation in 1934 with the amalgamation of the Tokio Salvage Co. and the Teikoku Salvage Co., the Nippon Salvage Co. Ltd. of Tokyo with support from the leading Japanese insurance companies has always endeavoured to develop new and effective techniques in salvage work. One of the principal areas of study was in the field of underwater welding and after much experiment and training, they had by 1965 developed underwater welding apparatus and their divers had acquired skill and a high degree of efficiency in the use of this apparatus.

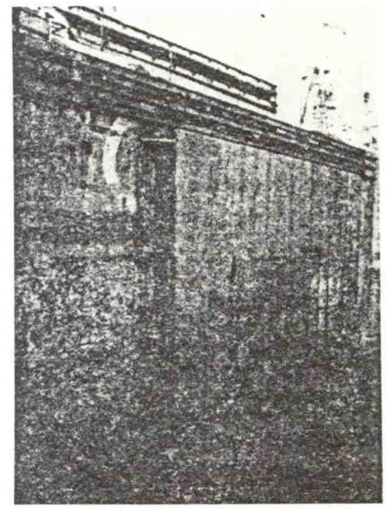
Examples of their work in 1969 and 1970 were the salvage operations on the *George S Embiricos*, the *Nikkosan Maru* and the *Pearl Creek*, in all of which large areas of patching by underwater welding were accomplished.

Recently the Nippon Salvage Co. Ltd. performed extremely valuable salvage work on the bulk carrier *Ogden Congo* off the south coast of Korea. The *Ogden Congo* (20,711 g.r.t.) had been on a voyage with a full cargo of anthracite from the U.S.A. to South Korea when she was in collision with the Korean containership *Chong Suk* (11,452 g.r.t.) on July 13th this year. The latter vessel's bulbous bow pierced the *Ogden Congo's* starboard shell plating in way of the bulkhead between Nos 3 and 4 holds, causing a large hole and indentation 13m. long by 14m. high, 95 per cent of which being below sea level. The salvage tug *Koyo Maru* which is kept on station at Moji with salvage gear and materials onboard, was loaded with steel for the huge patching work and left her base for the casualty three hours after receiving instructions on July 14th.

When she arrived at the scene the *Ogden Congo* was found with a draught far in excess of her summer full load draught due to her Nos 3 and 4 holds being flooded. She was also found in a sagging condition of more than 30cm., which was a cause of concern, requiring great care during the salvage operation. However, the immediate requirement was for a patch to cover the vast damaged area so that the sea water could be pumped from the flooded holds.

The large damaged fracture area was sealed with eight reinforced steel plates each 12.5m. long, placed vertically side by side and each side welded together underwater. Thereafter, the ends were sealed to the ship's side by carefully shaped plates which were welded into position. Owing to the deformation aft of the steel patch and because of the need to prevent the weak section in way of the patch from further fracturing as the vessel's sagging condition decreased, the slender wedge-like opening at the aft between the vessel's shell plating and the steel patch was sealed with a U-shaped steel channel bar and the plate was shaped to fit the opening and welded to both the patch and the vessel's shell plating. After pumping out Holds Nos 3 and 4 further internal stiffening was fitted. Whilst the operation was in progress the tug *Koyo Maru* was required to undertake another job and she was replaced on July 24th by the tug *Seiha Maru*.

The work was completed in 25 days despite the vessel being exposed to the influence of Typhoons *Maury* and *Ogden*, which caused her to take shelter three times. After inspection of the completed work the Bureau Veritas classification surveyor expressed great satisfaction with the workmanship of the salvors. The *Ogden Congo* is now undergoing permanent repairs at a Japanese shipyard and the salvors were very pleased to receive confirmation that no fractures appeared on or in way of the steel patch thus proving that the wedge-shape "cushion" patch had served its purpose.



The steel patch on the "Ogden Congo" pictured in the Japanese repair yard. The photograph gives a clear view of the box-like steel patch almost entirely fabricated and welded underwater, 13m. long by 12.5m. high requiring about 50 tons of steel plate, H-beam and channel bars.

It is understood that over 300 tons of steel was required for the repair of the damage.

by Desmond Baker,
Executive Director, Marine Claims,
Willis, Faber & Dumas Ltd,
London Agents for the Nippon
Salvage Co. Ltd.

Major Soviet liner conversion contract

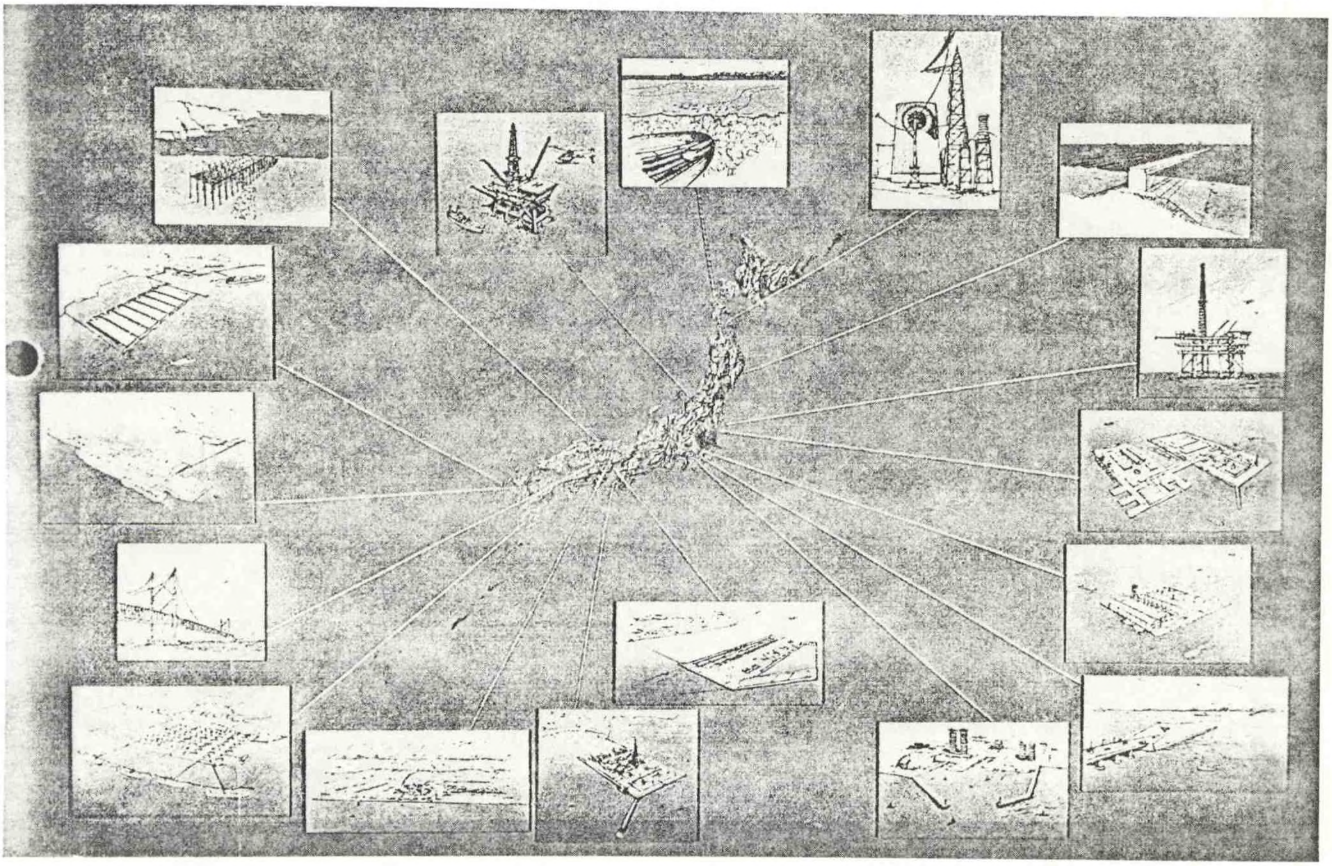
IT seems that the success and publicity of Hapag Lloyd Werft's conversion of the former liner *France* into the Caribbean cruise liner *Norway* has been instrumental in the Bremerhaven-based yard succeeding in winning two passenger liner refits from the Soviet Union. After protracted negotiations, the U.S.S.R. has placed a major contract with the West German shipyard for the annual overhaul of the 24,981 g.r.t. liner *Maksim Gorkiy* and the substantial refit of the 19,872 g.r.t. liner *Mikhail Lermontov*.

The 1968-built *Maksim Gorkiy* (the former *Hamburg*) is due to arrive at the Hapag Lloyd shipyard on November 17th this year and will stay for 25 days. Work to be carried out on this HDW-built vessel consists mainly of basic overhaul work. A much bigger workload though will be involved in the East German built *Mikhail Lermontov*, which is expected to enter the yard on January 4th next year, for a major refit lasting 135 days.

This vessel, one of five sisterships built for the U.S.S.R. by VEB Mathias Thesen Werft between 1964 and 1972, will have nearly her entire passenger area modernised. Passenger cabins on the Boat, Upper, Second and Third Decks will be entirely refurbished and cabins previously without private baths will be fitted with them. In addition, luxury cabins will be installed on the boat deck. On the Saloon Deck, the Entertainments Room will be completely re-built, to provide seating for 540 passengers on two levels. Also on the Saloon Deck a new shop and offices are to be built, with the Dining Saloon also being refurbished. The above mentioned work will entail considerable alteration to the vessel's existing air-conditioning and ventilating systems.

On the vessels machinery side, extensive alterations will be made to the liner's existing engine room. No further details are known at the moment except that a new waste disposal incinerator will be installed. *Mikhail Lermontov*, built in 1972, is propelled by two Cegielski-built Sulzer diesel engines developing 21,000 b.h.p. and giving a speed of 20.5 knots.

Ministry of Transport　　Ministry of International Trade & Industry
Committee on Oceanic Resources, KEIDANREN　　The Kozai Club



NEW OFFSHORE SPACE UTILIZATION IN JAPAN
-COAL-FIRED POWER PLANTS ON MAN-MADE ISLANDS

T. Nishimura
Ministry of Transport

Present Status of Offshore Space Utilization

Japan is an island nation with a total area of 370,000km². Steep mountains dominate the inland areas, and only about 30% of the land is inhabitable. Yet this small land area supports a vast population of 117 million. The population, it is estimated, will reach 140 million in the middle of the 21st century. In order to continue to sustain the nation's society and economy, to continue to provide jobs for the people, and to continue to improve the living standard while maintaining the quality of the country's environment, vast new land spaces will be required. Existing flat areas, however, have already been highly utilized, making it difficult to meet various land-space demands within the existing limited land surface area.

For a land-short island nation, offshore space is a precious resource because of its enormous potential for the creation of new land space. Thus offshore space utilization will become one of the major pillars of Japan's plan for social and economic progress in the years to come.

Historically, as far as industrial raw materials and other mineral resources are concerned, Japan has been an impoverished nation. What has contributed much to Japan's current social and economic progress is the effective utilization of land space throughout the islands — particularly the high-density utilization of areas bordering the sea. Today, coastal areas are being used both as "production space" or industrial zones and as "living space" or cities. Incidentally, coastal cities, towns and villages occupy a mere 30% of the total area, but represent about 50% of the nation's total population and 60% of total industrial shipments.

Let us take a look at the present state of the country's offshore space utilization and the estimated space demand in the year 2000 (Table 1). Presently available offshore areas to water depths of 20m total approximately 3.1 million ha., of which some 50% is being used. In the coming two decades, it is estimated that space demand will exceed supply by about 1.5 million ha. This growing space demand will, in the future, necessitate offshore space utilization in deeper water and farther from shore.

Table 2. Economic Sea Zones of 10 Countries

(unit: 1,000 km²)

Country	Area
U.S.A.	7,620
Australia	7,010
Indonesia	5,410
New Zealand	4,830
Canada	4,700
U.S.S.R.	4,480
Japan	3,860
Brazil	3,170
Mexico	2,850
Chile	2,290

ble 1. The Present Status of Japan's Offshore Space Utilization and Estimated Area Demand in 2000, According to Purpose

(Unit: 1,000 ha)

	Present status				2000			
Water depth	0-20m	20-50m	50-100m	100-200m	0-20m	20-50m	50-100m	100-200m
Total offshore space	3,088	4,985	7,974	14,436	3,088	4,985	7,974	14,436
Coastal fishing industry (fish farming)	511	222	215	56	1,730	3,421	4,076	4,021
Fishing ports	195	—	—	—	470			
Ports and harbors	662	—	—	—	1,800			
Sea routes	20	—	—	—	54			
Ocean-related recreation	28	—	—	—	278			
Reclaimed areas	119	—	—	—	188			
Dumps	4	—	—	—	14			
Offshore airports	—	—	—	—	4			
Total utilization space	1,569	222	215	56	4,538	3,421	4,076	4,021
Remaining offshore space	1,519	4,763	7,759	14,380	−1,450	1,564	3,898	10,415

Creation of New Offshore Space — an Offshore Man-made Island

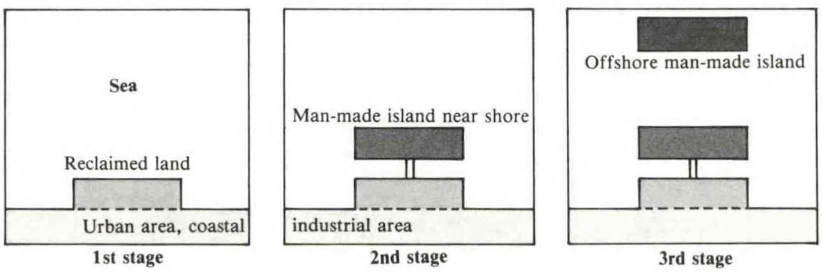
The patterns of offshore space utilization shown in Fig. 1 can be classified into three stages, i.e., 1st stage: reclamation of sea areas adjoining the shore mainly in bays and the Inland Sea; 2nd stage: man-made islands located near the shore and closely related to existing urban and industrial areas; and 3rd stage: offshore man-made islands, which will be discussed in this booklet.

The present booklet proposes that offshore space utilization be advanced from the earlier stages of reclamation and man-made islands near the shore to the offshore man-made island concept through the construction of man-made islands farther offshore, thus creating new functional space as well as spheres in and around the islands.

An offshore man-made island offers many advantages and meets many social needs, as follows:

- □ The endeavor to utilize offshore space, while making the most of offshore locations and, in so doing, assuring environmental preservation of inland regions, will result in the expansion of the nation's land space and the improvement of the well-being of the people.
- □ The offshore man-made island concept provides a wider range of freedom in both site selection and scale determination. In the field of transportation, it will also accommodate large vessels.
- □ This concept will have less impact on the current and future use of seaboard areas and shorelines than other concepts. Also, the calm water area secured between the island and the existing land will provide an area for use by the fishing industry, recreation activities, and sea traffic. In this way, newly created land, existing land, and the sea area created between them can be utilized through total planning, thus making it possible to revitalize existing land areas.
- □ The concept also permits the relocation or construction of facilities which are now difficult to build in cramped and very densely utilized existing land areas. This will help improve the environment, disaster-prevention provisions, and general views of existing land areas.
- □ Judging from the in-depth know-how gained through the creation of space in the 1st and 2nd stage projects described above, and considering the outstanding level of technological standards attained by Japanese shipbuilders and port/harbor engineering companies, construction of offshore man-made islands has already reached the stage of technological feasibility.
- □ When a reclamation-type man-made island is built, in addition to the utilization of the island, the hill or mountain from which earth was taken for the reclamation can also then be used as flat land.

Fig. 1. Pattern of Offshore Space Utilization



Locating Offshore Man-made Islands

Along with the growth of the population and the expansion of the nation's economy, the demand for land space will continue to rise and the need for stable supplies of energy sources will become important for Japan. On the other hand, it will be difficult to use more of the existing shorelines in view of their present high degree of utilization and also in view of increasingly stringent demands being made for the preservation of the natural environment in Japan. Particularly in the large metropolitan areas and the areas surrounding them, where electricity demand is expected to continue to rise sharply, it has become virtually impossible to build new power stations. Power plants are thus moving farther and farther away from urban areas, giving rise to grave concern about higher transmission costs and a possible inability to maintain power supplies on a steady basis.

These factors have spurred ongoing efforts to meet the growing space demand by utilizing the sea. However, high-density utilization of offshore space is already in progress in the form of coastal industrial complexes, sea routes for ships, fish farms, etc., mainly located in the Inland Sea and within bays. In order to meet the rising demand for space in the future, it will be necessary to utilize offshore space in deeper waters facing the open seas.

The present study will examine siting conditions for a 3 million kW coal-fired thermal power plant and an alternative design with an annexed coal storage yard. Site selection was made based on the results of studies of the natural conditions at various coastal areas, the state of sea-area use, the power supply-demand balance, trends in coal supply and demand, and the economic feasibility of the offshore man-made island project. As a result, 21 candidate sites were initially selected, as shown in Fig. 2.

Fig. 2. Candidate Sites for Location of Offshore Man-made Islands

Basic Design Conditions and Layout of an Offshore Man-made Island

In preparing the basic design for an offshore man-made island, Nos. 6 (Site A) and 10 (Site B) were selected from the 21 candidate sites shown in Fig. 2, for case studies because of their proximity to large cities where the need for such a project is greater than elsewhere.

The Site A (average water depth 20m) design proposes the construction of a 3 million kW coal-fired power plant with an annexed coal storage yard capable of handling 15 million tons of coal a year. The handling capacity takes into account the estimated future growth of power and coal demand. The Site B (average water depth 35m) design is a study of the construction of the coal-fired power plant alone, based on an estimated high level of power demand, with comparatively low coal demand.

If the man-made island is of the reclamation type, the power plant and the coal storage yard will be built on reclaimed land in the conventional onshore manner. If the island is of the floating type, these facilities will be built on the barge.

Thus the mode of utilization of the offshore man-made island and the structural type of the power plant and coal storage yard will be studied with respect to (1) the floating type and (2) the reclamation type, for both Site A (20m deep) and Site B (35m deep).

Table 3 shows the design conditions for the offshore man-made island and those for the subject sites.

Table 4 shows the scale of the man-made island, and Figs. 3 to 6 show the layouts of the man-made islands.

Table 3. Basic Design Conditions for Offshore Man-made Island

Sea area	Site A		Site B	
Uses	Coal-fired thermal power plant (with coal storage yard)		Coal-fired thermal power plant	
Case study No.	A-1	A-2	B-1	B-2
Structural type of power plant and coal storage facility	Floating	Reclamation	Floating	Reclamation
Power output capacity	1 million kw × 3		1 million kw × 3	
Coal storage	2.4 million tons (Annual handling: 15 million tons)		1.2 million tons (Annual handling: 7.5 million tons)	
Ash dump	20 million m^3 (sufficient for 15 years of continuous operation)		20 million m^3 (sufficient for 15 years of continuous operation)	
Port facilities	100,000 dwt × 3 berths 10,000 dwt × 2 berths 5,000 dwt × 1 berth 2,000 dwt × 1 berth		100,000 dwt × 3 berths 5,000 dwt × 1 berth 2,000 dwt × 1 berth	
Industrial water	Fresh water: 23,000 tons/day Seawater: 135 tons/sec		Fresh water: 15,000 tons/day Seawater: 135 tons/sec	
Number of employees	500		400	
Water depth	17 m ~ 23 m (average 20 m)		25 m ~ 40 m (average 35 m)	
Distance from shore	3 km (min.)		2 km (min.)	
Seabottom soil	Sand ($N \geqq 15$, $\phi = 35°$)		Sand ($N \geqq 15$, $\phi = 35°$)	
Wave height, cycle	$H1/3 = 9$ m, $T1/3 = 14$ sec		$H1/3 = 10$ m, $T1/3 = 13$ sec	
Tide	H.H.W.L. +2.10 m H.W.L. 1.50 m L.W.L. 0		H.H.W.L +3.60 m H.W.L. +2.10 m L.W.L. +0.30 m	
Earthquake	$Kh = 0.15$		$Kh = 0.15$	
Maximum wind velocity	45 m/sec in 10 minutes		50 m/sec in 10 minutes	
Bearing stratum	−35 m($N \geqq 50$)		Rock layer 10 m below sea bottom	

Table 4. Scale of Offshore Man-made Island

		A-1	A-2	B-1	B-2
Area	ha	208	311	148	225
Reclamation area	ha	—	176	—	140
Multi-column type administration yard	ha	8	—	8	—
Ash dump area	ha	134	135	88	85
Breakwater	m	1,370	750	2,100	1,300
Breakwater revetment(ash dump)	m	3,000	2,950	1,825	1,740
Breakwater reventment (reclamation)	m	—	1,600	—	1,400
Bulkhead (ash dump)	m	1,750	—	2,000	1,000
Bulkhead (reclamation)	m	—	1,100	—	1,400
Soil for reclamation	m^3	—	46,000,000	—	50,000,000
Stone requirement	m^3	6,690,000	6,880,000	8,870,000	11,190,000
Sand requirement	m^3	10,130,000	9,290,000	10,780,000	8,420,000
Power-plant barge	m	420 × 80 × 27 (3 barges)	—	420 × 80 × 27 (3 barges)	—
Coal-storage barge	m	420 × 80 × 35 (6 barges)	—	420 × 80 × 35 (3 barges)	—
Barge mooring facility	Number	39	—	27	—
100,000-ton berth	m	1,100	1,100	800	700
10,000-ton berth	m	250	1,100	—	—
5,000- and 2,000-ton berths	m	250	250	—	300
Steel requirement	tons	1,610,000	1,090,000	1,420,000	1,080,000

Fig. 3. Layout of Floating-type Man-made Island — "Case Study A-1" (watar depth 20 m, power plant with coal storage yard)

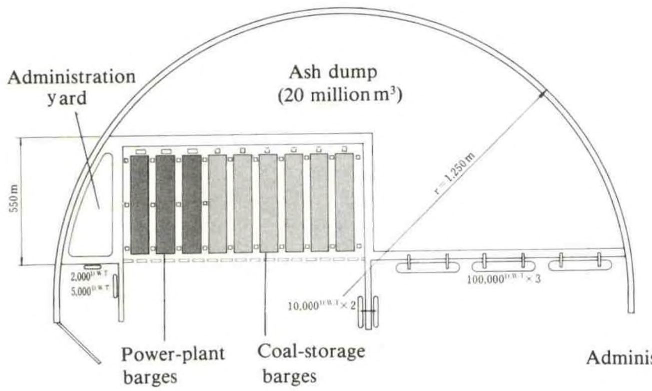
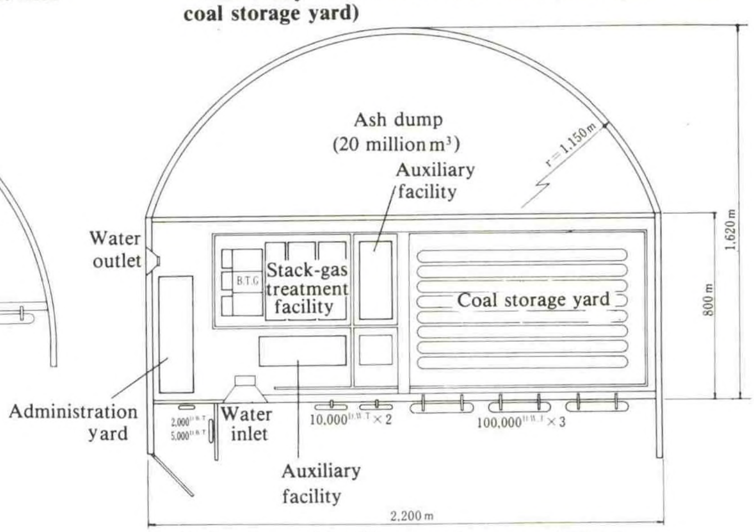


Fig. 4. Layout of Reclamation-type Man-made Island — "Case Study A-2" (water depth 20 m, power plant with coal storage yard)



Coal storage 1.2 million tons for power plant use
1.2 million tons for coal storage purpose

Fig. 5. Layout of Floating-type Man-made Island — "Case Study B-1" (water depth 35 m)

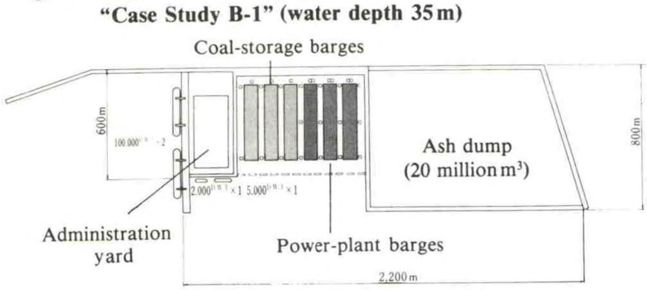
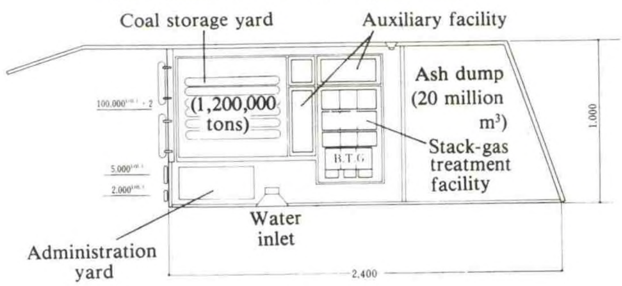


Fig. 6. Layout of Reclamation-type Man-made Island — "Case Study B-2" (water depth 35 m)



Principal Structures

Breakwater

There are many different types of breakwater structures. The appropriate structure is determined by taking into consideration the respective characteristic features of the structural types and (1) the arrangement of the planned breakwater, (2) the natural conditions at the site, (3) the conditions under which the breakwater will be utilized, (4) the construction conditions, (5) economic and other factors. For example, in the case of a caisson breakwater at great water depths, the construction requirements for the base ground for the installation of the caissons necessitate the adoption of the high-mound composite breakwater design.

Studies were made on a curved surface vertical type slit caisson breakwater. Fig. 7 shows a diagram of the breakwater structure for Site A.

The size of the curved surface vertical type slit caisson is 32.6m long, 19.4m wide, and 14.6m high, and it weighs 1,694 tons.

Water inlet and outlet

As shown in the layout of the offshore man-made island, cooling water for the thermal power plant is taken in via the bulkhead facing the shore and warm waste water is discharged into the open sea side. For the water inlet section, a caisson with an opening is installed in the lower section of the bulkhead structure. This caisson will serve as a kind of breakwater for minimizing the impact of waves on the pump room and preventing any inflow of sea surface warm water. The opening is 200m wide, the opening of the pump room 90m wide, and the water depth 12m. Similarly, the water outlet is a caisson structured as a kind of breakwater with an opening for water discharge. It is installed in the lower section of the curved surface vertical type slit caisson breakwater, minimizing the impact of waves on the water tail race. The structure has an opening about 100m wide, and the tail race is about 30m wide, with an inclination provided from the water surface to a depth of 10m (18m at Site B).

Schematic diagrams of the water inlet and outlet are shown in Fig. 8.

Fig. 7. Diagram of Curved Surface, Slit-caisson Type Breakwater (water depth 20m)

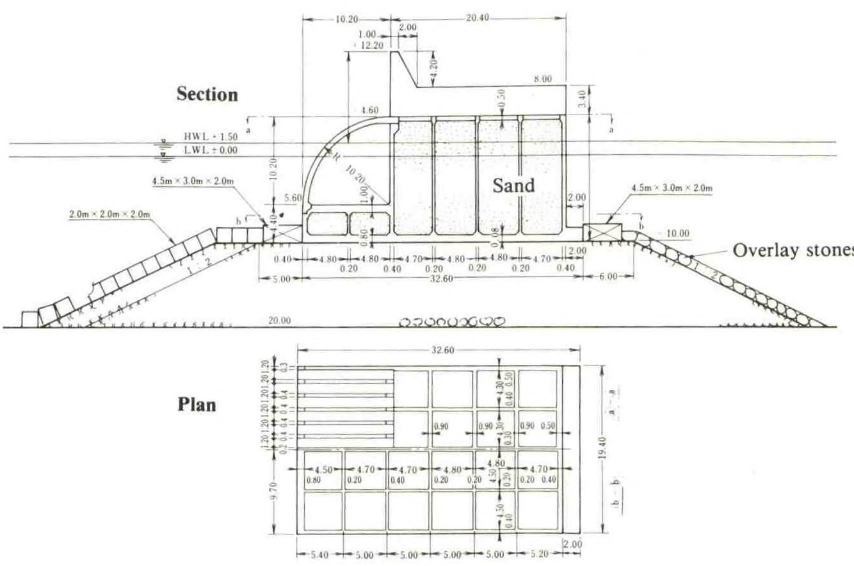
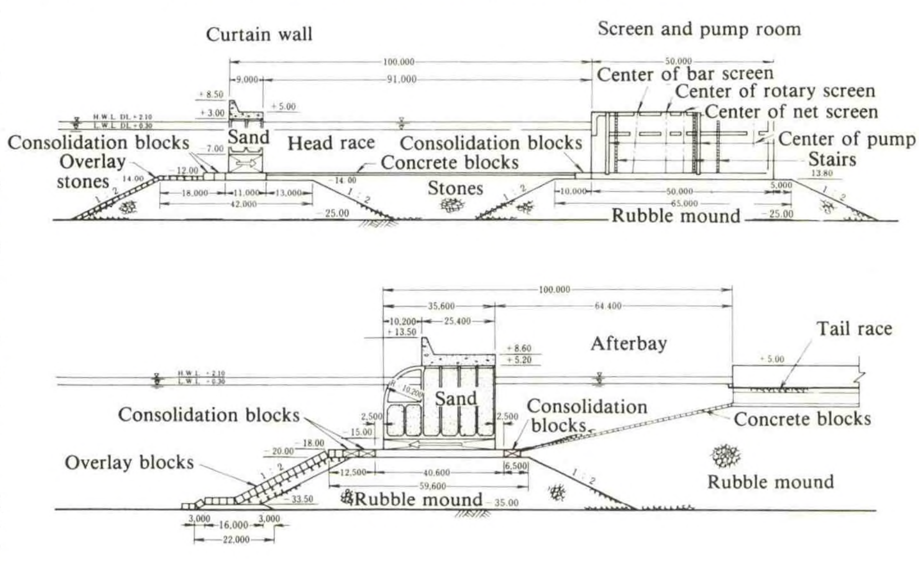


Fig. 8. Diagram of Water Inlet and Outlet (water depth 35m)



Power facilities

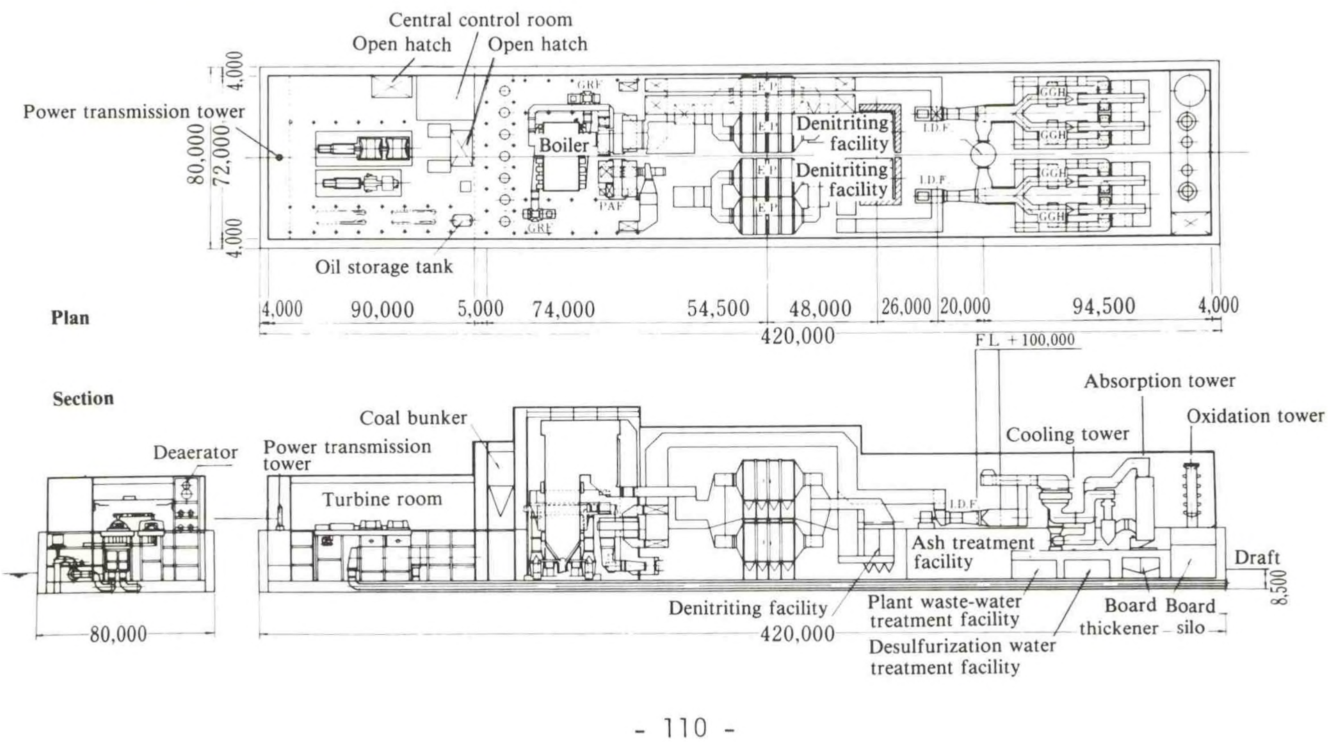
Power generating facilities, including the boiler, turbine generators, and environmental control equipment on the reclamation-type offshore man-made island are designed similarly to those for conventional coal-fired power plants operating onshore. Power facilities on the floating-type island are designed primarily based on the design specifications for a land-based coal-fired power plant, taking into account such factors as pitching/rolling and vibrations peculiar to the barge concept. For the barge concept, the design tolerances for various power facilities are determined based on experience and expertise with conventional land-based facilities and the results of studies on pitching/rolling and inclinations, as shown in Table 5.

The conceptual design for the power facilities in the floating-type island is shown in Fig. 9.

Table 5. Design Tolerances for Floating Type Island

Item	Design tolerances	
	Land-based facilities	On-barge facilities
Angle of inclination due to barge pitching	—	less than ±2.5°
Angle of inclination due to barge rolling	—	less than ±5.0°
Horizontal rate of acceleration	less than 0.2g	less than 0.2g
Relative deflection between turbine shoes	25/less than 100mm/10m	25/less than 100mm/10m

Fig. 9. Diagram of Power-plant Barge and Major Equipment



Coal storage

For the reclamation-type island, the outdoor storage yard type, using stackers and reclaimers, which is widely used in modern large-capacity land-based coal-fired power plants, was adopted for stocking and handling coal.

For the floating-type island, the hopper coal-storage barge design was adopted, with coal being received at the upper section of the barge by means of conveyors. It is discharged via the fixed-quantity discharger and conveyors from the lower section of the barge.

The ceneptual design for the hopper coal barge is shown in Fig. 10, and the coal storage system for "Case Study A-1" is shown in Fig. 11.

Fig. 11. Coal Storage System for "Case Study A-1"

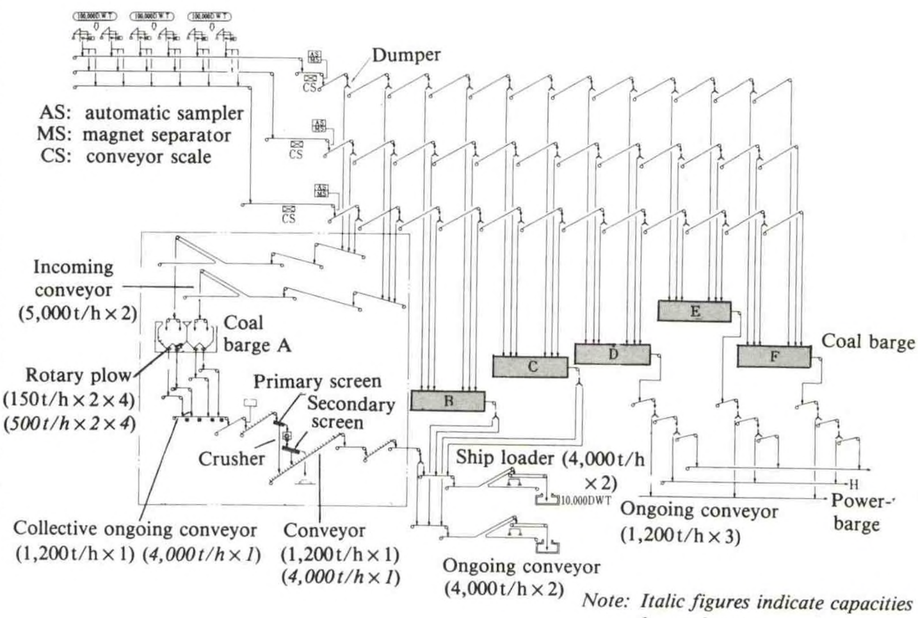
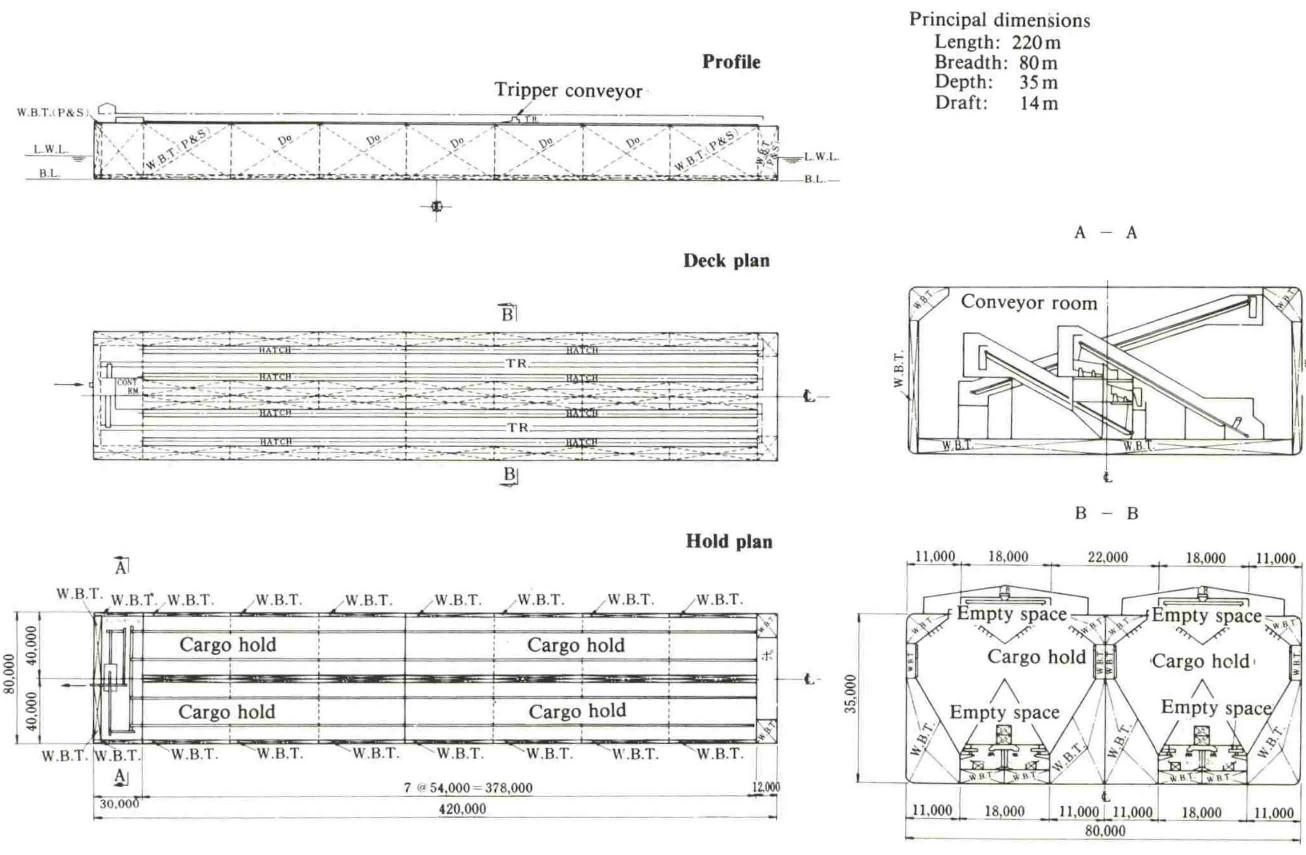


Fig. 10. Conceptual Design for Hopper-type Coal-storage Barge (40,000 DWT)



Power transmission

A submarine cable will transmit electricity generated in the coal-fired power plant on the offshore man-made island. The required voltage for the submarine cable is 500 kV.

The cable systems for the power plants on both the reclamation-type and the floating-type man-made islands are shown in Fig. 12.

Power-transmission facilities on the offshore man-made island must be designed with due consideration to linking technology for absorbing various amounts of displacement between the transmission facilities and the island's fixed facilities which are caused by the pitching/rolling, inclination, etc. of the barge. Another important design consideration is the installation of a large-capacity submarine cable. The outgoing cable from the barge, in particular, is designed so as to be connected with the mooring dolphin via the expansion/contraction absorbing mechanism for the barge's pitching/rolling.

The pantograph collector section of the expansion/contraction absorbing mechanism moves in accordance with the movements of the barge, thus changing the curvature of the cable.

The cable is designed so that its aluminum coat can safely withstand 30 years of accumulated strain imposed on it when it is subjected to changes in curvature. The structure is shown in Fig. 13.

Fig. 12. Cable System

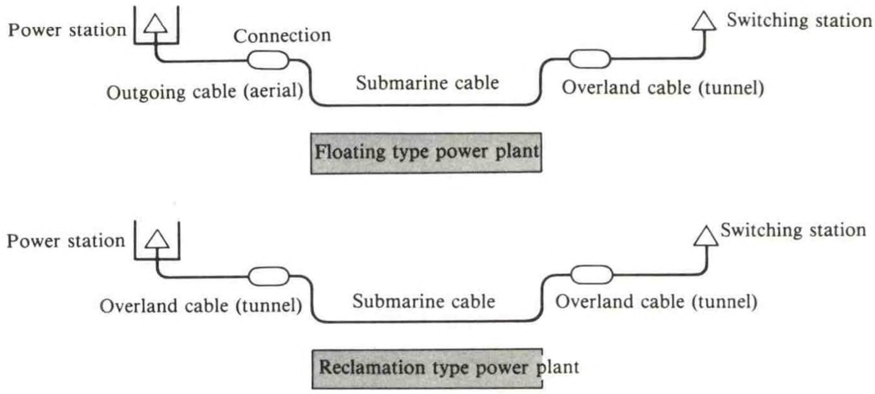
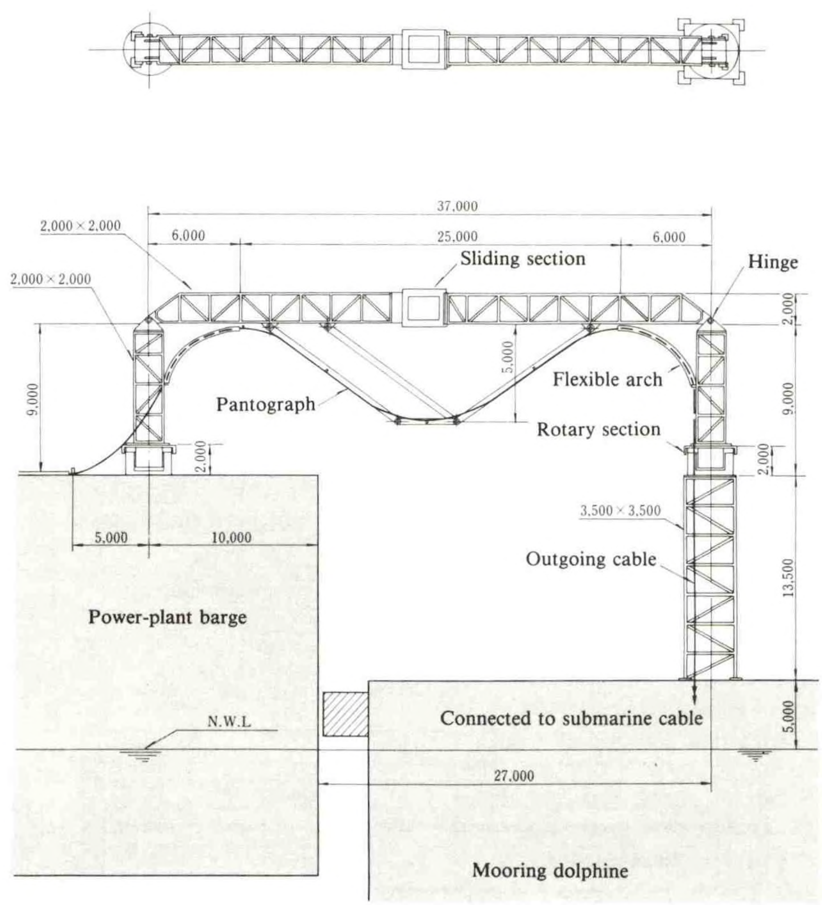


Fig. 13. Power Cable Expansion/Contraction Control Mechanism



Environmental Impact

Environmental assessment of the impact of the offshore man-made island project on the adjoining sea areas was performed. The following is a summary of the results of the assessment.

☐ Smoke, soot and dust

With respect to SOx, which has comparatively high emission concentrations, concentration levels turned out to be one-tenth of that prescribed by the Air Quality Standards, with minimal effects on surrounding coastal areas. Fig. 14 shows an example of the results of calculations of ground-level concentrations.

☐ Warm waste water

The results of the estimation of the diffusion of warm waste water indicated that, with the floating-type power plant, temperatures near the shoreline would rise by about 1 degree C, with little effect on the environment. Generally, no warm waste water problems are experienced with large-capacity electricity-generating stations facing the open sea. Fig. 15 shows an example of the results of estimation of warm waste water diffusion.

☐ Coal ash

Properties of coal ash and relevant rules and regulations were studied, and on this basis an ash treating system (circulating system) was designed. Fig. 17 shows an example of an ash treating system flowsheet. Fig. 16 shows the reclamation process using coal ash.

☐ Fly dust

The results of diffusion calculations of coal dust generated from the unloader, stacker, reclaimer, ship loader, etc., show that there will be no particular problems. (The amount of coal dust scattered on the facing shore is virtually zero.)

☐ Noise

The results of facing-shore noise level simulations indicate that noise levels are extremely low.

Fig. 14. Ground-level Concentration of Flue Gas (stability condition coefficient; stack height 200 m)

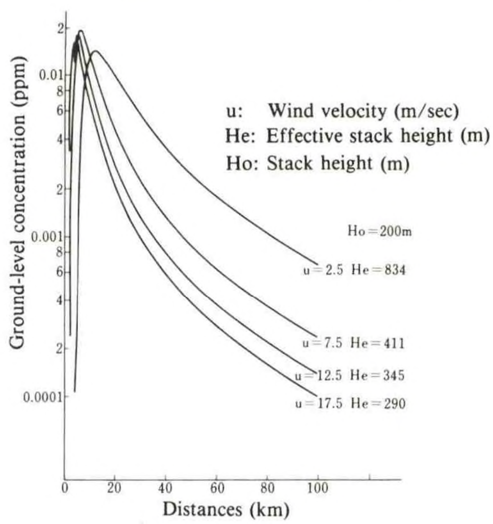


Fig. 15. Diffusion of Warm Waste Water (V = 10 cm/sec)

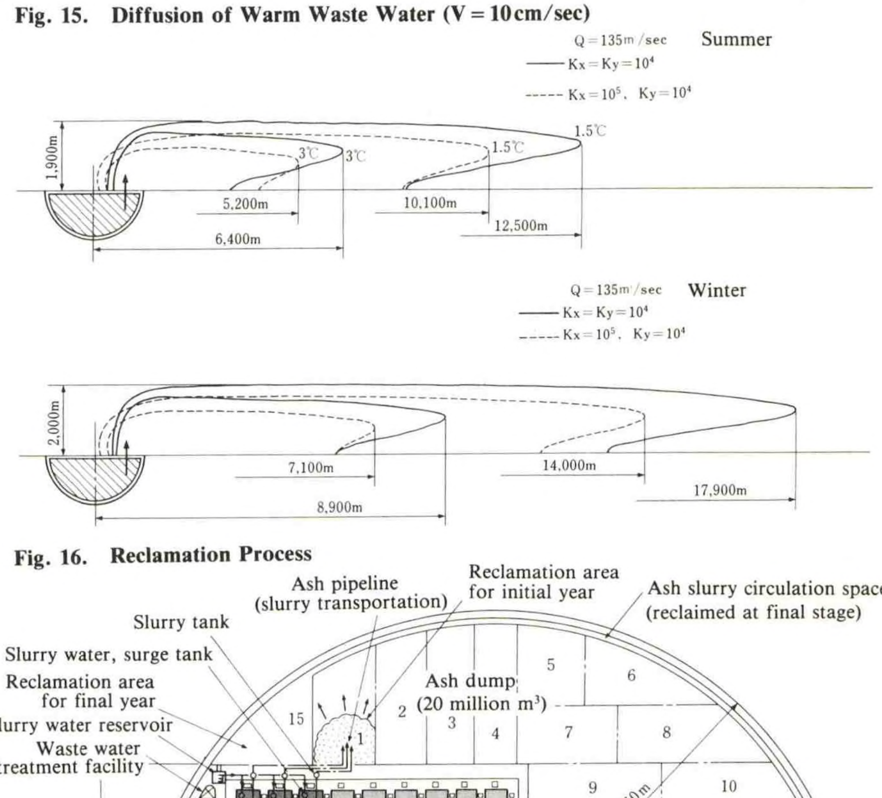
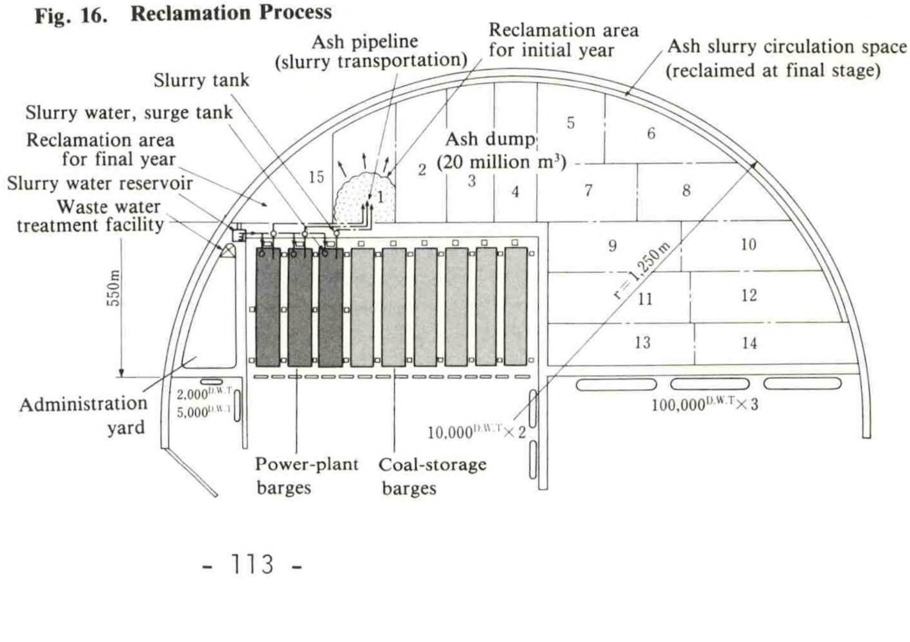


Fig. 16. Reclamation Process



With the floating-type island, the areas affected by underwater noise are confined to an extremely narrow area.

□ Natural environment in the sea area

The results of calculations of wave height distributions in the sea areas on the ocean side of the offshore man-made island show that a very wide calm area will be formed. Fig. 18 shows an example of the results of calculations of such wave heights.

Shore deformation resulting from the construction of the offshore man-made island was also estimated. Tombolo is also expected to form in the affected sea area. Fig. 19 shows an example of the results of estimation of shore deformation.

□ Environmental monitoring

A conceptual plan for an environmental monitoring system was formulated to measure the quality of the air, warm waste water diffusion and distribution, etc., in areas adjoining the site for the offshore man-made island project. Table 6 shows major monitored items and measurement specifications.

Fig. 17. Ash Treatment System Flowsheet

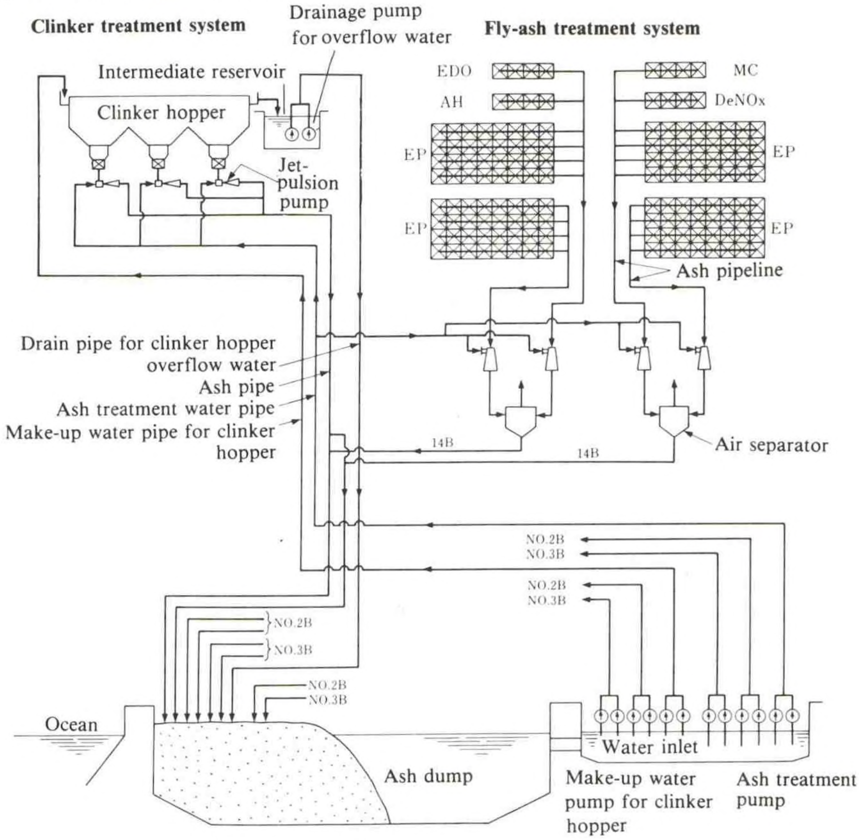


Table 6. Monitored Items and Methods of Measurement for Environmental Protection

Pollutants	Measurement place	Measurement method	Measurement frequency
Power plant			
SOx	Stack inlet	JIS K 0103 Infrared absorption	Constantly
NOx	Same as above	JIS K 0104 Chemiluminescence	Same as above
Dust and soot	Same as above	JIS Z 8808 Circular filter paper	Every two months (min.)
Dust and soot within compounds	Several places within compounds	Dust jar	On occasion
Cooling water temperature	Exit and entrance of condenser	Thermocouple or resistance thermometer	Constantly
Areas surrounding power plant			
SOx	3 ~ 5 places	JIS B 7952 Solvent conductivity	Constantly
NOx	3 ~ 5 places	JIS B 7953 Extinction luminous intensity	Constantly
Fly dust and soot	3 ~ 5 places	JIS B 7952 Diffusing	Constantly
Wind direction and velocity, and temperature	1 place	Vane anemoscope and anemometer and platinum resistance thermometer	Constantly

Fig. 18. **Wave Height behind Man-made Island ("Case Study A-1", during typhoon)**

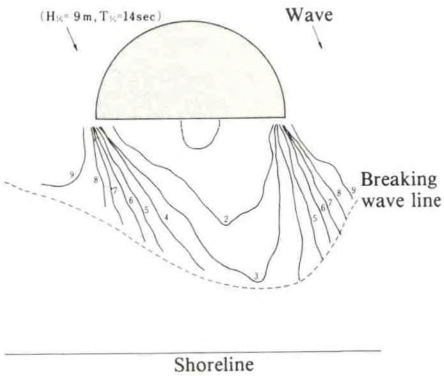
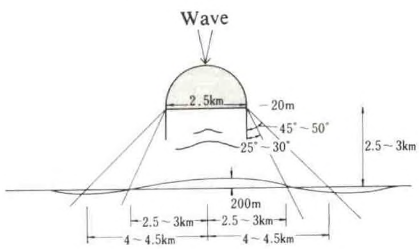


Fig. 19. **Shore Deformation behind Man-made Island ("Case Study A-1")**



Work Schedule

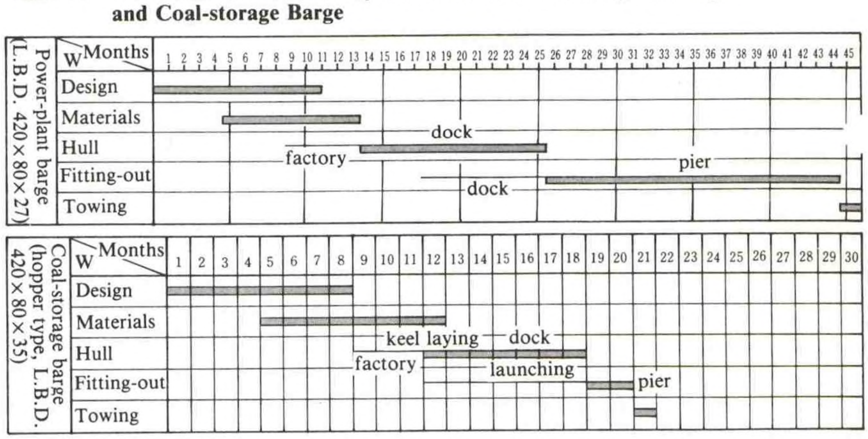
Table 7. Work Schedule for Floating-type Man-made Island ("Case Study A-1")

Work item \ Years	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Environmental surveys and deliberation by Electricity Supply Commission		■	■	■													
Temporary equipment and preparation work					■	■											
Breakwater						■	■	■									
Bulkhead								■	■	■	■	■					
Administration yard									■	■	■						
Mooring facility								■	■	■	■	■					
Power-plant and coal-storage barges (factory manufactured)*						■	■	■	■	■	■						
Power supply cable											■						
Commissioning												■	■	■			

Table 8. Work Schedule for Reclamation-type Man-made Island ("Case Study A-2")

Work item \ Years	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Environmental surveys and deliberation by Electricity Supply Commission		■	■	■													
Temporary equipment, preparation work					■	■											
Breakwater						■	■	■									
Bulkhead							■	■	■	■	■	■					
Reclamation									■	■	■	■					
Power plant												■	■				
Power supply cable													■				
Commissioning														■	■	■	

Table 9. Work Schedule for Factory Manufacture of Power-plant Barge and Coal-storage Barge



W: Work items

On-Board Analysis of Mean Wave Direction with Discus Buoy*

by

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ABSTRACT

The mean wave direction can be calculated with the covariances between the heave velocity, pitch, and roll of a surface-following buoy without computing directional wave spectra. The method has numerically been examined with linearly simulated directional waves and tested on a 10-meter discus buoy in the sea. The field test demonstrates the feasibility of on-board analysis of the mean wave direction and the newly-defined angular spreading parameter, even though the instrumentation employed in the test is found to require improvement. The numerical analysis also clarifies the amounts of statistical variation of directional parameters, which may be referred to as guidelines for the reliability of field measurements of directional wave characteristics.

I. INTRODUCTION

Directional wave observations are made for various purposes. Oceanographers are endeavouring in clarifying directional spectral characteristics, through which they can examine the mechanism of wave generation, transformation, attenuation and many other wave processes. Engineers are mainly interested in the direction from which storm waves attack the structures under their design. They also seek for the information of the direction-wise frequencies of incoming waves for the planning of harbour protection and other purposes. Detailed

*Originally presented at the International Conference on Winds and Waves Directionality, Paris, September 1981.

information of directional wave spectra sometimes becomes an excessive burden of data for engineers, when they try to compile the observation results of one year or more into a table of direction-wise frequencies of wave heights and periods.

The wave direction however is a parameter difficult to define quantitavely. It is an unsettled question how we can define the representative wave direction when swell and seas of similar heights are coming from the direction quite different each other. Longuet-Higgins [1] has shown two definitions of the representative directions for a random, moving surface: i.e., the mean direction and the principal direction. The present paper in its first half examines the applicability of these definitions to ocean waves especially of bimodal directionality. The examination suggests the mean wave direction to be employed in the analysis of ocean waves.

The analysis of mean wave direction is preferably made on the real-time basis for prompt utilization of observation results. The definition by Longuet-Higgins makes it possible to calculate the mean wave direction by means of the covariances between the vertical velocity of surface elevation and the surface slopes in the x- and y-directions. With a surface-following buoy, the real-time analysis of mean wave direction should be feasible, and a field test was done with a discus buoy of 10 m in diameter, which has already been in service for wave height measurements, to investigate the technical feasibility. The second part of the present paper describes the results of the field test.

II. DEFINITION OF WAVE DIRECTION AND SPREADING PARAMETERS

A. Mean Direction and Principal Direction

For a random, moving surface with the directional spectrum denoted by $E(\ell,m)$ in the rectangular coordinates of wave numbers of ℓ and m, Longuet-Higgins [1] has defined the mean direction $\bar{\theta}$ as follows:

$$\bar{\theta} = \tan^{-1}(\bar{m}/\bar{\ell}) = \tan^{-1}(M_{01}/M_{10}) \tag{1}$$

where

$$\bar{m} = M_{01}/M_{00}, \quad \bar{\ell} = M_{10}/M_{00} \tag{2}$$

$$M_{pq} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E(\ell,m)\, \ell^p\, m^q\, d\ell\, dm \tag{3}$$

As the quantity $\bar{\ell}$ and $\bar{m}$ represent the mean wave numbers along the ℓ- and m-coordinates, $\bar{\theta}$ denotes the direction of the center of gravity of directional spectrum drawn from the origin of coordinates.

Longuet-Higgins has also defined the principal direction θ_p as the direction along which the root-mean-square wave number is the largest, or the wave crests are the densest. It is given by

$$\theta_p = \frac{1}{2}\tan^{-1}\left(\frac{2M_{11}}{M_{20}-M_{02}}\right) \tag{4}$$

The spectral moment M_{pq} of Eq. (3) can be evaluated for the conventional frequency-direction representation of directional spectrum $S(f,\theta)$ by the following formula:

$$M_{pq} = \int_0^\infty \int_{-\pi}^{\pi} S(f,\theta)\, k^{p+q} \cos^p\theta \sin^q\theta \, d\theta \, df \tag{5}$$

where k denotes the wave number satisfying the dispersion relation of the following at the water depth of h:

$$4\pi^2 f^2 = gk \tanh kh \tag{6}$$

It should be noted here that the principal direction θ_p can be obtained in the half-plane ($-\pi/2 < \theta_p \leq \pi/2$) only, while the mean direction is obtained in the full-plane ($-\pi < \bar{\theta} \leq \pi$).

B. Case of Bi-directional Waves

The simplest case of water waves with bimodal directionality is the superposition of two trains of regular waves from different directions. Figure 1 is the spectral representation of this case, where each wave train is shown as a point spectrum with the energy E, wave number k, and the direction θ. To facilitate the explanation, the mid-angle direction between the two wave direction θ_A and θ_B is denoted with Θ and called the central direction. The angular difference between Θ and θ_A or θ_B is denoted with Ω. Thus,

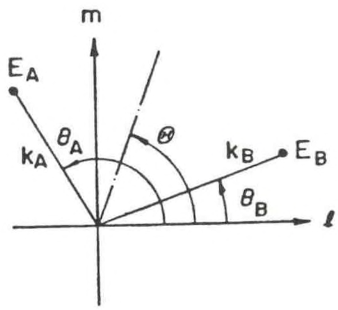

Fig. 1 Definition Sketch

$$\Theta = \frac{1}{2}(\theta_A + \theta_B), \quad \Omega = \frac{1}{2}(\theta_A - \theta_B) > 0 \tag{7}$$

For the sake of simplicity, we take $\theta_A > \theta_B$.

The mean and principal wave directions for the case of Figure 1 are calculated as follows:

$$\tan(\bar{\theta} - \Theta) = \frac{E_A k_A - E_B k_B}{E_A k_A + E_B k_B} \tan \Omega \quad (8)$$

$$\tan(\theta_p - \Theta) = \frac{E_A k_A^2 - E_B k_B^2}{E_A k_A^2 + E_B k_B^2} \tan 2\Omega \quad (9)$$

Examination of Eq. (8) proves that the mean wave direction $\bar{\theta}$ remains in the range of $\theta_B \leq \bar{\theta} \leq \theta_A$. Equation (9) on the other hand yields the principal wave direction θ_p in the range of $\theta_B \leq \theta_p \leq \theta_A$ only when the angular difference of two wave trains 2Ω does not exceed 90°. If 2Ω exceeds 90°, θ_p becomes either smaller than θ_B or greater than θ_A, because $\tan 2\Omega$ takes a negative value in this case. The situation is depicted in Figure 2 which shows the variation of θ_p with the relative increase of the energy of the wave B.

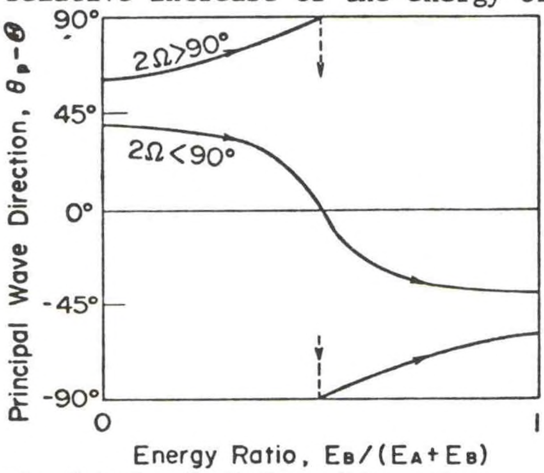

Fig.2 Principal Wave Direction of Bimodal Waves

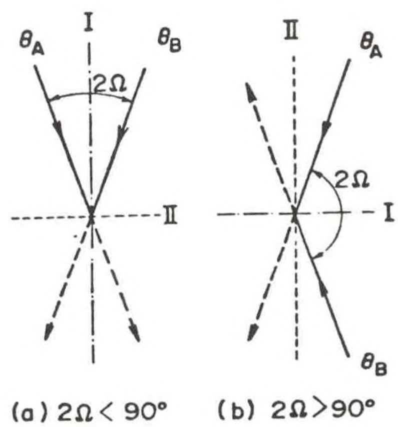

Fig.3 Directions of Propagation of Bi-directional Waves

Physically the apparently odd behaviour of θ_p is explained with the fact that the distinction between the progression and retrogression of wave trains cannot be made with the second moments of spectrum alone. Figure 3 shows two corresponding cases of bi-directional waves with $2\Omega \gtrless 90°$. In the both cases the central direction is the line denoted with I. In the case of (a) with $2\Omega < 90°$, the combined wave crests of two wave trains are the densest around the direction of I and so is the principal direction. In the case of (b) with $2\Omega > 90°$, however, the wave crests are the densest around the direction of II and the principal direction is shifted by 90° or so from the central direction.

The above example suggests that the principal direction defined by Longuet-Higgins is not an appropriate parameter for ocean waves with bimodal directionality.

C. Proposal of Mean Spreading Angle

Longuet-Higgins has further proposed a parameter called the long-crestedness as a measure of angular spreading of a random, moving surface. It is calculated with the spectral moments by the following formula:

$$\gamma = \left\{ \frac{(M_{20} + M_{02}) - \sqrt{(M_{20} - M_{02})^2 + 4M_{11}^2}}{(M_{20} + M_{02}) + \sqrt{(M_{20} - M_{02})^2 + 4M_{11}^2}} \right\}^{1/2} \tag{10}$$

The parameter γ has been derived as the inverse of the ratio of the root-mean-square wave number along the principal direction (maximum) to the one along the direction perpendicular to the former (minimum). Longuet-Higgins has shown that γ takes the value of 0 for unidirectional waves. Nagata [2] has further indicated that the maximum value of γ is 1 for random waves with directionan homogeneity. As it will be discussed later, ocean waves show the value of γ relatively close to 1.

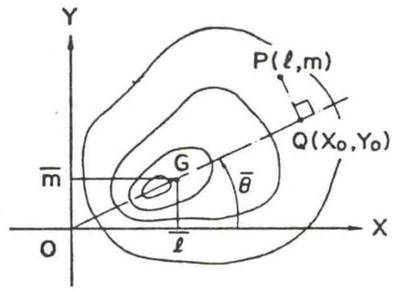

Fig.4 Sketch of Directional Spectrum

The parameter γ can also be proven to take the value of 1 for waves with bimodal directionality when the angular difference of two wave directions is equal to 90° and the energies of two wave trains are at the such relation to make $\theta_p = \Theta$. This can be easily understood by considering the physical definition of γ for such a case of $\theta_A = 45°$, $\theta_B = -45°$, $E_A = E_B$, and $k_A = k_B$ in Figure 1. Therefore, the long-crestedness parameter is not appropriate as an index of the bimodality of directional spectra.

An alternative measure of angular spreading of directional spectrum is conceived hereupon. First the root-mean-square spread distance R of spectrum from the axis along the mean wave direction from the origin is introduced. As shown in Figure 4, a line from an arbitrary point $P(\ell,m)$ in the spectral coordinates is drawn perpendicular to the axis $\overline{OG}$, and the crossing point Q is defined. Then by using the distance $\overline{PQ}$, R is derived as

$$R^2 = \frac{1}{M_{00}} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} E(\ell, m)\, \overline{PQ}^2 \, d\ell \, dm = \frac{M_{01}^2 M_{20} - 2M_{10}M_{01}M_{11} + M_{10}^2 M_{02}}{M_{00}(M_{10}^2 + M_{01}^2)} \qquad (11)$$

The spread distance R has the dimension of wave number. Then, by comparing R with the mean wave number $\bar{k} = (\bar{\ell}^2 + \bar{m}^2)^{1/2}$, we can define the following angle θ_K:

$$\theta_K = \tan^{-1}(R/\bar{k}) = \tan^{-1}\left\{ \frac{\sqrt{M_{00}}\ \sqrt{M_{01}^2 M_{20} - 2M_{10}M_{01}M_{11} + M_{10}^2 M_{02}}}{M_{10}^2 + M_{01}^2} \right\} \qquad (12)$$

The above angle θ_K is named as the mean spreading angle in the present paper. For unidirectional waves θ_K is zero, while θ_K becomes 90° for waves with directional homogeneity.

III. NUMERICAL EXPERIMENTS ON DIRECTIONAL MEASUREMENT WITH SURFACE BUOY

A. Standard Directional Wave Spectrum

The foregoing discussions on the representative direction of bi-modal waves and spreading parameters are further extended to waves with continuous directional spectra by means of numerical simulations of wave profiles and motions as well as numerical evaluation of spectral moments. For such examinations, the directional spectrum is given as the product of the frequency spectrum S(f) and the angular spreading function $G(\theta|f)$: i.e.,

$$S(f,\theta) = S(f)\, G(\theta|f) \qquad (13)$$

For the frequency spectrun, the following one due to Bretschneider [3] with the values of coefficients modified by Mitsuyasu [4] to satisfy the statistical theory is employed here:

$$S(f) = 0.257\, H_{1/3}^2\, T_{1/3}^{-4}\, f^{-5} \exp[-1.03(T_{1/3} f)^{-4}] \qquad (14)$$

where $H_{1/3}$ and $T_{1/3}$ denote the significant wave height and period, respectively.

As for the angular spreading function, the one proposed by Mitsuyasu et al. [5] is employed because it is considered as the most reliable description of ocean wave characteristics. The following is its modified version by Goda and Suzuki [6] with S_{max} being treated as an independent parameter to be selected by engineers for design purposes:

$$G(\theta|f) = G_0 \cos^{2S}\left(\frac{\theta-\theta_0}{2}\right) \tag{15}$$

where,

$$G_0 = \left\{ \int_{\theta_{min}}^{\theta_{max}} \cos^{2S}\left(\frac{\theta-\theta_0}{2}\right) d\theta \right\}^{-1} \tag{16}$$

$$S = \begin{cases} S_{max} \cdot (f/f_p)^5 & : f \leq f_p \\ S_{max} \cdot (f/f_p)^{-2.5} & : f > f_p \end{cases} \tag{17}$$

$$f_p = 1/(1.05\, T_{1/3}) \tag{18}$$

In the above, θ_0 denotes the direction of the propagation of waves as a group. For unimodal directional waves with symmetric characteristics, θ_0 is the same with $\bar{\theta}$ and θ_p. The range of integration in Eq. (16) for the normalization coefficient G_0 is set as $\theta_{max} = \pi$ and $\theta_{min} = -\pi$ in the numerical examination in the present paper.

The angular spreading coefficient S_{max} is assigned the value of 10 to represent wind waves by referring to the range of observed data by Mitsuyasu et al. [5]. The value of S_{max} for swell should be chosen by taking into account the conditions of the swell source area, decay distance and others. As a guideline the value of 25 to 75 or more is recommended for swell [6, 7].

Waves with bimodal directionality is represented by adding two directional spectral density functions with the preassigned heights, periods, S_{max}, and directions.

B. Directional Estimation with Covariances

The spectral moments defined by Eq. (5) can be estimated with the covariances between the time histories of several wave motion data. For a surface-following buoy employed for directional measurements, the data to be recorded are the heave velocity η_t, pitch angle η_x, and roll angle η_y of the buoy. By assuming the transfer functions of buoy motions to wave motions being equal to 1 for the dominant frequency range of wave spectra, the covariances between the above three data are related to the spectral moments as in the following:

$$\overline{\eta_t^{\,2}} = \int_0^\infty \int_{-\pi}^{\pi} f^2\, S(f,\theta)\, d\theta\, df = M_{00}^*$$

$$\left.\begin{aligned}
\overline{\eta_t \eta_x} &= \int_0^\infty \int_{-\pi}^{\pi} f\, S(f,\theta)\, k \cos\theta \, d\theta \, df &= M_{10}^* \\
\overline{\eta_t \eta_y} &= \int_0^\infty \int_{-\pi}^{\pi} f\, S(f,\theta)\, k \sin\theta \, d\theta \, df &= M_{01}^* \\
\overline{\eta_x^{\,2}} &= \int_0^\infty \int_{-\pi}^{\pi} S(f,\theta)\, k^2 \cos^2\theta \, d\theta \, df &= M_{20} \\
\overline{\eta_x \eta_y} &= \int_0^\infty \int_{-\pi}^{\pi} S(f,\theta)\, k^2 \cos\theta \sin\theta \, d\theta \, df &= M_{11} \\
\overline{\eta_y^{\,2}} &= \int_0^\infty \int_{-\pi}^{\pi} S(f,\theta)\, k^2 \sin^2\theta \, d\theta \, df &= M_{02}
\end{aligned}\right\} \quad (19)$$

This is an extension of the approach by Nagata [2] who derived the method of directional estimation with the records of a two-components current meter.

Among the above spectral moments, M_{00}^*, M_{10}^*, and M_{01}^* are not the same with the corresponding ones of Eq. (5). The difference is the presence of the multipliers of f and f^2 in the integrands of Eq. (19), but its influence upon directional output is considered minimal. Thus, one may use the covariances of Eq. (19) as the substitutes of spectral moments of Eq. (5) in estimating various directional parameters. For example, the mean wave direction is estimated by the formula of

$$\bar{\theta} = \tan^{-1}(\overline{\eta_t \eta_y} \,/\, \overline{\eta_t \eta_x}) \quad (20)$$

The long-crestedness parameter γ and the mean spreading angle θ_K are evaluated for the standard spectrum of Eqs. (13) to (18) with the modified spectral moments

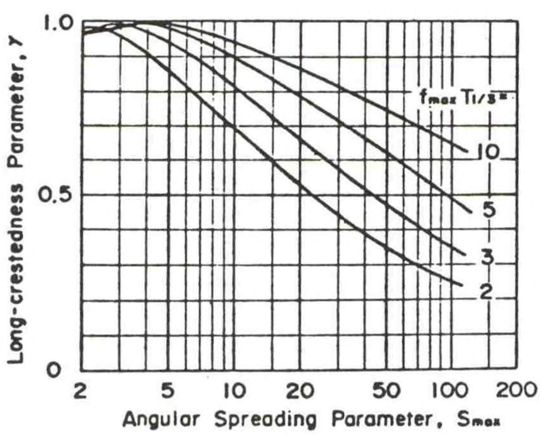

Fig. 5 Long-crestedness Parameter

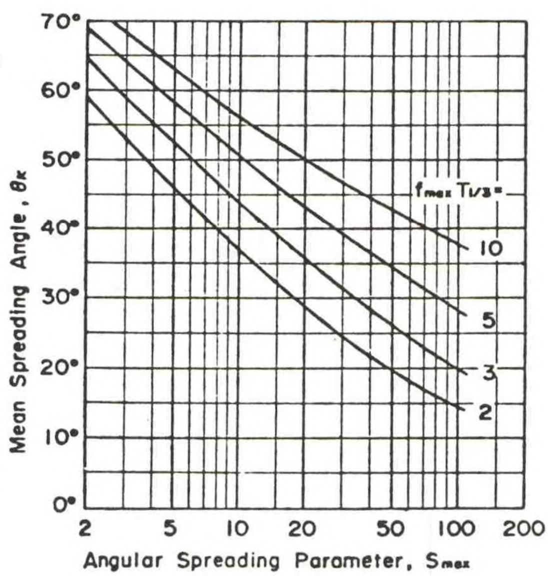

Fig. 6 Mean Spreading Angle

of Eq. (19). The results are shown in Figures 5 and 6. Both parameters are plotted against the angular spreading parameter of S_{max} for four different levels of the cutoff frequency f_{max}, which must enter into the numerical integrations of Eq. (19) as well as in the actual wave measurements. These figures indicate that wind waves have the long-crestedness parameter of 0.7 to 0.9 and the mean spreading angle of 35° to 55°.

C. Simulation of Directional Waves

The time histories of the heave velocity, pitch angle, and roll angle of a surface-following buoy, which are denoted by ζ_i in general, have been simulated with the following standard formula:

$$\zeta_i(t) = \sum_{m=1}^{M} \sum_{n=1}^{K} K_i(f_m, \theta_n)\, a_{m,n} \cos(2\pi f_m t + \varepsilon_{m,n} + \phi_i) + w_i(t) \quad (21)$$

where $K_i(f_m, \theta_n)$ and ϕ_i denote the amplitude and phase of the transfer function of the variable ζ_i to the surface profile of waves, respectively, $a_{m,n}$ is the amplitude of component wave, $\varepsilon_{m,n}$ is the random phase angle uniformly distributed between 0 and 2π, and $w_i(t)$ is a Gaussian-distributed random variable simulating noises inherent in the wave measurements. The terms with the horizontal coordinates x and y are dropped in Eq. (21) by taking the origin of coordinates at the mean position of the buoy under the assumption of small amplitude motions.

The amplitude $a_{m,n}$ is determined from the directional spectrum as:

$$a_{m,n} = \sqrt{2\, S(f_m)\, \Delta f_m}\; \sqrt{G(\theta_n | f_m)\, \Delta\theta_n} \quad (22)$$

The simulations have been done with the frequency components of M = 101 and the directional components of K = 72 for most cases. The frequency f_m is randomly chosen in an equally-spaced frequency range, whereas the direction θ_n is determined by eqully deviding the range of $-\pi$ to π. All the simulated time histories are composed of 1024 consecutive data points with the time interval of $\Delta t = 1$ s. The noise level is 1 per cent of the signal in the root-mean-square value unless otherwise stated.

The transfer functions have been calculated by assuming the buoy follows the wave motion perfectly. Additional information on computational techniques may be found elsewhere, e.g. [8].

D. Representative Direction of Bimodal Directional Waves

Examples of simulation tests with bimodal directional waves are shown in Figures 7 and 8. The waves A are assigned the significant period of $T_{1/3} = 8$ s with the spreading parameter of $S_{max} = 10$ representing wind waves, while the waves B are given the values of $T_{1/3} = 16$ s and $S_{max} = 100$ modelling swell from a remote source. Two combinations of wave directions are tested: the one with $\theta_A = 40°$ and $\theta_B = -40°$, and the other with $\theta_A = 60°$ and $\theta_B = -60°$. Since the simulation is linear, the absolute value of wave height does not affect the result and the ratio of their energy levels is varied gradually as indicated in the abscissas of Figures 7 and 8. Simulations are repeated eight times with different wave profiles for a given condition, and the mean and the standard deviation by eight runs are indicated with the open or closed circles and the vertical bars equivalent to the magnitude of standard deviation.

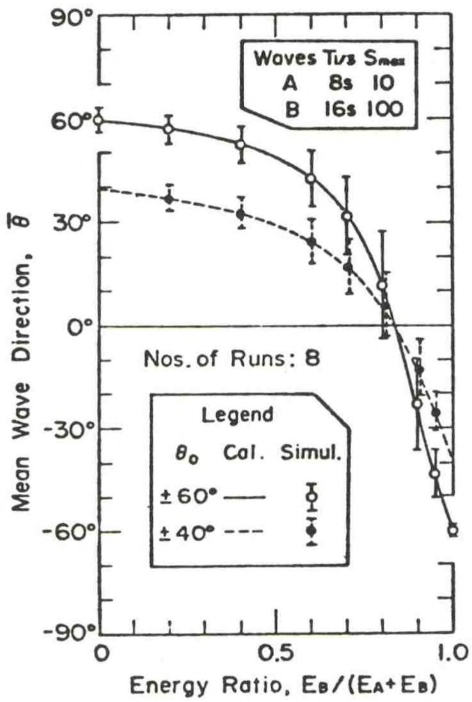

Fig. 7 Mean Wave Direction of Bimodal Waves

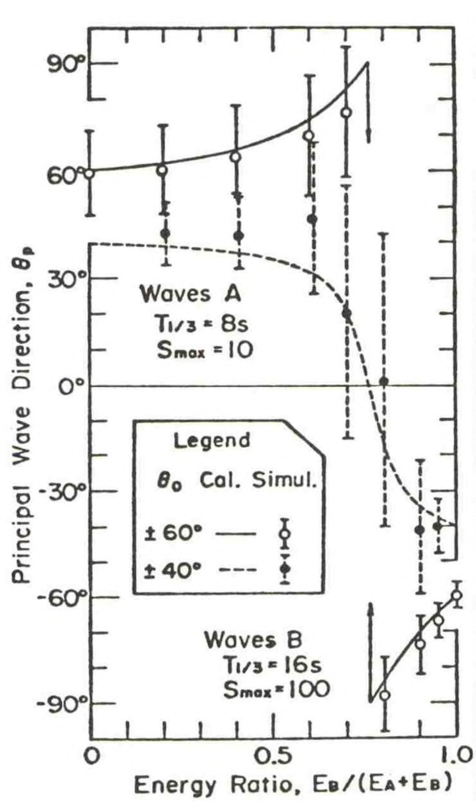

Fig. 8 Principal Wave Direction of Bimodal Waves

Figure 7 exhibits the mean wave direction estimated by Eq. (20) with the covariances obtained from simulated buoy motion records. The solid and dashed lines represent the mean directions calculated from the moments of the input directional spectra by numerical integrations. The agreement between simulations and calculations is the evidence that the mean wave direction can be estimated directly from the covariances without computing directional spectra.

The odd behaviour of the principal wave direction depicted in Figure 2 appears again in Figure 8. When the directions of two wave systems are 80° apart, the principal direction gradually varies between +40° and -40° as the ratio of their energy levels varies. But when the directions of two wave systems are 120° apart, the principal direction gradually increases from 60° toward 90° as the energy level of the waves B starts to increase. At the energy ratio of $E_B/(E_A+E_B) \doteqdot 0.76$, the principal direction switches to -90° and then moves up to -60° as the energy level of the waves B further increases.

The variation of the mean wave direction between the directions of two wave systems is not proportional to their energy ratio. If so, $\bar{\theta}$ would take the direction of $\theta = 0°$ at $E_B/(E_A+E_B) = 0.5$, but it does so at $E_B/(E_A+E_B) \doteqdot 0.83$. In general, the short-period part of bimodal waves excercises greater influence upon the mean wave direction than the long-period part when a surface-following buoy is employed for directional measurements. The effect of wave period is approximately obtained from Eq. (8) though the mean wave direction exhibits a tendency of slightly approaching to the direction of waves with greater S_{max}.

E. Spreading Parameter of Bimodal Directional Waves

The variation of the mean spreading angle defined by Eq. (12) for waves with bimodal directionality is shown in Figure 9. The wave characteristics are the same with those of Figures 7 and 8. As the ratio of energy levels varies from 0 to 1, the mean spreading angle increases from the starting value of wind waves with $S_{max} = 10$ toward some maximum values, and then decreases toward the ending value of swell with $S_{max} = 100$. The mean spreading angle of bimodal waves takes the maximum value at the energy ratio which yields $\bar{\theta} = \Theta$, and the maximum value is always greater than one half of the angular difference between the bimodal directions. A large value of the mean spreading angle, say over 60°, is quite a good evidence of the presence of bimodal directionality, though a small value of θ_K does not necessarily negate the possibility of bimodal directionality. The agreement between simulations and calculations for θ_K and the fact that θ_K is obtainable from the three covariances between η_t, η_x, and η_y lead to the suggestion that θ_K should be included in the real-time analysis of buoy motion records so as to obtain a good measure of angular spreading at the same time with the information of mean wave direction.

Inappropriateness of the long-crestedness parameter γ as a measure of angular spreading for waves with bimodal directionality is demonstrated in Figure 10. Two wave trains of identical characteristics are simulated to cross each other at the angle ranging from 30° to 150°. The open circles and the solid line represent the case of symmetric wind wave system with $S_{max} = 10$, while the closed circles and the dash-dot line represent the case of symmetric swell with $S_{max} = 100$. The long-crestedness parameter approaches very close to 1.0 at the crossing angle of $2\Omega = 90°$ if not exactly 1.0 as predicted by theory, and it is symmetric with respect to the axis at $2\Omega = 90°$. Thus, the long-crestedness parameter is valid only in indicating how close is the angular difference between bimodal directions to 90° if waves are of bimodal directionality.

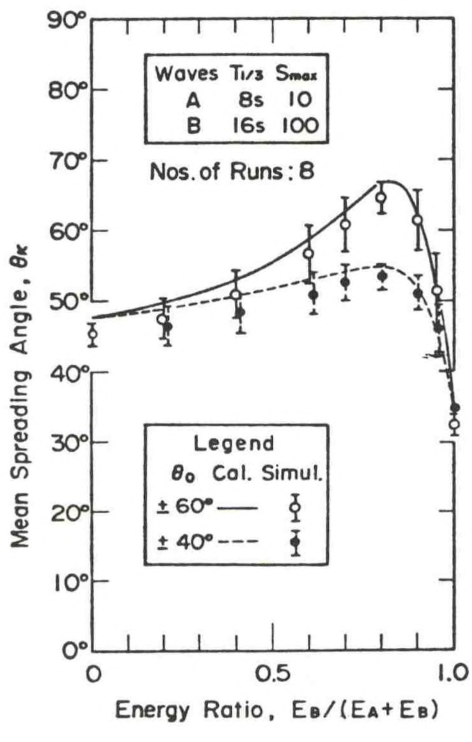

Fig. 9 Mean Spreading Angle of Bimodal Waves

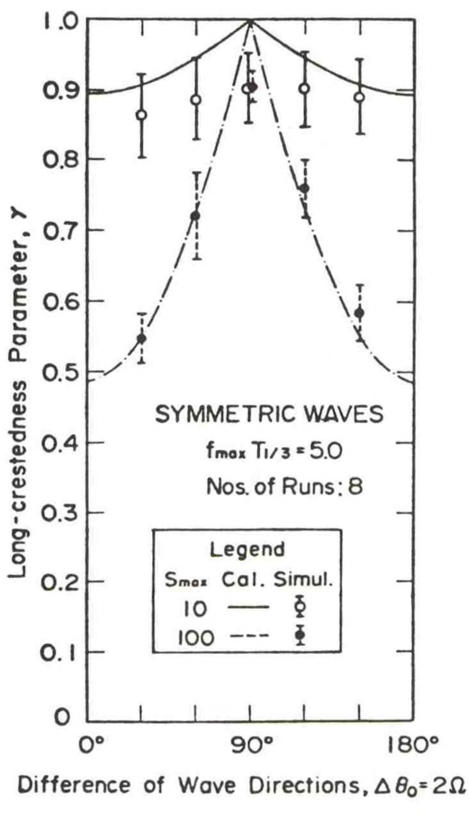

Fig.10 Long-crestedness Parameter of Symmetric Bimodal Waves

F. Statistical Variability of Directional Parameters

Figures 7 to 11 all list the amounts of standard deviations of simulation data. These deviations are considered to represent the statistical variations of ocean waves themselves and not the peculiarity of

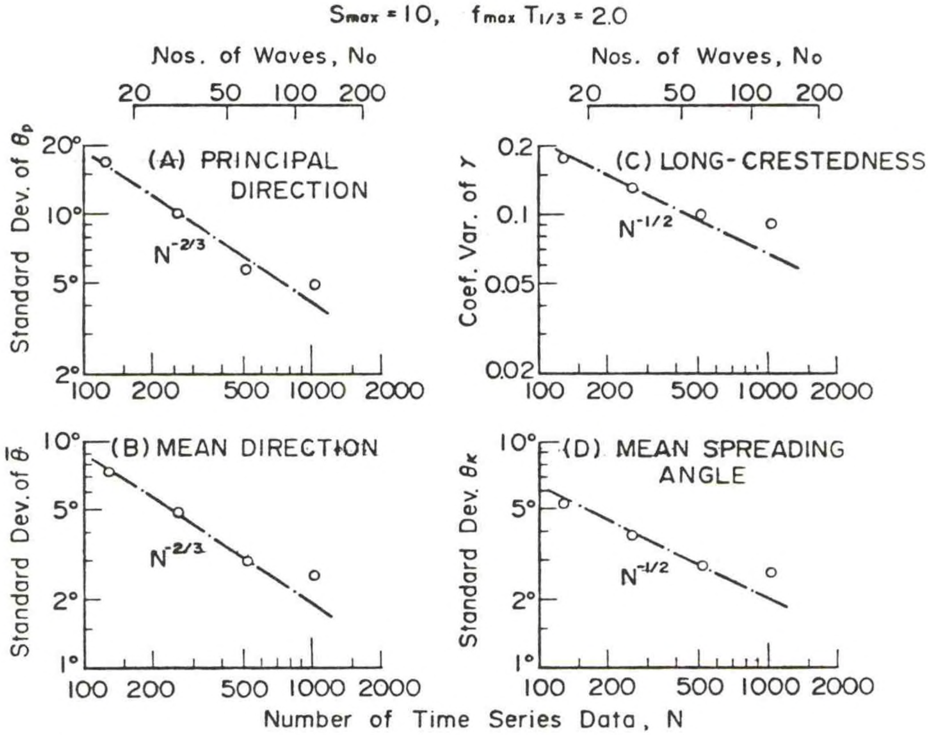

Fig. 11 Statistical Variation of Directional Parameters

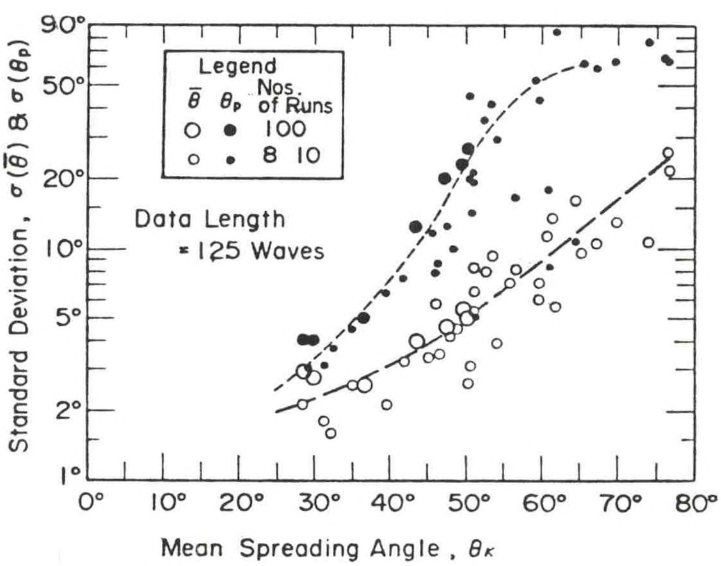

Fig. 12 Standard Deviations of Mean and Principal Wave Directions

simulation data [8,9]. In order to examine the amounts of statistical variations, simulations of waves with unimodal directionality have been carried out for one hundred runs each for various wave conditions. Artificial noises are not added in these simulations.

Figure 11 exhibits the effect of data length upon the statistical variability of several directional parameters. The significant wave period is set at $T_{1/3} = 10$ s, and the data length in terms of the number of waves is listed at the upper portion of the figure. The standard deviations of the mean and principal wave direction seem to vary in proportion to $N^{-2/3}$ where N is the number of data point, while the coefficient of variation of the long-crestedness parameter and the standard deviation of the mean spreading angle vary in proportion to $N^{-1/2}$.

The standard deviations of the mean and principal wave directions are also affected by the mean spreading angle as shown in Figure 12, which include the data of bimodal directional waves. The data length corresponds to the record of about 125 waves. Figure 12 clearly demonstrates the tendency that the smaller the angular spreading, the smaller the variability of estimated wave directions. Furthermore, the principal wave direction marked with closed circles yield much larger deviations than the mean wave direction, indicating another inferiority as the directional parameter. Based on this data, the mean wave direction estimated for wind waves is better given the range of error of about 10° by the 2σ criterion on account of the statistical variability of ocean waves alone.

Examination has been further made on the variability of frequency-wise parameters. The density of component waves with respect to the frequency as well as the data length have been varied to provide a range of variation of the equivalent degree of freedom, r, in the spectral analysis. The smaller number of either the frequency components or the periodograms by the Fast Fourier Transform analysis in the frequency band of one spectral estimate is considered to govern the equivalent degree of freedom. First, the coefficient of variation of the power spectral densities of heave, pitch, and roll motions have been examined, and they are found in agreement with the statistical theory. Next, the following equality between the co-spectra has been examined:

$$C_{11}(\omega) = \frac{\omega^2}{k^2} \left[C_{22}(\omega) + C_{33}(\omega) \right] \tag{23}$$

where C_{11}, C_{22}, and C_{33} denote the auto-cospectra of heave velocity, pitch angle, and roll angle, respectively, and ω stands for the circular frequency of 2πf. The coefficient of variation of the above equality is shown in Figure 13, which indicates its proportionality to $r^{-1/2}$. This coefficient of variation also seems to increase with

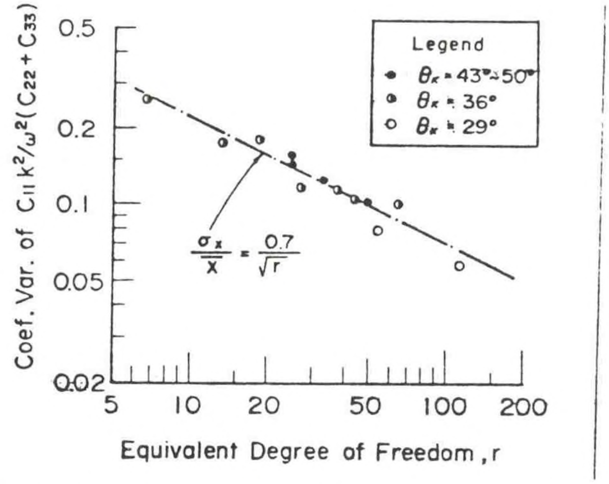

Fig. 13 Coefficient of Variation of Equality between Co-spectra

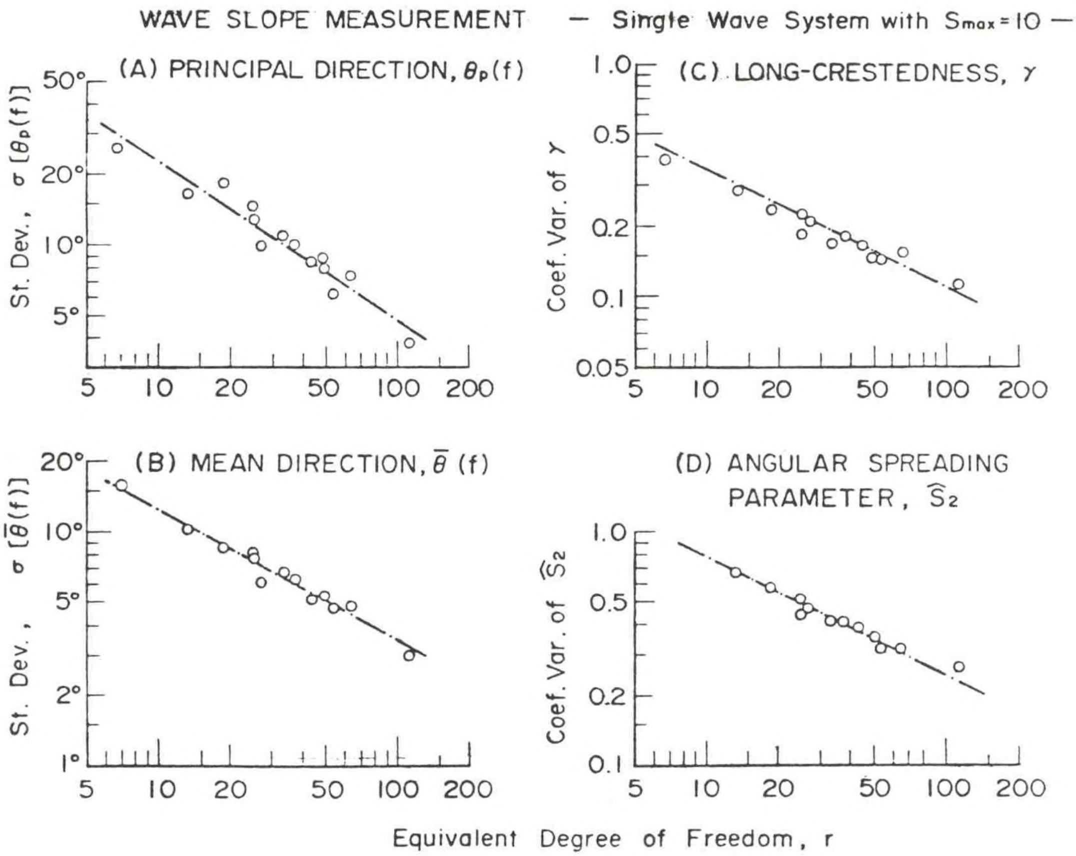

Fig. 14 Statistical Variation of Frequency-wise Parameters

the increase of the mean spreading angle according to other data of simulation studies [10].

As demonstrated by Longuet-Higgins et al. [11] the cross spectral analysis of the motion of a surface-following buoy yields the estimates of the frequency-wise mean direction, principal direction, long-crestedness parameter, and angular spreading parameter. The estimation of these parameters is all subject to the statistical variations as exhibited in Figure 14, where the case of unimodal waves with $S_{max} = 10$ is shown. The frequency-wise principal direction is seen to have much larger deviation than the frequency-wise mean direction. The frequency-wise long-crestedness parameter and angular spreading parameter $\hat{S}_2$, both estimated by the second harmonic terms of angular spreading function, have quite large coefficients of variations. Certainly, the statistical variability of these frequency-wise parameters will be affected by the overall angular spreading of waves in concern, too.

These results of Figures 11 to 14 will serve as guidelines of the magnitude of probable errors involved in the measurements of directional wave characteristics. The data length and the equivalent degree of freedom in spectral analysis may be so chosen to yield the optimum combination of the fineness and accuracy of information sought for in the measurements.

IV. FIELD TESTS WITH DISCUS BUOY

A. Test Site and Instrumentation

A discus buoy with the diameter of 10 m has been stationed since 1978 off the Port of Kochi, Shikoku at the location shown in Figure 15 at the water depth of about 120 m. The buoy belongs to the Third District Port Construction Bureau, Ministry of Transport, and is functioning to measure wave profiles by means of a vertical accelerometer and an anologue circuit for double integration. On September 11, 1980, it recorded the largest waves of $H_{1/3} = 10.9$ m and $T_{1/3} = 14.0$ s when Typhoon No. 8013 passed west of the buoy.

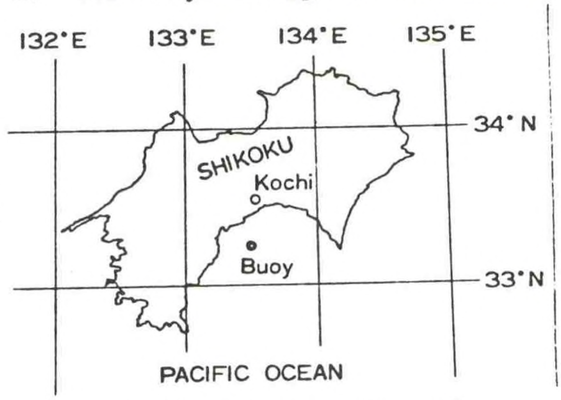

Fig. 15 Location Map of Discus Buoy

Field tests of directional measurements were carried out by borrowing the buoy for one month from November 17 to December 18,

1980. A vertical accelerometer and a two-axis inclinometer of pendulum type were installed near the center of buoy's hull, and a servo-controlled magnetic compass was attached upon the mast of buoy. All the data were recorded on a digital cassette tape controlled by a microprocessor for operations of 20 minutes every two hours. After ten days or so of automatic recording the tape was exchanged for a new one, and the recorded tape was analysed in the laboratory.

B. Sea Conditions and Instrumental Performance

The measurement period happened to belong to the time of quite calm sea, contrary to the expectation. The significant wave height in this period was less than 2.5 m without any noticeable storm.

Another difficulty encountered was the fact that the output of inclinometer was quite annuled by the sway and surge acceleration of the buoy though it was somewhat anticipated. Figure 16 shows the ratio of the sum of power spectral densities of pitch and roll to that of heave acceleration normalized with the acceleration of gravity. If the instrumentations work correctly, the ratio should be 1, but the expected equality is observed in a narrow frequency range around 0.35 Hz only. In this frequency range, the pitch response of buoy to the wave slope still maintain the value near to 1 while the surge response have begun to decline. The increase of the spectral density ratio in the frequency above 0.25 Hz seems to have originated from the difference in the response characteristics between the pitch and surge motions.

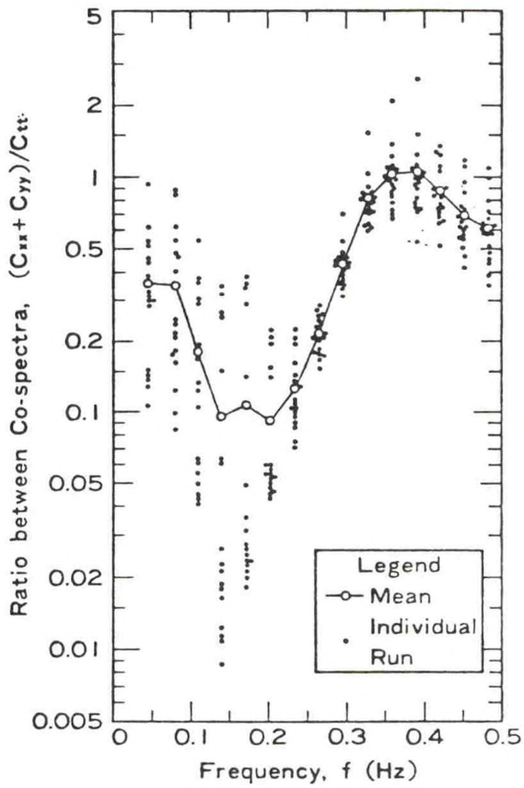

Fig. 16 Equality betwee Co-spectra of Heave, Pitch and Roll

C. Some Results of Field Tests

From the records obtained, 17 cases were selected for analysis. The significant wave height estimated from the zero-th moment of heave spectrum ranged from 0.6 to 1.5 m and the mean wave period was from 5 to 8 s. Time histories of heave velocities were reconstructed by numerical integration of acceleration records. The mean and principal wave directions, the long-crestedness parameter and the mean spreading angle were calculated from the covariances, while various frequency-wise directional parameters were obtained by the cross spectral analysis.

The mean wave direction generally followed the direction of local wind. This is because the low frequency components of pitch and roll motions were not properly recorded as discussed with Figure 16 and the outputs mostly represented the motions in the high frequency range, which corresponded to the frequencies of locally-generated

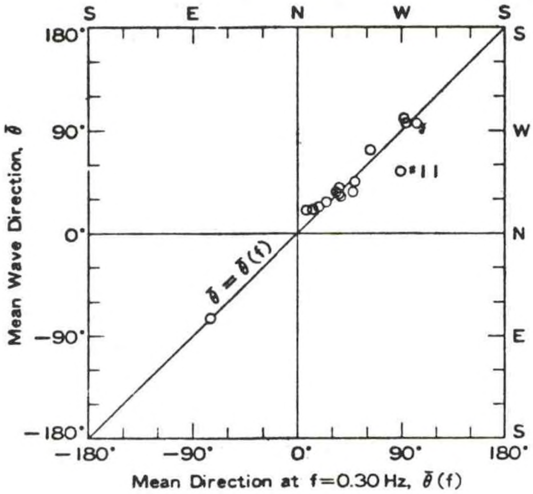

Fig. 17 Mean Wave Direction versus Mean Direction at f = 0.30 Hz

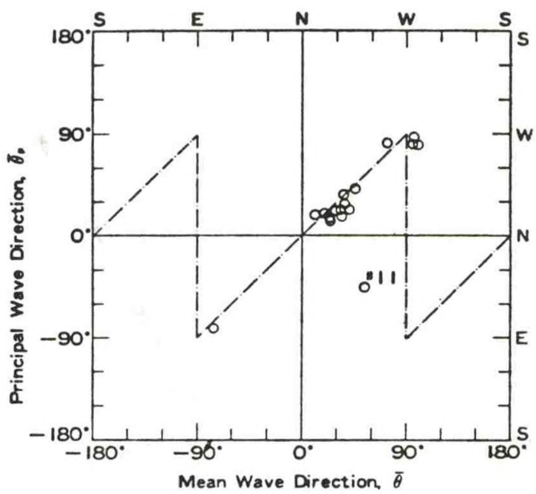

Fig. 18 Principal Wave Direction versus Mean Wave Direction

wind waves. Figure 17 compares the mean wave direction estimated from the covariances of buoy motion records and the mean direction at the frequency band of f = 0.30 Hz obtained by the cross spectral analysis. Except for the Case No. 11, both directions are in good agreement, indicating the reliability of directional estimation by means of the covariances. Figure 18 shows comparison of the mean and principal wave directions. Because the analysis of principal direction is confined in the half plane, the theoretical relation between the two directions becomes as shown with the sawtooth-like dash-dot line. Except for the Case No. 11, the two directions are in agreement within the allowable range of statistical deviation.

The reason of strange behaviour of the Case No. 11 is explained as the result of the presence of conspicuous bimodality in its directional spectrum. Figure 19 shows the power spectral density of heave acceleration C_{tt}, and the sum of pitch and roll spectral densities, $(C_{xx} + C_{yy})$. As noticed in the spectrum of C_{tt}, two wave systems with the modal frequencies of 0.2 and 0.35 Hz coexisted in this case. The low-frequency waves came from the direction of 120° from the north counterclockwise, while the high-frequency waves came from the direction of -10° as seen from the frequency-wise mean direction shown in Figure 20. This is a case of bimodal directionality with the cross angle greater than 90°. As discussed earlier, the principal direction should be away from the central direction by 90° or so in such a situation. In the Case No. 11, the central direction is 55° and the principal direction is -43°, and the relation is in accord with the theory. For this particular case, the mean spreading angle registered the value of 73°. while the long-crestedness parameter was 0.76.

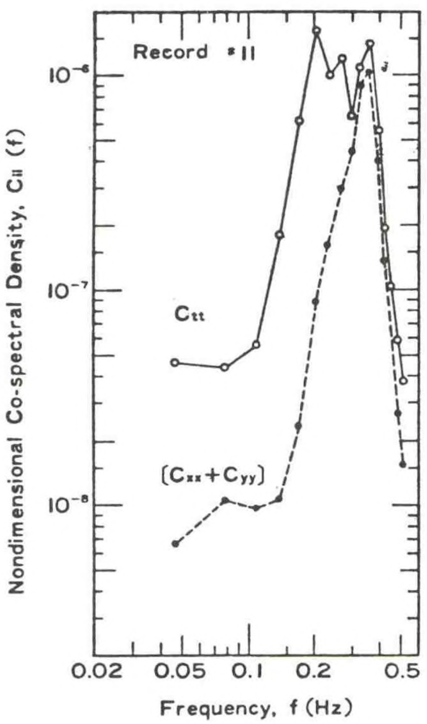

Fig. 19 Spectral Density of Case No. 11

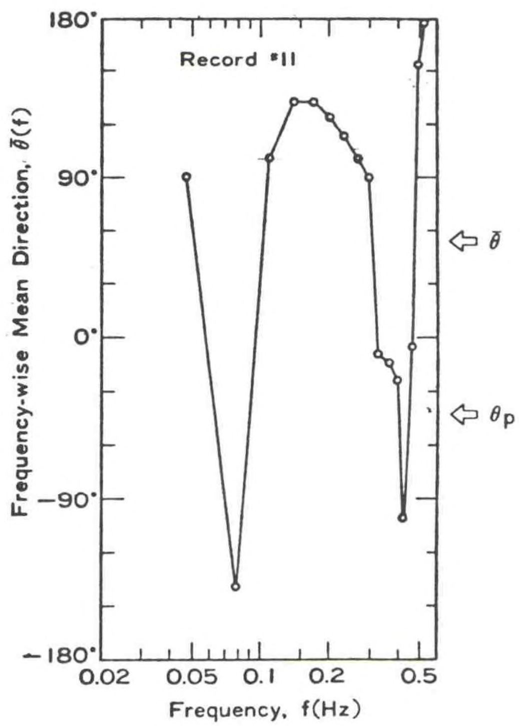

Fig. 20 Frequency-wise Direction of Case No. 11

The estimation of mean direction in the frequency below 0.1 Hz is considered unreliable, because of the poor performance of the inclinometer on the buoy in motion. Future tests are being planned with a better inclinometer and an on-board microprocessor to yield the outputs of mean wave direction and mean spreading angle.

V. SUMMARY

Major results of numerical examinations and field tests on directional wave measurements with a surface-following buoy described in the above can be summarized as in the following:

1. The mean wave direction can be calculated with the covariances between the heave velocity, pitch angle, and roll angle of the buoy, and it serves as the representative direction of unimodal as well as bimodal directional waves.
2. Use of the principal wave direction should be avoided because it yields an improper direction for waves having bimodal directions of more than 90° apart.
3. Use of a newly-defined mean spreading angle is recommended instead of the long-crestedness parameter as a measure of angular spreading of directional waves, because the former has a capability of indicating bimodal directionality while the latter does not.
4. The amounts of statistical variability of various directional parameters have been clarified, and they will serve as guidelines of the magnitude of probable errors involved in directional wave measurements.

The present paper is based on the joint research project No.55-9 of the Port and Harbour Research Institute with the Matsushita Communication Industrial Co., Ltd. A part of expenses for the field tests was covered by the science and technology subsidy budget of the Ministry of Transport awarded to the latter company.

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Directional Wave Spectrum for the Design of Harbour Structures

by

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INTRODUCTION

Ocean waves are characterized with the irregularity of surface profiles. Wave crests are terminated here and there, moving into various directions. The terminology of "short-crested waves" has been used to denote such irregular ocean waves. Mathematically, the irregularity of ocean waves are described with the concept of directional spectrum. Oceanographers have been endeavouring to measure directional wave spectra in order to clarify the mechanisms of wave generation, propagation, and transformations.

Directional wave spectrum is important for engineering problems, too. Responses of marine facilities to ocean waves are greately affected by directional characteristics of wave spectra. Planning and designs of harbour facilities are also required to take into account directional wave spectra. Since 1978, the Bureau of Ports and Harbours, Ministry of Transport, is advising the use of directional wave spectra in the design of harbour facilities in Japan through the Circular Note of the Director General of the Bureau of Ports and Harbours [1]. The present paper introduces the features of directional wave spectrum being employed in Japan.

STANDARD FORM OF DIRECTIONAL WAVE SPECTRUM

Functional Form

The directional wave spectrum is generally expressed as the product of frequency spectrum $S(f)$ and an angular distribution function $G(f,\theta)$; that is,

$$S(f,\theta) = S(f)\, G(f,\theta) \tag{1}$$

The frequency spectrum $S(f)$ is given the unit of m^2s or its equivalent one, while $G(f,\theta)$ is normalized so as to yield the unit value without a dimension when integrated over the full range of wave direction.

The functional form of $S(f)$ can be taken as Bretschneider's spectrum [2] modified by Mitsuyasu [3] for the numerical values of coefficients. Thus,

$$S(f) = 0.257\, H_{1/3}^{2}\, T_{1/3}^{-4}\, f^{-5} \exp[-1.03\, (T_{1/3} f)^{-4}]. \qquad (2)$$

This is a type of two-parameter spectrum designat by an arbitrary combination of significant wave height and period, $H_{1/}$ and $T_{1/3}$. Functionally, Eq. 2 is the same with the Pierson-Moskowitz spec um and the ISSC spectrum [e.g., 4], and seems to be the most representati of well developed wind waves. Equation 2 is sometimes applied to swell too, whenever the engineer's needs arise, with the execuse of little information available on the standard form of swell spectra. The modal frequency or the frequency at spectral peak is set to satisfy the following relation:

$$f_p = \frac{1}{1.05\, T_{1/3}} . \qquad (3)$$

This relation was proposed by Mitsuyasu [3] and has been confirmed to be representative of sea waves [4].

Another choise of frequency spectrum is the generalized JONSWAP spectrum of the following [4]:

$$S(f) = \alpha_0 H_{1/3}^{2}\, T_p^{-4}\, f^{-5} \exp[-1.25 (T_p f)^{-4}]\, \gamma^{\exp[-(T_p f - 1)^2 / 2\sigma^2]}, \qquad (4)$$

where,

$$\alpha_0 \simeq \frac{0.0624}{0.230 + 0.0336\,\gamma - 0.185 (1.9 + \gamma)^{-1}} , \qquad (5)$$

$$\sigma = \begin{cases} \sigma_a : & f \leq f_p \\ \sigma_b : & f > f_p , \end{cases} \qquad (6)$$

$$\gamma = 1 \sim 10, \quad \sigma_a \simeq 0.07, \quad \sigma_b \simeq 0.09.$$

The parameter α_0 in Eq. 5 has been empirically formulated from the results of numerical integration of Eq. 4 so as to satisfy the theoretical relation between the zero-th moment of spectrum and significant wave height. The generalized JONSWAP spectrum may be employed to represent wind waves developed by strong winds over short fetches, which are usually characterized with sharp spectral peaks.

As to the angular distribution function, the formula proposed by Mitsuyasu et al. [5] based on their detailed observations seems most reliable at present. In a slightly modified form, it is written as

$$G(f,\theta) = G_0 \cos^{2S}(\theta/2), \qquad (7)$$

where,

$$G_0 = \left\{ \int_{\theta_{min}}^{\theta_{max}} \cos^{2S}(\theta/2)\, d\theta \right\}^{-1} , \qquad (8)$$

$$S = \begin{cases} S_{max}\cdot(f/f_p)^5 & : f \leq f_p, \\ S_{max}\cdot(f/f_p)^{-2.5} & : f \geq f_p. \end{cases} \quad (9)$$

The angle θ is measured from the mean direction of wave propagation. The term of G_0 is so introduced to normalize $G(f,\theta)$. The parameter S has the maximum value at $f = f_p$ and decreases at the both sides of spectral peak.

Selection of S_{max}

Figure 1 is a demonstration of wave patterns, which shows the contours of surface elevations above the mean water level; the portion of wave troughs is left as blank. This figure is a result of numerical simulation by the principle of linear superposition with the spectrum of Eqs. 1, 2, and 7 to 9. The parameter S_{max} is subjectively chosen as 10 and 75, respectively. It will be seen that $S_{max} = 10$ yields the wave pattern quite random and somewhat resembling that of wind waves, while $S_{max} = 75$ may corresponds to the wave pattern of swell.

The original proposal of Mitsuyasu et al. [5] for S_{max} is to relate it with the nondimensional frequency parameter as

$$S_{max} = 11.5\cdot(2\pi f_p U/g)^{-2.5}, \quad (10)$$

where U denotes the wind speed and g is the acceleration of gravity. Equation 10 is not readily applicable for engineering problems because the design wave height and period are often designated without reference to the wind speed. The knowledge of wave growth depicted in the Sverdrup-Munk-Bretschneider method suggests that the increase of the parameter $2\pi f_p U/g$ ($=U/C_p$) is associated with the decrease in the wave steepness H_0/L_0. Thus, S_{max} can be assumed to increase as the wave steepness decreases.

From the above discussions, the author has proposed the following values of S_{max} for engineering applications [6]:

$$S_{max} = \begin{cases} 10 & : \text{for wind waves,} \\ 25 & : \text{for swell with short to medium decay distance,} \\ 75 & : \text{for swell with medium to long decay distance.} \end{cases} \quad (11)$$

SOME PROPERTIES OF ANGULAR DISTRIBUTION FUNCTION

Though the above proposal is somewhat subjective, $S_{max} = 10$ for wind waves is not without ground, because it yields the overall angular distribution almost the same with the law of $(2/\pi)\cos^2\theta$ and the formula of SWOP. Figure 2 shows the nondimensional cumulative curves of wave energy calculated for the directional wave spectrum with the combination of Eq. 2 and Eqs. 7 to 9. The term of $P_E(\theta)$ is calculated by

$$P_E(\theta) = \frac{1}{m_0}\int_{-\pi/2}^{\theta}\int_0^{\infty} S(f,\theta)\, df\, d\theta. \quad (12)$$

The diagram can be utilized to allocate the relative wave energy to several wave directions such as expressed in sixteen points bearings. Calculation of $P_E(\theta)$ also yields the approximate relation of

$$\ell \simeq 0.11\, S_{max} \; : \; \ell \geq 2, \tag{13}$$

for the type of the following angular distribution function:

$$G(f,\theta) \equiv G(\theta) = \frac{2\ell!!}{\pi(2\ell-1)!!} \cos^{2\ell}\theta, \tag{14}$$

where $2n!! = 2n\cdot(2n-2)\cdots4\cdot2$ and $(2n-1)!! = (2n-1)\cdot(2n-3)\cdots3\cdot1$.

When applying the above spectrum in shallow water, some correction to S_{max} is necessary because the phenomenon of wave refraction makes the angular distribution narrower. Calculation of wave refraction in the water of parallel straight bathmetry has yielded the diagram for the change of S_{max} as shown in Fig. 3. The abscissa is the ratio of water depth, h, to the deep-water wavelength, L_0, corresponding to the significant wave period, $T_{1/3}$. The angle $(\alpha_p)_0$ denotes the incident wave angle to the boundary of deep to shallow waters. As the effect of $(\alpha_p)_0$ is small, the diagram may be utilized for waters of general bathmetry.

APPLICATIONS OF DIRECTIONAL WAVE SPECTRUM

Figure 4 is the wave refraction coefficient in the water of parallel straight bathmetry, calculated with the directional spectrum described hereto. Some differences are observed in the refraction coefficient of wind waves with $S_{max} = 10$ and swell with $S_{max} = 75$. In the water of complex bathmetry, the conventional analysis of wave refraction with the monocromatic wave concept becomes inaccurate, and the effect of directional wave spectrum becomes pronounced.

The use of directional wave spectrum is almost compulsory in the analysis of wave diffraction behind breakwaters. Figure 5 is an example of the comparison of wave diffraction diagrams by monocromatic waves (left) and by directional spectral wave (right) [7]. The difference in the contours of diffraction coefficient, or the ratio of diffracted wave height to incident height, is so obvious that engineers must make decision to choose one of them. Simultaneous field wave observations outside and inside breakwaters have proven the inaccuracy of monocromatic diffraction diagrams and the reliability of spectral diffraction diagrams [8].

The example of Fig. 5 is based on the angular distribution function of Eq. 14 with $\ell = 1$. Figure 6 is an example of diffraction diagrams with the angular distribution function of Eqs. 7 to 9 with the frequency spectrum of Eq. 2. Spectral calculation predicts the variation of representative wave period by wave diffraction as shown in the left-hand portions of the diagrams, although the variation has not been confirmed by field observation data.

Use of directional wave spectrum is needed in many other engineering problems. Wave forces exerted upon a large offshore structures is an example, and the analysis of wave power extraction is another. No marine facilities can be designed with a simple method by monocromatic wave concept unless it is proven as an acceptable approximation to the method by directional random waves. The directional wave spectrum presented hereon is the engineer's proposal and is subject to modifications in the future, when much more information on directional wave characteristics will become available through various field observation projects. Until that time, the proposed spectrum will continue to serve engineers in planning and designs of habour facilities.

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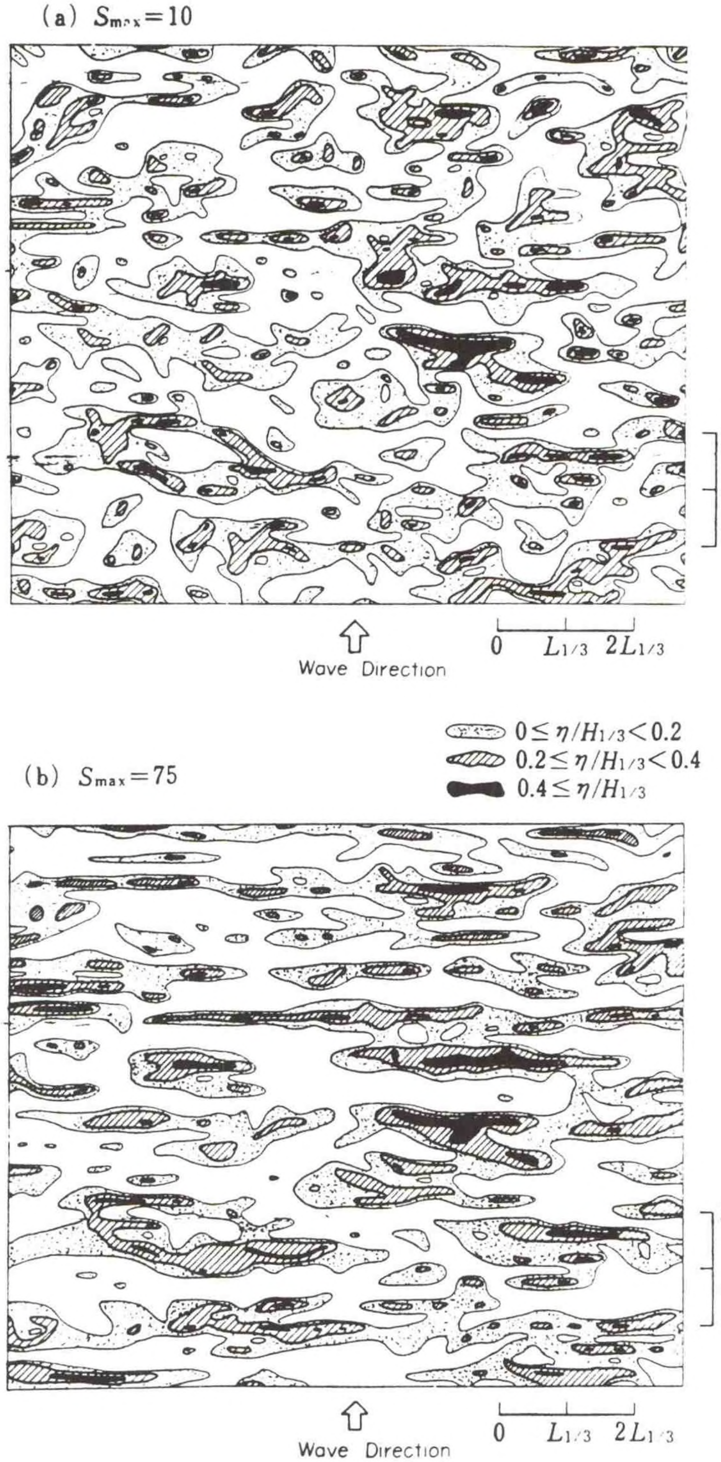


Fig. 1 Surface Elevation Contours of Random Waves Numerical Simulation

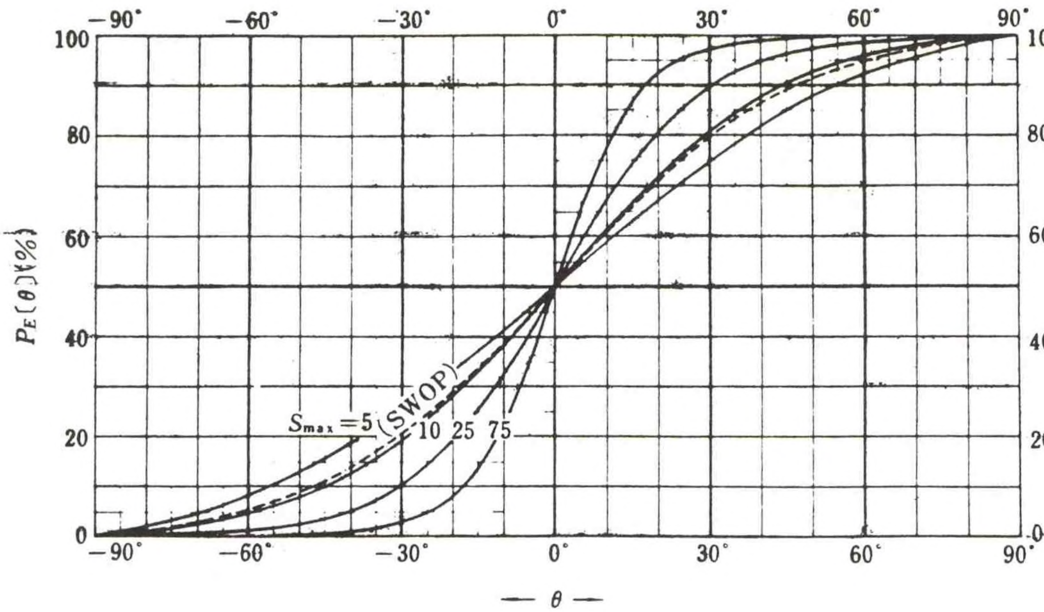


Fig. 2 Cumulative Curves of Relative Wave Energy with Respect to Azimuth from the Principal Wave Direction

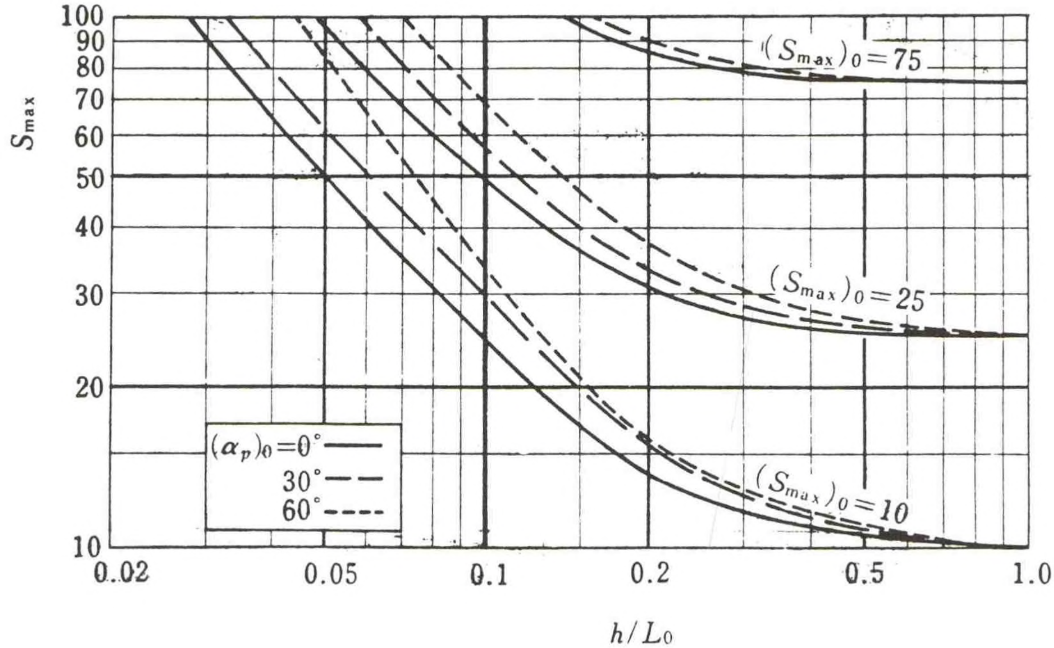


Fig. 3 Change of Parameter S_{max} due to Wave Refraction in Shallow Water

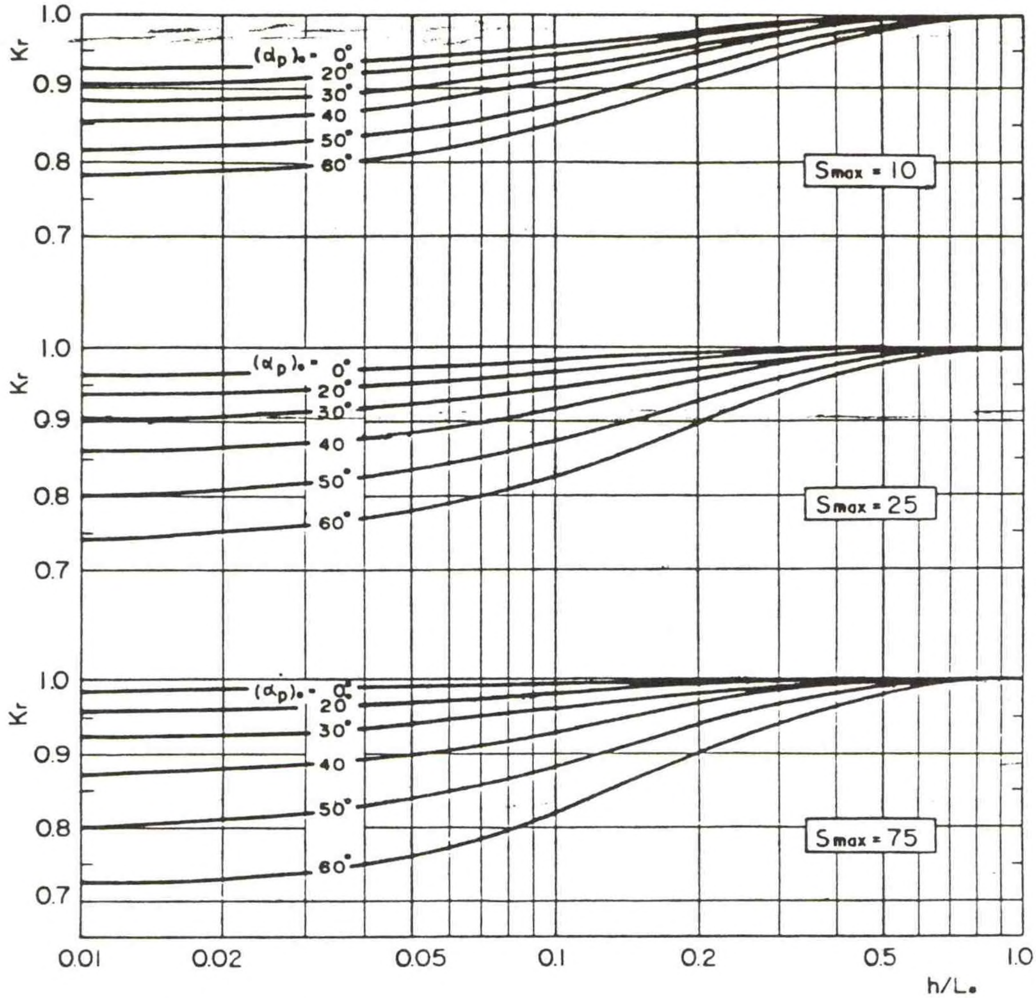


Fig. 4 Refraction Coefficient of Directional Random Waves in a Coast with Parallel Straight Contour Lines

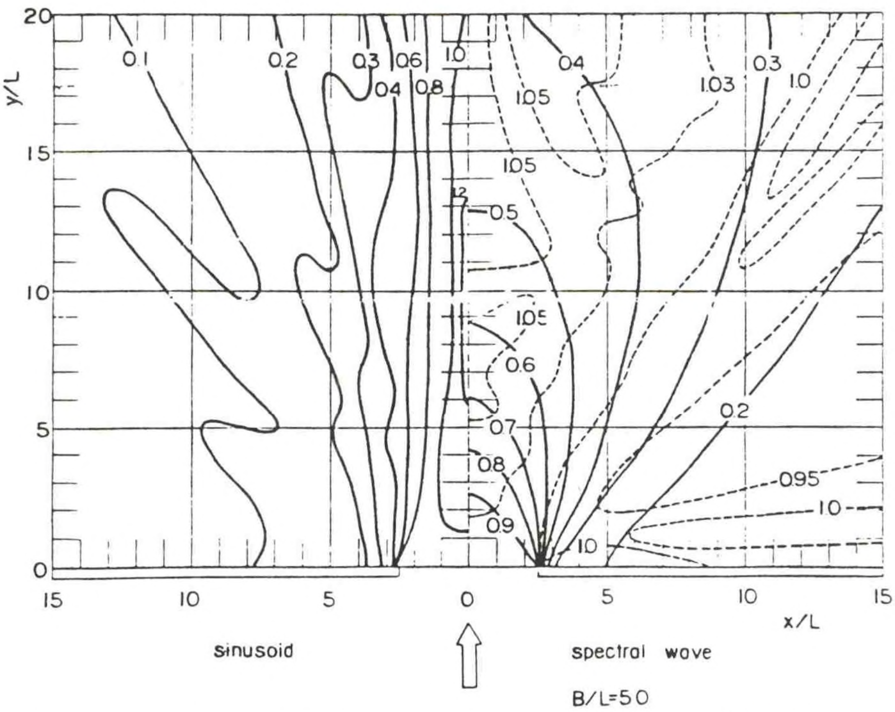
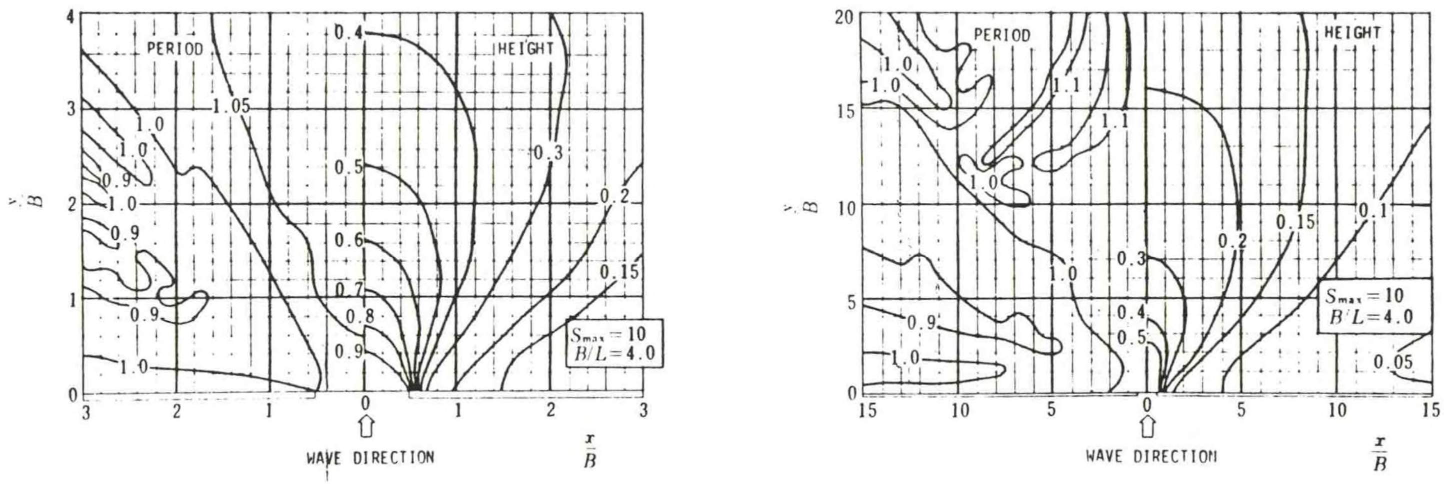
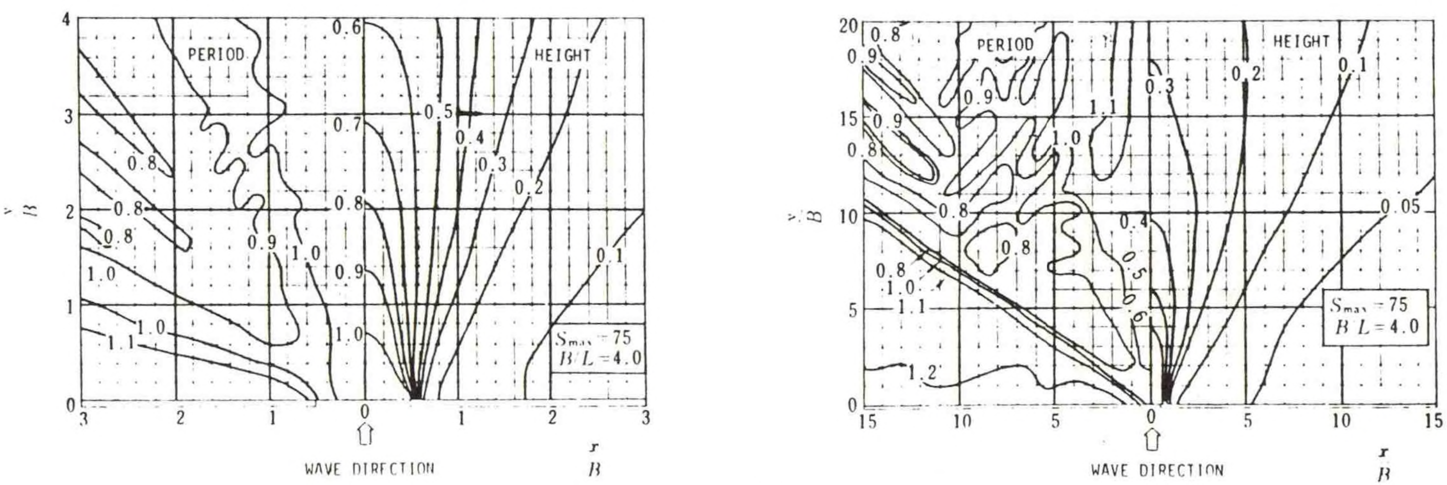


Fig. 5 Comparison of Monocromatic and Random Diffraction Diagrams for the Case of B/L = 5.0 (after Nagai [9])



(1) S_{max} = 10



(2) S_{max} = 75

Fig. 6 Diffraction Diagrams of a Breakwater Gap with B/L = 4.0 for Directional Random Waves of Normal Incidence

Facilities for Recovery of Oil and Gas from the Outer Continental Shelf

by

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After discovery of an oil and gas reserve has been made in the offshore area, development of the field generally takes place from a fixed platform. The greatest number of these structures are in the Gulf of Mexico area of the United States where there are nearly 2,800 located on the Outer Continental Shelf (OCS). The design criteria for these types of platforms includes design against a storm recurrence interval of 100 years, as well as other local environmental phenomena. In general in the Gulf of Mexico, this would include maximum winds of 249 kilometers per hour (kmph) and waves of 15 meters (m). A platform designed for this criteria in 47 m of water currently contains approximately 3,100 metric tons (MT) of steel. However, as oil and gas development moves into deeper water and into areas of more extreme, environmental conditions, such as unstable seafloors and more severe wind and wave conditions, more unique platform designs than the normal Gulf of Mexico type platform are being employed. This paper describes a few of these types of platforms that have been installed or are currently in the design phase.

Tension Leg Platform (TLP) Conoco Inc.

Plans for the world's first TLP, a floating drilling and production facility, have been announced by Conoco Inc., for the Hutton Field in the North Sea. Although no actual installation plans have been proposed for this type facility in the United States OCS area, there have been a few preliminary discussions with lessees who are considering utilization of a TLP for development of deepwater prospects greater than 366 m. These discussions have involved one potential Gulf of Mexico location and one site off the southern California coast. The TLP superstructure resembles a semisubmersible-type floating drilling rig. The superstructure, unlike the semisubmersible-type floating drilling rig which is connected to the seabed with mooring lines and anchors, is connected to the seabed with vertical structural tubes or cables in a pretensioned condition. These pretensioned structural members will virtually eliminate the movements of heave, pitch, and roll while the lateral seakeeping movements of sway and yaw are compliantly restrained. Buoyancy will be provided by the large watertight chambers composed of the vertical columns and the connecting horizontal pontoons located on the bottom side of the superstructure. An excess of buoyancy greater than the platform weight will keep the "legs" in tension for all weather and loading conditions. Each "leg" will be pretensioned to almost 900 MT for current designs. Column height must be sufficient to support the deck above the wave crest elevations for maximum storm and tidal conditions. The TLP will be permanently installed so that it can resist the effects of extreme environmental conditions and continue operations similar to conventional fixed platforms. As with current conventional fixed platforms, all structural components will be designed for a minimum of 20 years service life. Key components are relatively simple and intrinsically reliable, redundant, inspectable, maintainable, and replaceable.

Additionally, a TLP can be moved and reinstalled in another location raising the prospect of one platform being used to develop more than one field. Designers believe that the TLP is economically feasible for water depths greater than 460 m. Another desirable feature of the TLP is the fact that all the production facilities can be installed and hooked-up at an onshore base, thereby, making the float-out and installation less weather sensitive than for a fixed platform. Important savings in both time and money can thereby be realized.

We believe that the utilization of TLPs is an important step in the development of offshore technology, pointing the way toward solving the deepwater problem.

COGNAC Platform - Shell Oil Company, et. al.

The tallest and heaviest steel platform ever built, COGNAC, stands 386 m tall (with drilling rigs atop), weighs approximately 54,000 MT, and will support a total of 62 conductors. It stands in water 312 m deep and is designed to withstand the combined forces induced by a 21 m, 11.5 second period wave, a 1.2 m per second surface current, and a wind speed of 200 kmph acting on the structure (240 kmph acting on deck components).

Due to its large size and weight, it was necessary to build and launch COGNAC in three separate sections. The base section weighing 12,800 MT was launched in the summer of 1977. The lowering and positioning of this section was accomplished with remarkable accuracy using computer control techniques and a computerized control room installed on one of the launch barges. Once positioned on the ocean floor, 24 piles, each 190 m long and weighing 424 MT, were driven to a total penetration of 137 m using an underwater hammer designed and built especially for this job. The following summer, the launching and lowering of the middle and top sections were accomplished. The underwater joining of these sections to the preinstalled base section, and to each other, required remarkable accuracy and was accomplished using acoustic telemetry and underwater television as well as diver assistance. Initially, the sections were held in place by temporary hydraulic leg clamps. However, work immediately began to install ten leg pins to permanently secure the three sections together. Each pin was 1.8 m in diameter, weighing 680 MT, and extended from the mud line up into the lower 52 m of the top section. Once the pin grouting operations were accomplished, the jacket installation was complete.

Next, using a temporary deck section as a working area, 62 well conductors were installed extending from the top down to 91 m below the mud line. This completed, the permanent deck was then installed in eight units. The deck provides a 8,100 square meter work area and is the largest ever built in the Gulf of Mexico. Installation of the COGNAC Platform was at that point complete (Fall of 1978).

Many records were set by the installation of Platform COGNAC.

- World's deepest water platform, 312 m

- World's heaviest steel platform, 54,000 MT

- World's first three-part platform

- More well slots (62) than any other Gulf of Mexico platform

- New endurance records for divers working at depths of 260 to 312 m

- First complete offshore platform construction utilizing the underwater hammer

CERVEZA Platform - Union Oil Company of California

The CERVEZA platform, installed in the summer of 1981 for the Union Oil Company of California in the Gulf of Mexico, is the world's largest single-piece offshore structure. Of the three platforms now standing in water depths greater than 244 m, each represents a different solution to the problem of developing oil and gas reserves in deepwater locations.

HONDO, Exxon's giant platform, was built in one piece, cut into two, and then reassembled as it floated horizontally near where it now stands in 260 m of water off the southern California coast.

COGNAC was built in three pieces which were installed vertically over a two-year period (1977 and 1978) and now stands in the Gulf of Mexico in 312 m of water.

CERVEZA was built, launched, and installed in one piece. The mammoth steel jacket, without decking, is 290 m tall. At its base, CERVEZA measures 107 m x 79 m and at the top 46 m x 25 m. The jacket weighs 24,000 MT, and with the main and cellar decks and 34 well conductors installed, the total structure weight is 36,000 MT. With the installation of two drilling rigs, the overall height is 350 m from the top of the rig to the sea floor.

CERVEZA was loaded out on the 198 m long, specifically-designed launch barge on June 6, 1981. It traveled down the Atchafalaya River to the Gulf of Mexico where seven tugs began a 2-day tow over 338 kilometers (km) of open water to the installation site. The jacket was launched on June 18, 1981--about 2 km south of the actual installation point. It was ballasted into an upright position, and using satellite telemetry, was maneuvered into final position--a remarkable 41 m from the imaginary X on the Gulf of Mexico floor. The installation of 8 1.5 m main piles, 16 1.8m skirt piles, 34 well conductors, and the main and cellar decks was completed in September 1981.

As of March 30, 1982, one well has been drilled from CERVEZA, and a second is being drilled by the single rig that has been installed.

CERVEZA was designed to withstand a storm with the combined forces of a 23 m, 13-second period wave and sustained winds of 217 kmph. In addition to this 100-year storm criteria, the structure also was designed for a fatigue life of a minimum of 40 years and provided with cathodic protection for 20 years by 2,200 magnesium/aluminum alloy sacrificial anodes. CERVEZA's final cost was approximately $90 million, providing a deepwater operational base for drilling

40 wells and producing 25,000 b/d of oil and 96 MMcfd of natural gas. Initial production is scheduled for 1985. The co-owners will have invested over half a billion dollars in the project from the lease sale in 1974 to the first dollar of revenue in 1985. The CERVEZA project demonstrates that the offshore industry can solve the deepwater problems in order to increase domestic oil and gas production, but it requires large capital expenditures in addition to forward thinking technologists.

Guyed Tower - Exxon's LENA Platform

This platform is to be located in 305 m of water in the Mississippi Canyon Area, Gulf of Mexico. The steel tower legs have no batter, and the tower is of square shape with piles located at the center of the structure. The tower is designed to contain 12 large (6 m in diameter x 35 m long) buoyancy tanks within the tower framing to provide buoyancy during the launching process. The tower will be anchored by 20 guy cables which are protected from corrosion and ship damage from a point 30 m below the water surface to their termination of the tower and which terminate at the seabed with clump weights which, in turn, are tied to anchor piles with chains. Before this structure was designed, a similar but smaller guyed tower platform was installed as a test platform in 91 m of water in the Grand Isle Area, Gulf of Mexico. The tower was studied for about 2 years, and the information gathered from the test structure was used in the design of this tower in 305 m of water. The tower has three decks (drilling, production, and cellar deck) and will be supported by 8 main piles, 6 torsion piles, and 58 well conductors. Installation of the jacket is scheduled for the summer of 1983. The jacket tower legs are 1.2 m in diameter, and the wall thickness varies from a minimum of 19 millimeters (mm) to a maximum of 64 mm. The tower piles are 1.3 m in diameter with wall thickness varying from a minimum of 32 mm to a maximum of 64 mm at the mud line and are driven 171 m below the mud line. Torsion piles are 1.8 m in diameter, vary from a minimum of 38 mm to a maximum of 64 mm wall thickness, are to be driven 30 m below the mud line, and will be installed in the tower before the launch. The anchor piles are 1.8 m in diameter with wall thickness varying from 25 mm to a maximum of 51 mm and are to be driven 40 m below the mud line. The tower will be launched from the side of a barge specifically modified for this launch. The total weight of the tower including decks and pilings is about 26,000 MT.

Mud Slide Platform - Texoma Oil Company

This platform is to be located in the South Pass Area in 53 m of water where the Mississippi River flows into the Gulf of Mexico. This area is prone to sea bottom movement. The jacket will be supported by five piles--four skirts and one center pile. The center pile is 4.6 m in diameter, and the skirt piles are 2.4 m in diameter. To give an idea of the sea-bottom conditions, it is estimated that each pile can be expected to reach approximately 27 m penetration into the seabed under its own weight. The center pile has a maximum wall thickness of 57 mm. The center pile will be driven to about 69 m and the skirt piles to about 105 m below the mud line. All the wells will be drilled through the center pile.

Another unique feature of this platform is that it will be launched with removable mud mats. After all center and skirt piles are driven and securely shimed to the jacket, the mud mats will be cut off and removed. This will be done so that mud forces will not be transferred to the jacket through the mud mats. After the jacket is leveled and all five piles are securely shimed, the annulus space between the piles and the sleeves will be grouted with cement grout. The jacket is scheduled for installation in May 1982 and the deck in August 1982. The piles will be driven by a hammer with a rated energy of 104,700 kilogram-meters. The total weight of the jacket, decks, and pilings is about 5,900 MT.

HUTHNANCE Platform - Gulf Oil Corporation

Installed in a water depth of 119 m of an area of the Mississippi Delta subject to bottom movements, this platform is designed to withstand those forces imposed by a wave height of 21 m acting in concert with winds of 200 kmph. Additionally, it is designed to withstand those forces produced by the movement of 44 m of foundation soil (22 m of overrun plus 22 m of slide) in the longitudinal direction and by various combinations of wave heights, winds, and foundation movements. In order to protect the 24 conductors from the effects of soil movement, six conductors are installed interior to each of the four 2.2 m diameter vertically oriented forward legs. It should be noted that leg cross-bracing has been excluded from the structure in the presumed mud flow direction for a distance of approximately 8 m above the mud line in order to reduce any additional mud flow forces. The platform is supported both vertically and horizontally by eight piles which penetrate the sea floor to a depth of 162 m.

This particular design concept incorporates many of the design features unique to designs of platforms for installation in areas subject to bottom movements, namely:

1. Installation of conductors in a few vertically oriented, relatively thick-walled (near mud line), large diameter leg members.

2. Extension of the leg members for some distance below the mud line.

3. Elimination of cross-bracing structure in the area and direction of anticipated mud movement.

PORT FACILITY AND OCEAN TRANSPORTATION DEVELOPMENTS FOR U.S. COAL

by

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Objective

The principal objective of this paper is to assess the port loading capacity in the U.S. in 1985 and ocean transportation capacity to meet the projected growth of U.S. coal exports. This is accomplished by examining in detail the status of existing and projected coal loading terminals in the five leading supplying nations and the three coastal regions of the U.S. Information on the number, capacity, water depth, and vessel size capacity in relation to evolving transport requirements of coal is provided. This paper also looks at coal shipping requirements into the future, examines ship requirements and technology developments as they apply to coal export.

Discussion

Over 160 million tons of coal are anually moving over the world's oceans. U.S. coal makes up about 40% of this world total. Most of the current world coal trade is in metallurgical coal, but the worldwide demand for steam coal is rising rapidly (Figure 1).

In keeping with the growing demand for worldwide coal movement, world coal ports and the coal carrying fleets are undergoing profound changes. The greatest part of the international coal shipment has been carried by versatile bulk carriers and combination carriers. Figure 2 shows the dramatic and sustained growth of dry bulk fleets. Capacity grew five-fold in the past 15 years. Total capacity is now over 150 million DWT.

World bulk trades are expected to double over the next 20 years growing to 2.4 billion tons in the year 2000. At present, the supply of ships is larger than the demand. As supply and demand come into balance, we should see a rapid increase in voyage rates and a large ordering of dry bulk ships including colliers. Substantial coal carriers will be constructed.

Figure 3 shows the growing importance of large colliers in coal shipping's future. In the year 2000, over one-half of all oceanborne coal will be moved in vessels of over 100,000 DWT. Figure 4 shows the economies of scale of coal ships. If we double the size of the ship from, say, 60,000 to 140,000 DWT, the cost per ton is reduced over 30%. This is from the curve labled "constrained or realistic case." The lower curve labled "unconstrained case" shows the kind of savings that could be obtained if the world harbors were of unlimited depth. This graph points out why we're seeking larger and larger ships in the world coal trades.

If U.S. ports are to remain competitive, and if receiving ports are to obtain the lowest transportation costs, they must either deepen their harbors to handle these ships or adopt alternative technology, such as in Table 1.

The projected increase of worldwide coal movements will create a five-fold growth in shipping demand over the next 20 years. There are some 336 ships now carrying coal. This is expected to grow to over 1,300 ships in twenty years.

Advanced technology can be used to great advantage to improve the prospects of coal exports. New technology, by reducing costs and improving productivity, will further increase coal exports. One such advanced technology system involves slurry systems, converting coal into a slurry and moving it from mine mouth to slurry carrying ships loaded at offshore terminals. These systems offer promise of faster loading, elimination of airborne pollution from coal dust, and economies of scale that can result from supersized slurry ships loading at offshore terminals. Figure 5 is one such system investigated by the Maritime Administration and the Boeing Company. It involves the pipeline transportation of Utah coal to Southern California, ship loading from an offshore buoy, ocean transportation on a special slurry carrying ship, and overseas discharge at another offshore buoy.

Another way to obtain benefits of slurry loading of large ships offshore is to accept coal from conventional rail cars in port and then force the coarse coal without substantial grinding through a submerged pipeline to a waiting vessel offshore. Hydraulic transfer schemes of this type have been proposed by the Boeing Company and by Wheelabrator Frye Inc. All of the required technology for this appears to be available. Figure 6 shows pictorially one of these concepts for potential application on the U.S. East Coast.

Another technology that permits one to lower ocean transportation costs is the use of wide beam shallow draft vessels (Figure 7). Most U.S. coal ports have channels with draft restrictions of 40 to 45 feet, meaning that vessels larger than 60,000 to 85,000 DWT cannot be fully loaded. Technology now exists to construct special shallow draft dry bulk carriers that can increase a vessel's cargo capacity by 50% without an increase in draft. This would mean 45 ft. draft ships carrying 140,000 DWT. The attached sketch shows such a shallow draft ship being proposed for U.S. coal export. Because of the unusual proportions, a wide beam ship would be more expensive to build and more costly to propell than a conventional 140,000 DWT ship. But it would not require channel and harbor dredging. On an overall cost-per-ton basis, the larger shallow draft ship would be 16% cheaper than the conventional 45 ft. draft ship, as shown on Figure 8.

Before looking at capacity of port loading facilities, let me first discuss channel depths and vessel size capabilities in the U.S. and other major coal exporting countries. As shown in Table 2, eight major U.S. ports are vying for deeper channels in order to load larger colliers. The U.S. lacks port facilities with channel depths capable of loading conventional carriers of 100,000 DWT and over. With the exception of Long Beach and Los Angeles, channel depths at other coal ports on the East Coast and the Gulf Coast limit loading colliers to the pan-max size (60,000 to 80,000 tons). While other major exporter nations can accomplish dredging improvements within a few years, the U.S. planning, authorization, and appropriation process can take as long as 25 years. Recognizing this severe impediment, the Reagan Administration has introduced legislation that would place the decision and the cost of deepening U.S. port channels with local port authorities and other public bodies. This would terminate the traditional U.S. Government role in financing channel deepening and maintenance projects. Through user fees, Government costs associated with port dredging would be recovered. In this manner it is believed that port improvement projects would proceed more rapidly at a pace consistent with commercial demand rather than Federal budget constraints. As shown in Table 3, major ports and other leading coal supplying nations of Australia, South Africa, Canada, and Poland have or expect to have minimum channel depths of 15 meters to handle under 100,000 DWT vessels. While coal terminals accessible to carriers of 100,000 DWT exist in Japan and Western Europe, many ports will continue to be inaccessible to large colliers. Therefore, major dredging in the U.S. is not a clear issue.

Let me now turn to port throughput capacity. Table 4 is the present situation for the major coal exporting nations showing the number of terminals, coal exports, and the current capacity of their loading facilities. As you can see, South Africa is the only nation that had no excess capacity in 1980. U.S. coal export capacity in 1980 (Table 5) was approximately 130 million tons, centered largely on the East Coast which handled nearly 70% of all U.S. exports. An additional 82 million tons are under construction which will boost U.S. capacity to some 212 million tons by 1985, an increase of 63%. An additional 310 million tons are planned. This expansion program will enable the U.S. to meet projected coal exports for 1985 to 1990. If anything, there is a growing concern that the U.S. will have overcapacity. The final outcome of planned development will be largely determined by the speed in which new and expanded terminals can be brought on line and the strength of future demand. In turn, demand will be affected in part by the ability of the U.S. to price competitively as well as the desire of coal importing nations to provide long term contracts.

The future outlook of the U.S. is very good, despite some of the problems recently experienced. The sharp rise in demand for the steam coal caught the U.S. with facilities that were ill-equipped to handle steam coal and lacking sufficient capacity. This has resulted in long vessel waiting time, demurrage, and a strained domestic transportation system. The solution is requiring the coordinated effort of government and private industry.

Numerous measures have been taken by railroad, coal operators and private terminal operators to increase effective port loading capacity. In the past 18 months, temporary use of loading facilities designed for other bulk commodities, use of mid-stream barge to ship loading, utilization of alternative bulk handling piers, use of alternative transportation routes, and managerial efficiencies achieved by various parties in the coal export chain have effectively doubled existing coal loading capacity. In October 1981, coal was loaded for export at an annual rate of over 120 million tons.

Implementation of these improvements can best be seen by the reduction in the number of vessels waiting at Baltimore and Hampton Roads and the average wait time for these vessels. Figure 9 shows that in early 1981, there was a peak number of vessels waiting -- 136 vessels with a wait time of up to 50 days. The numbers of ships have been drastically reduced and the waiting time is now less than 10 days. The problems of the past in U.S. coal loading ports have been drastically reduced.

While these short term measures have reduced significantly the costs of importing coal from the U.S., inadequate near term capacity is still a problem. Terminal capacity is rapidly expanding through the construction of new coal piers or by expansion of existing piers. The present coal terminal capacity of the U.S. East Coast is 89.9 million tons with some 71 million tons underway. Another 141 million tons of potential expansion is planned (Table 6). The current export capacity on the Gulf Coast is 34 million tons with 19 million tons underway and an additional 119 million tons in various stages of planning (Table 7). The West Coast export facilities are a different matter. Development is not as advanced. As reflected by the limited existing capacity of 3 to 7 million tons, very little coal is shipped from the West Coast. However, the potential of moving western coal has initiated a flurry of activity. Eighty-two million tons of coal terminal expansion is being planned (Table 8).

The ports of Los Angeles and Long Beach are developing plans for major coal export terminal expansions. Several other West Coast ports have plans well underway for facilities, as can be seen by Table 8. In addition, agreements have been made to export Alaskan coal. Initial efforts are underway to establish a 2 million ton export facility at Seaward.

Findings

The outlook for the U.S. in coal export market continued expansion is very good despite some of the problems that we have recently experienced. The sharp rise in demand for steam coal caught the U.S. with facilities that were ill-equipped to handle steam coal and lacking sufficient capacity. The solution required coordinated efforts of Government and private industry. Private industry has responded with a capacity expansion program requiring an investment of over one billion dollars in private capital during the next five years. Within the next two years, U.S. capacity will be adequate to meet the export demand. In the interim, terminal operators have fine tuned existing facilities to increase capacity. The port capacity expansion program now underway will enable the U.S. to meet the projected coal demand for 1985 and 1990. If anything, there is growing concern that the U.S. expansion program will lead to overcapacity. New construction coal fleet growth can be expected to accelerate in the future. Large colliers (+100,000 DWT) will play a significant role. With harbor depth limitations and cost competition, new technology, such as large shallow draft ships and slurry ships, will grow in importance.

Conclusions

For the long term (beyond five years), a modern and efficient U.S. coal export infrastructure is being developed through the following:

- Existing Ports - These will continue to play a significant role in future coal exports. In addition to harbor and channel improvements, existing ports are exploring more efficient means of storing and transferring coal to enable their annual throughput to increase.

- New Ports - New ports will also be required. Plans are being developed for major new U.S. ports based on their strategic location, compatibility with future transportation infrastructure, environmental acceptability, and cost effectiveness.

- Offshore Deep Loading Ports - Offshore deep water loading ports in such places as the lower Delaware Bay are being considered. Figure 10 shows one such concept. This proposed concept employs a large tanker as a storage facility, a transfer ship which moves the coal from barge to the storage ship, and onto an ocean-going transport vessel. The efficiency of this concept is not as good as shoreside loading but does provide a mechanism to rapidly expand port capacity.

- Slurry Coal Ship Systems - Slurry coal systems are being developed to form a part of a balanced and efficient coal export program.

- Large Shallow Draft Ship Technology - Large shallow draft ship technology is in the design stage. Ports and terminals must be designed to handle wider beam shallow draft ships. These large shallow draft ships will allow coal to be moved from major ports to importing ports without major dredging requirements. A shallow draft ship operating at 45 ft. design draft operates at approximately 80% of the shipping cost of the conventionally designed ship at 45 ft. These cost savings are substantial and in many port development situations provide the desirable alternative.

TABLE 1

Port Dredging Alternatives

	Capital Cost (Millions)	Time Reqd. (Years)	Constraint
Port Dredging (100,000 DWT)	280-440/Port	9-Admin. 6-Cong. Fund 8-Design & Const.	Total Fed. funding doubtful
Coarse Coal Pipeline (250,000 DWT)	140-160	3	Private financing uncertain
Slurry Coal Pipeline	750	6	Private financing doubtful and right of way regulations
Offshore Barge Transfer (150,000 DWT)	80	1-2	Loading in rough water and higher freight rate
Large Shallow Draft Ship (120,000 DWT)	60	2	Large Bulk Ship Construction

Table 2

PORT/COUNTRY	CHANNEL DEPTH (meters) Existing	CHANNEL DEPTH (meters) Proposed	VESSEL DWT Existing	VESSEL DWT Proposed
UNITED STATES				
. New York	13.7	18.3	80	150
. Baltimore	12.8	15.2	80	100
. Hampton Roads	13.7	16.7	80	120
. Mobile	12.2	16.7	60	120
. New Orleans	12.2	16.7	60	120
. Galveston	12.2	17.1	80	130
. Los Angeles	15.5	19.8	100	200
. Long Beach	15.5	18.3	100	150

Table 3

	CHANNEL DEPTH (meters) Existing	CHANNEL DEPTH (meters) Proposed	VESSEL DWT Existing	VESSEL DWT Proposed
AUSTRALIA				
. Bowen		17.2		160
. Hay Point	17.1		150	
. Galdstone	12.2	15.4		150
. Newcastle	13.1	15.2		110
. Port Kembla	11.6	15.2		110
REPUBLIC OF SOUTH AFRICA				
. Richards Bay	19.0	22.8	160	250+
CANADA				
. Vancouver	19.8	21.3	165	200
. Quebec City	15.2		100	
. Sept Iles	20.0		200	
POLAND				
. Gdansk	15.2		100	

Table 4 SUMMARY OF PRINCIPAL COAL EXPORTING NATIONS-1980

Major Exporting Nations	Number of Ports/Terminals		1980 Exports (MT)	Effective Capacity (MTPA)
United States	21	25	83.4	130.4
Australia	5	10	41.8	70.0
Republic of South Africa	2	2	28.0	28.2
Canada	7	9	14.9	32.4
Poland	4	7	18.3	30.0
TOTAL	39	53	186.4	291.0

TABLE 5

SUMMARY OF U.S. COAL LOADING CAPACITY

COAST	TERMINAL CAPACITY (10^6 tons)			CAPACITY EXPANSION SCHEDULE (10^6 tons)					EFFECTIVE CAPACITY
	Existing	Underway	Planned	1981	1982	1983	1984	1985	1985
EAST COAST	89.9	71.5	141.5	3.0	33.0	37.0	60.5	79.5	302.9
GULF COAST	34.5	19.0	119.5	4.0	37.5	58.0	22.0	17.0	173.0
WEST COAST	3.0	-	81.7	-	4.0	3.5	15.0	59.2	84.7
GREAT LAKES	16.4	-	-	-	-	-	-	-	16.4
TOTAL	143.8	90.5	342.7	7.0	74.5	98.5	97.5	155.7	577.0
CUMULATIVE CAPACITY				150.8	225.3	323.8	421.3	577.0	

TABLE 6

U.S. COAL LOADING TERMINALS - EAST COAST

PORT/TERMINAL	*STATUS	CHANNEL DEPTH (feet) Existing	CHANNEL DEPTH (feet) Proposed	VESSEL SIZE (DWT) Existing	VESSEL SIZE (DWT) Proposed	TERMINAL CAPACITY (10^6 tons) Existing	TERMINAL CAPACITY (10^6 tons) Underway	TERMINAL CAPACITY (10^6 tons) Planned	CAPACITY EXPANSION SCHEDULE (10^6 tons) 1981	1982	1983	1984	1985	EFFECTIVE CAPACITY 1985
ALBANY, N.Y.														
o Atlantic Cement	1	32		30		1.0								1.0
o New Amsterdam Coal	2	32		30			4.0			4.0				4.0
NEW YORK, N.Y.														
o Clayton Terminal	1	36		35		1.0								1.0
o NY/NJ Port Authority Site	3	45	60	80	150			10.0					10.0	10.0
PHILADELPHIA, PA														
o Pier 124	1	40		40	80	3.0	7.0		2.0	5.0				10.0
o Port Richmond	3	40		60				4.5			4.5			4.5
o Fairless Hills	3	40		60				3.0				3.0		3.0
CAMDEN, N.J.														
o Beckett St.	1	40		60		.5		.5					.5	1.0
o Broadway Terminal	2	40		60			5.0		1.0	4.0				5.0
WILMINGTON, DE														
o Pigeon Point	4	40		60				5.0					5.0	5.0
BALTIMORE, MD														
o Curtis Bay	1	42	50	60	100+	16.6								16.6
o Curtis Bay	2	42	50	60	100+		12.0			12.0				12.0
o Canton Marine Terminal	2	42	50	60	100+		10.0				10.0			10.0
o Marley Neck	3	42	50	60	100+			15.0					15.0	15.0
NORFOLK, VA														
o Pier 6	1	45	55	80	100+	36.0								36.0
o Pier 5	1	45	55	40		4.0								4.0
NEWPORT NEWS, VA														
o Pier 14	1	45	55	80	100+	16.5								16.5
o Pier 15	1	45	55	40		5.3								5.3
o Pier 9	2	45	55	80	100+		12.0				12.0			12.0
o Dominion Terminals	3	45	55	80	100+			15.0				15.0		15.0

TABLE 6 (Continued)

U.S. COAL LOADING TERMINALS - EAST COAST (cont'd)

PORT/TERMINAL	*STATUS	CHANNEL DEPTH (feet) Existing	CHANNEL DEPTH (feet) Proposed	VESSEL SIZE (DWT) Existing	VESSEL SIZE (DWT) Proposed	TERMINAL CAPACITY (10^6 tons) Existing	TERMINAL CAPACITY (10^6 tons) Underway	TERMINAL CAPACITY (10^6 tons) Planned	CAPACITY EXPANSION SCHEDULE (10^6 tons) 1981	1982	1983	1984	1985	EFFECTIVE CAPACITY 1985
PORTSMOUTH, VA														
o Virginia Port Authority Site	3	45	55	80	100+			30.0					30.0	30.0
o Portsmouth Coal Terminal	2	45	55				4.0			4.0				4.0
CHESAPEAKE, VA														
o Higgerson-Buchanan	3	45	55					4.0			4.0			4.0
MOREHEAD CITY, N.C.														
o NCSPA - Bulk Facility	1	40	47	60	100+	3.0								3.0
o Radio Is. - Alla Ohio	3	40	47	60	100+			10.0				10.0		10.0
o Radio Is. - Gulf Interstate	3	40	47	60	100+			15.0				7.5	7.5	15.0
WILMINGTON, N.C.														
o Williams Terminals Co.	3	40		60				10.0				10.0		10.0
o Cleancoal Terminal	3	40		60				3.0			3.0			3.0
o American Coal Export	3	40		60				5.0		1.5	3.5			5.0
CHARLESTON, S.C.														
o Massey Coal Terminal	2	35	40	40	50		2.5	1.5		2.5			1.5	4.0
SAVANNAH, GA														
o Peoples	1	38	42	50	70	3.0								3.0
o Savannah Coal Terminal	2	38	42	50	70		15.0					15.0		15.0
o Hutchinson Island Co.	3	38	42	50	70			10.0					10.0	10.0
TOTAL						89.9	71.5	141.5	3.0	33.0	37.0	60.5	79.5	302.9

*STATUS CODE

1 - Existing
2 - Underway
3 - Planned
4 - Potential

TABLE 7

U.S. COAL LOADING TERMINALS - GULF COAST

PORT/TERMINAL	*STATUS	CHANNEL DEPTH (feet)		VESSEL SIZE (DWT)		TERMINAL CAPACITY (10^6 tons)			CAPACITY EXPANSION SCHEDULE (10^6 tons)					EFFECTIVE CAPACITY
		Existing	Proposed	Existing	Proposed	Existing	Underway	Planned	1981	1982	1983	1984	1985	1985
MOBILE, AL														
o McDuffie Island	1	40	55	60	100+	5.0	4.0	11.0	4.0			11.0		20.0
NEW ORLEANS, LA														
o Public Bulk Terminal (MRGO)	1	36		50		2.0		2.0					2.0	4.0
o Electro-Coal (55.4)	1	40	55	60	100+	8.0	4.0	18.0		4.0	18.0			30.0
o International Marine Terminal (57.0)	1	40	55	60	100+	4.0	11.0			11.0				15.0
o Freeport Coal (39.2)	3	40	55	60	100+			4.0			4.0			4.0
o International Matex (46.6)	3	40	55	60	100+			12.0			12.0			12.0
o NOLA Coal Loading (47.0)	3	40	55	60	100+			2.0			2.0			2.0
o Gateway Terminals (163.0)	3	40	55	60	100+			6.0				6.0		6.0
o Miller Coal (174.0)	3	40	55	60	100+			10.0			10.0			10.0
o Hunt Energy Corp (205.0)	3	40	55	60	100+			15.0					15.0	15.0
o River and Gulf Trans. Co. (213.0)	3	40	55	60	100+			11.0			11.0			11.0
BATON ROUGE, LA														
o Burnside Terminal	1	40	55	60	100+	2.0								2.0
MID-STREAM OPERATIONS														
o Lower Mississippi River	1	40	55	60	100+	13.5		22.5		22.5				36.0
GALVESTON, TX														
o Pelican Terminal Co.	3	40	56	60	100+			5.0				5.0		5.0
CORPUS CHRISTI, TX														
o Farrell-Cooper	3	43		75				1.0			1.0			1.0
TOTAL						34.5	19.0	119.5	4.0	37.5	58.0	22.0	17.0	173.0

*STATUS CODE

1 - Existing
2 - Underway
3 - Planned
4 - Potential

TABLE 8

U.S. COAL LOADING TERMINALS - WEST COAST

PORT/TERMINAL	*STATUS	CHANNEL DEPTH (feet) Existing	CHANNEL DEPTH (feet) Proposed	VESSEL SIZE (DWT) Existing	VESSEL SIZE (DWT) Proposed	TERMINAL CAPACITY (10^6 tons) Existing	TERMINAL CAPACITY (10^6 tons) Underway	TERMINAL CAPACITY (10^6 tons) Planned	CAPACITY EXPANSION SCHEDULE (10^6 tons) 1981	1982	1983	1984	1985	EFFECTIVE CAPACITY 1985
LOS ANGELES, CA														
o Berth 49-50	1	51		100		1.5								1.5
o Terminal Island	3	51	65	100	200			10.0					10.0	10.0
LONG BEACH, CA														
o Pier G #212-215	1	45		70		1.5		3.5			3.5			5.0
o Cerritos Channel	3	51	60	100	150			10.0					10.0	10.0
REDWOOD CITY, CA	3	32		30				2.0		2.0				2.0
SELBY, CA														
o Wickland Oil	3	35		50				15.0					15.0	15.0
SACRAMENTO, CA	4	30	37	30	40			3.0					3.0	3.0
STOCKTON, CA														
o Bulk Terminal	4	32	37	30	40			1.0					1.0	1.0
COOS BAY, OR	4	35		40				3.0					3.0	3.0
ASTORIA, OR														
o Tongue Point	4	40		60				10.0					10.0	10.0
PORTLAND, OR														
o Rivergate Site	3	40		60				10.0				10.0		10.0
KALAMA, WA														
o Industrial Park	3	40		60				5.0				5.0		5.0
BELLINGHAM, WA														
o Cherry Point	4	60		100				1.2					1.2	1.2

TABLE 8 (CONTINUED)

U.S. COAL LOADING TERMINALS - WEST COAST (cont'd)

		CHANNEL DEPTH (feet)		VESSEL SIZE (DWT)		TERMINAL CAPACITY (10^6 tons)			CAPACITY EXPANSION SCHEDULE (10^6 tons)					EFFECTIVE CAPACITY
PORT/TERMINAL	* STATUS	Existing	Proposed	Existing	Proposed	Existing	Underway	Planned	1981	1982	1983	1984	1985	1985
DUPONT, WA														
o Weyerhaeuser Site	4	60		150				3.0					3.0	3.0
GRAYS HARBOR, WA														
o South Shore Industrial Site	4	30	40	40	60			3.0					3.0	3.0
SEWARD, AK	3	35		40				2.0		2.0				2.0
TOTAL						3.0	-0-	81.7	-0-	4.0	3.5	15.0	59.2	84.7

*STATUS CODE

1 - Existing
2 - Underway
3 - Planned
4 - Potential

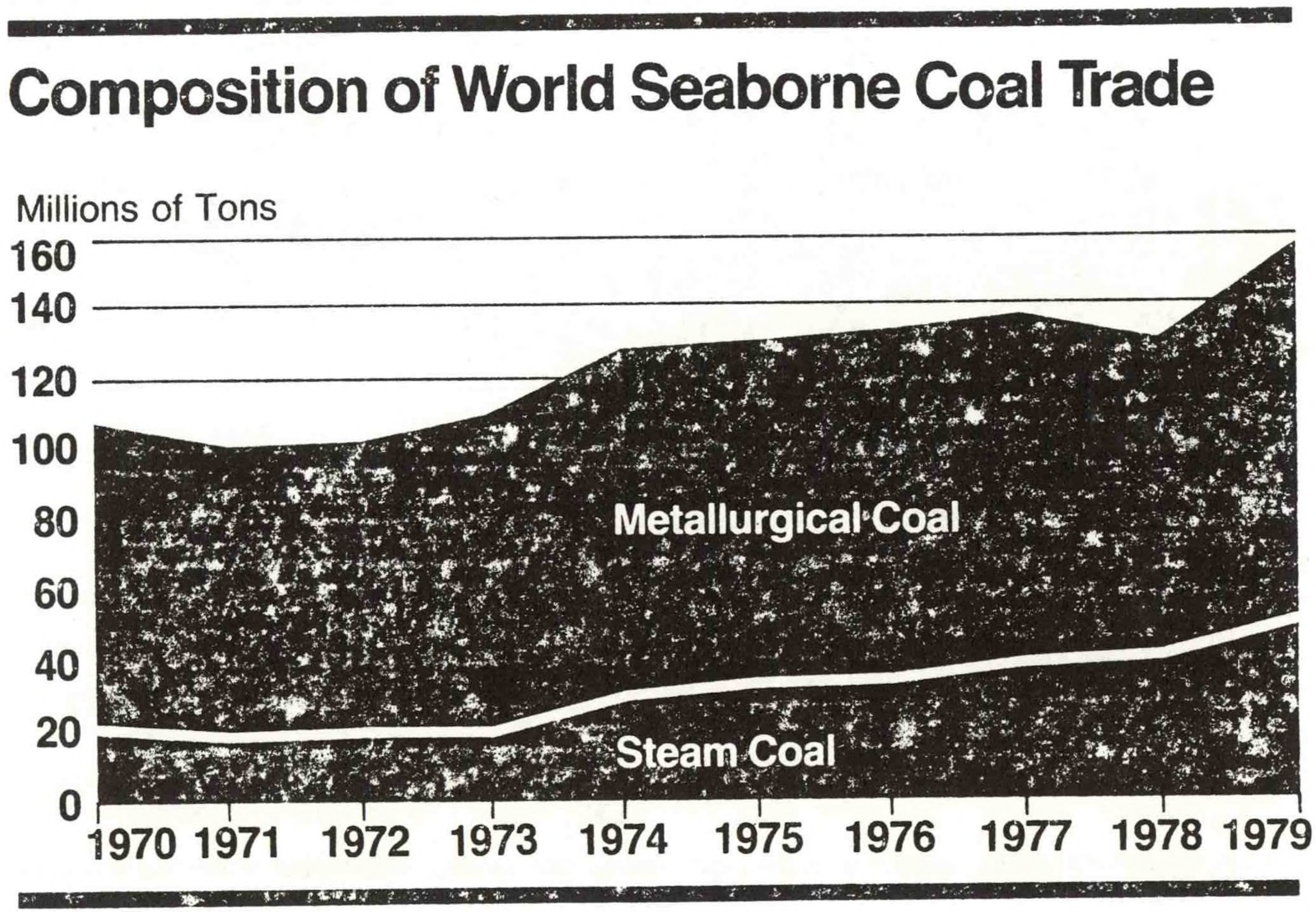

Composition of World Seaborne Coal Trade
Millions of Tons
160
140
120
100
80
60
40
20
0
1970 1971 1972 1973 1974 1975 1976 1977 1978 1979
Metallurgical Coal
Steam Coal

Figure 1

Growth of World Dry-Bulk Fleet

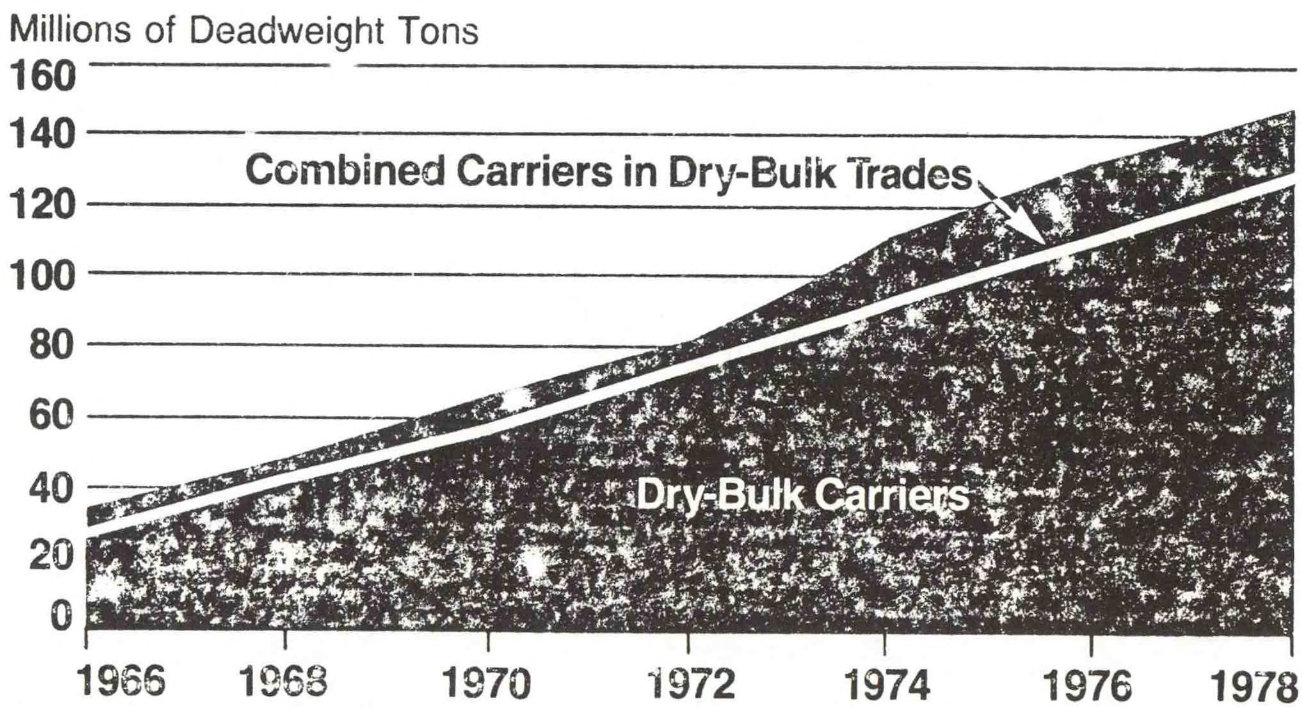
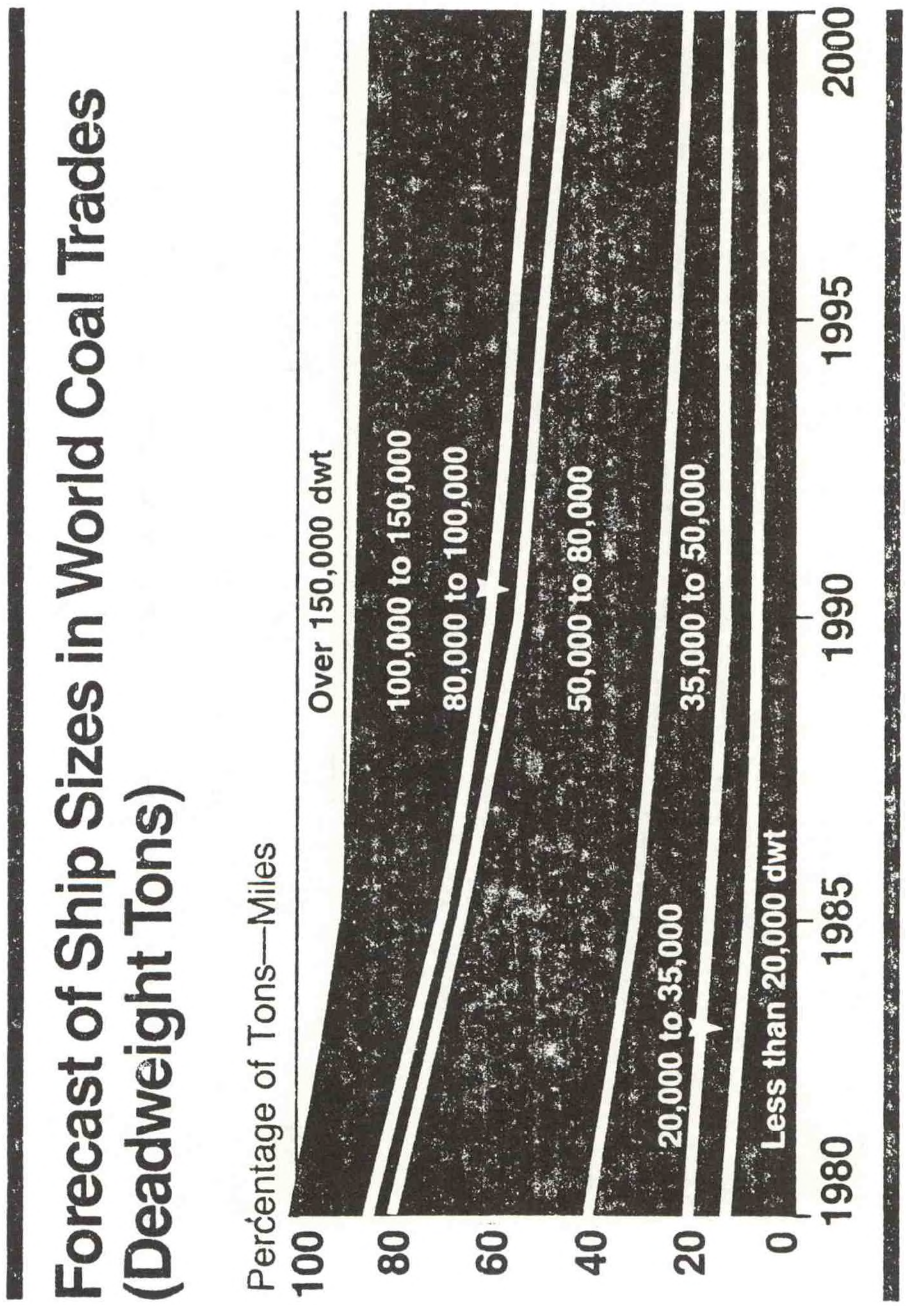


Figure 2



Forecast of Ship Sizes in World Coal Trades
(Deadweight Tons)
Percentage of Tons—Miles
100
80
60
40
20
0
1980
1985
1990
1995
2000
Over 150,000 dwt
100,000 to 150,000
80,000 to 100,000
50,000 to 80,000
35,000 to 50,000
20,000 to 35,000
Less than 20,000 dwt

Figure 3

Economies of Scale in Seaborne Coal Trade

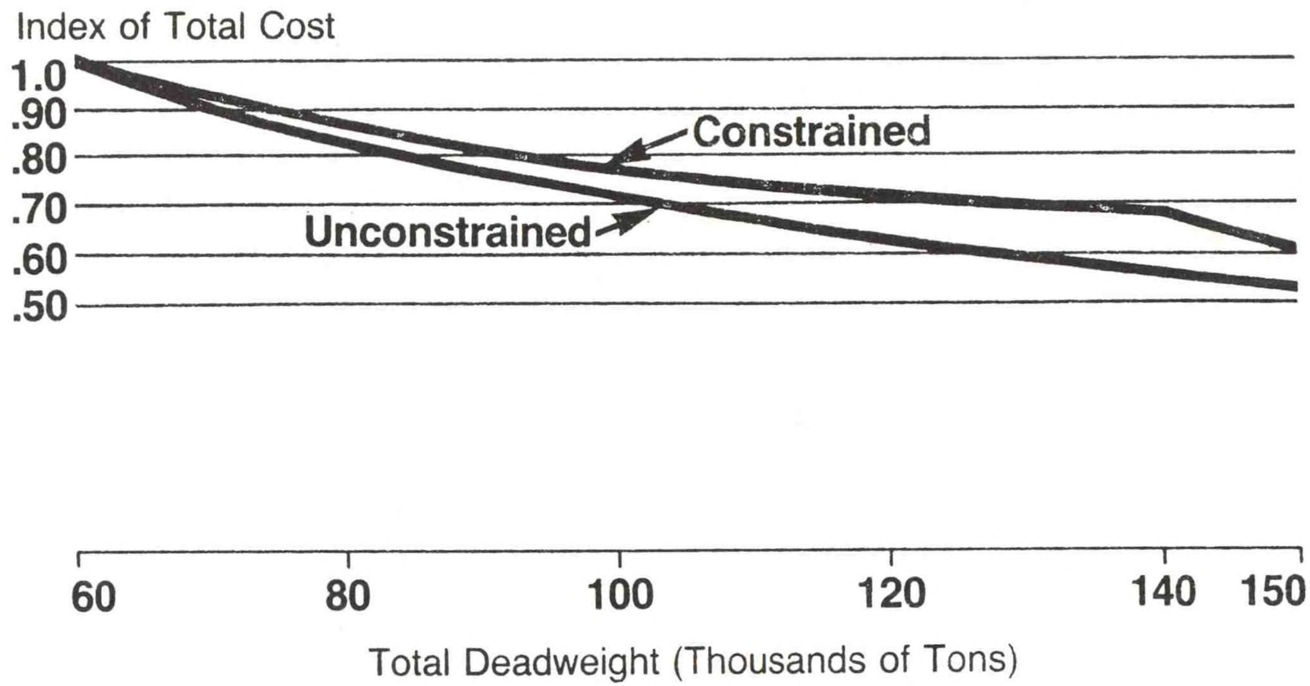


Figure 4

Shallow Draft Collier
144,000 DWT
Coal-Fired Steam Propulsion

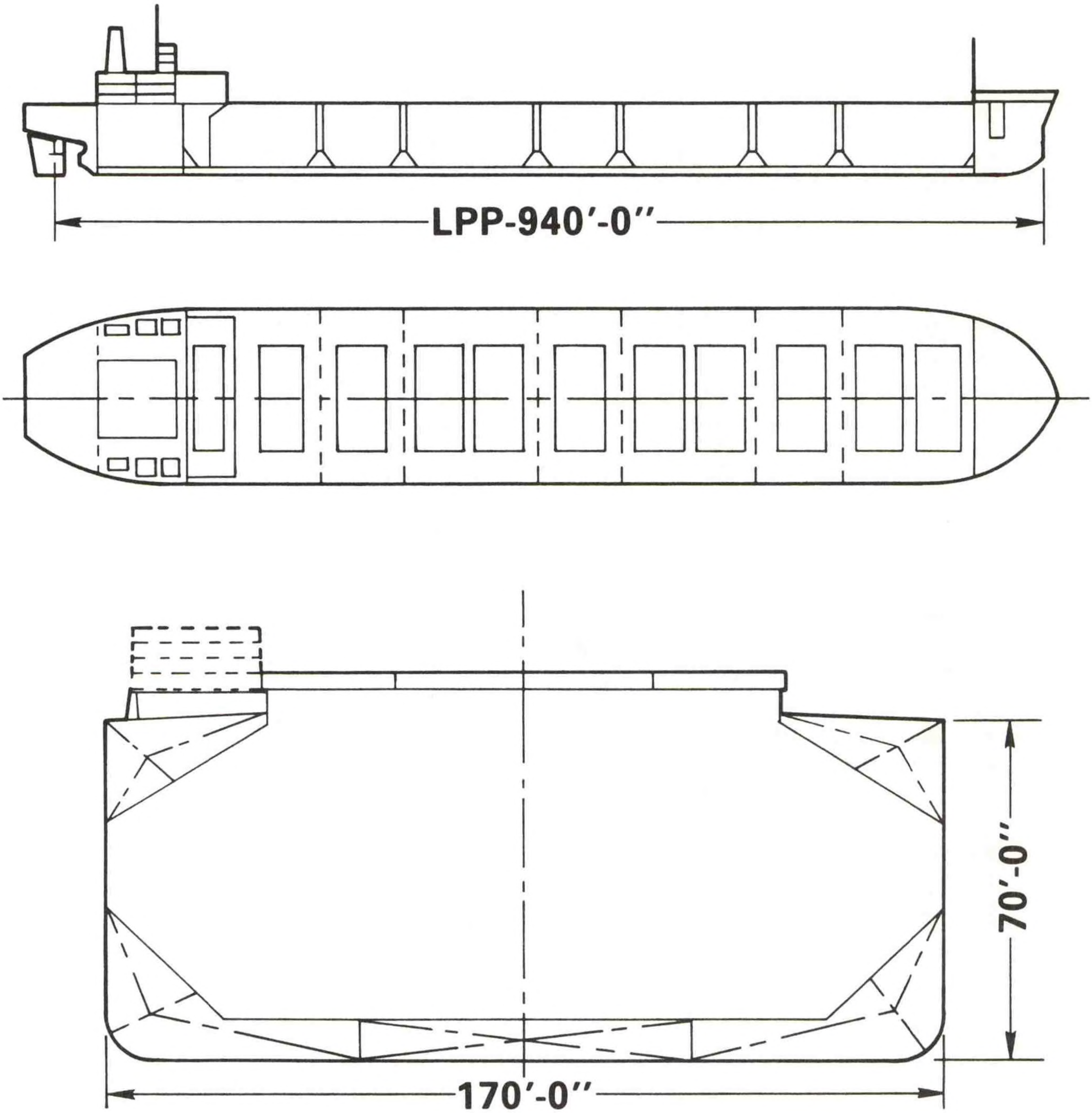


FIGURE 7

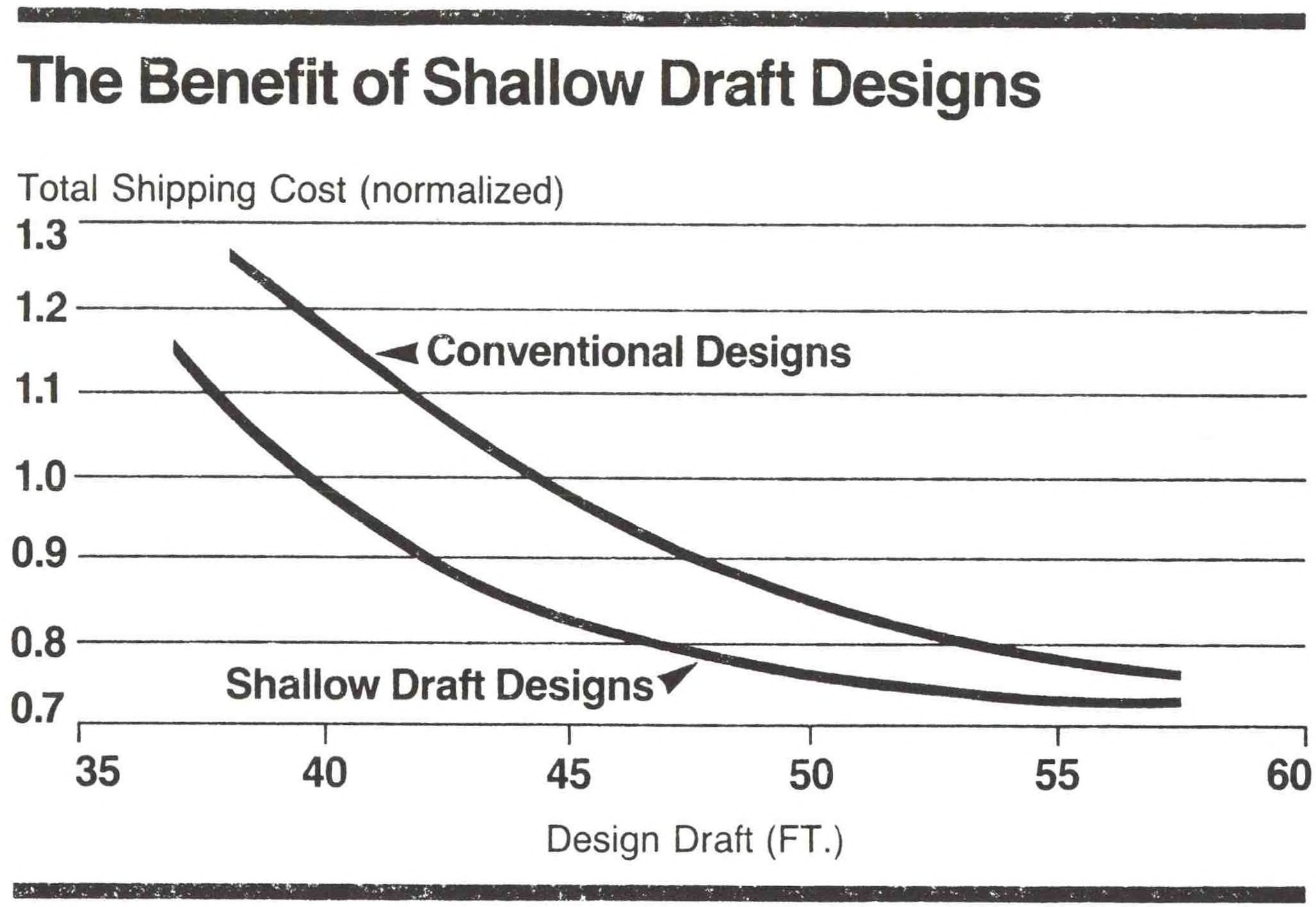

The Benefit of Shallow Draft Designs
Total Shipping Cost (normalized)
1.3
1.2
1.1
1.0
0.9
0.8
0.7
Conventional Designs
Shallow Draft Designs
35
40
45
50
55
60
Design Draft (FT.)

Figure 8

FIGURE 9

Vessel Experience
Hampton Roads

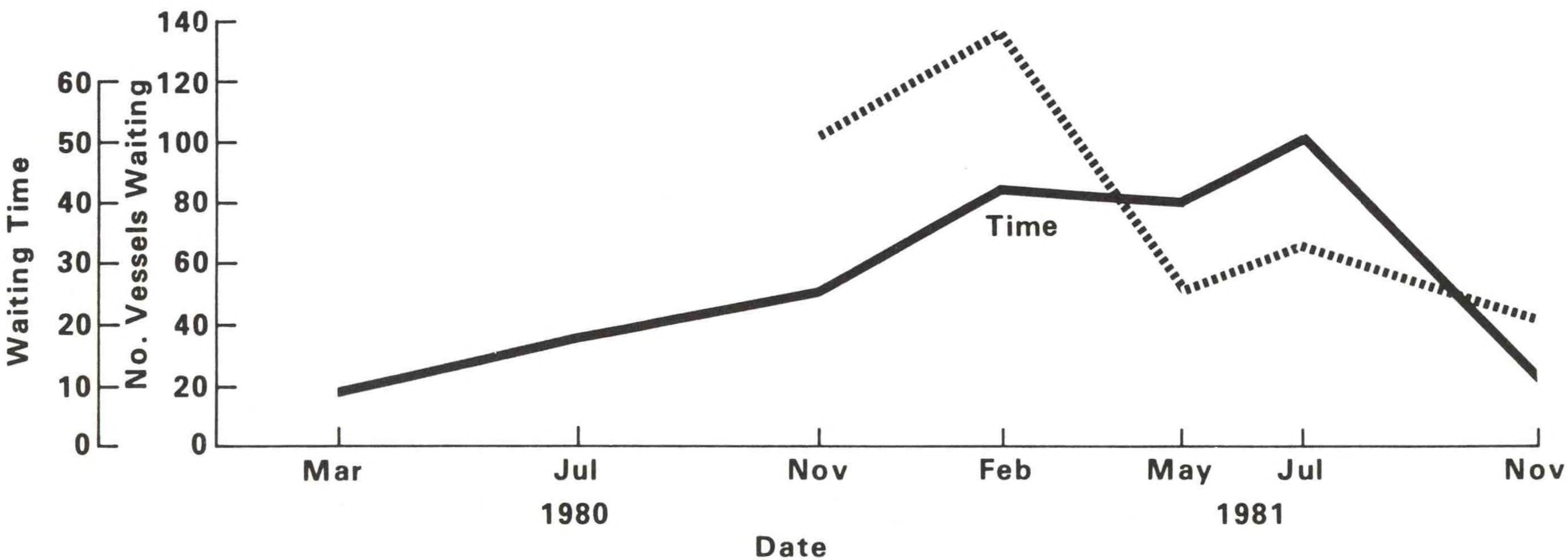
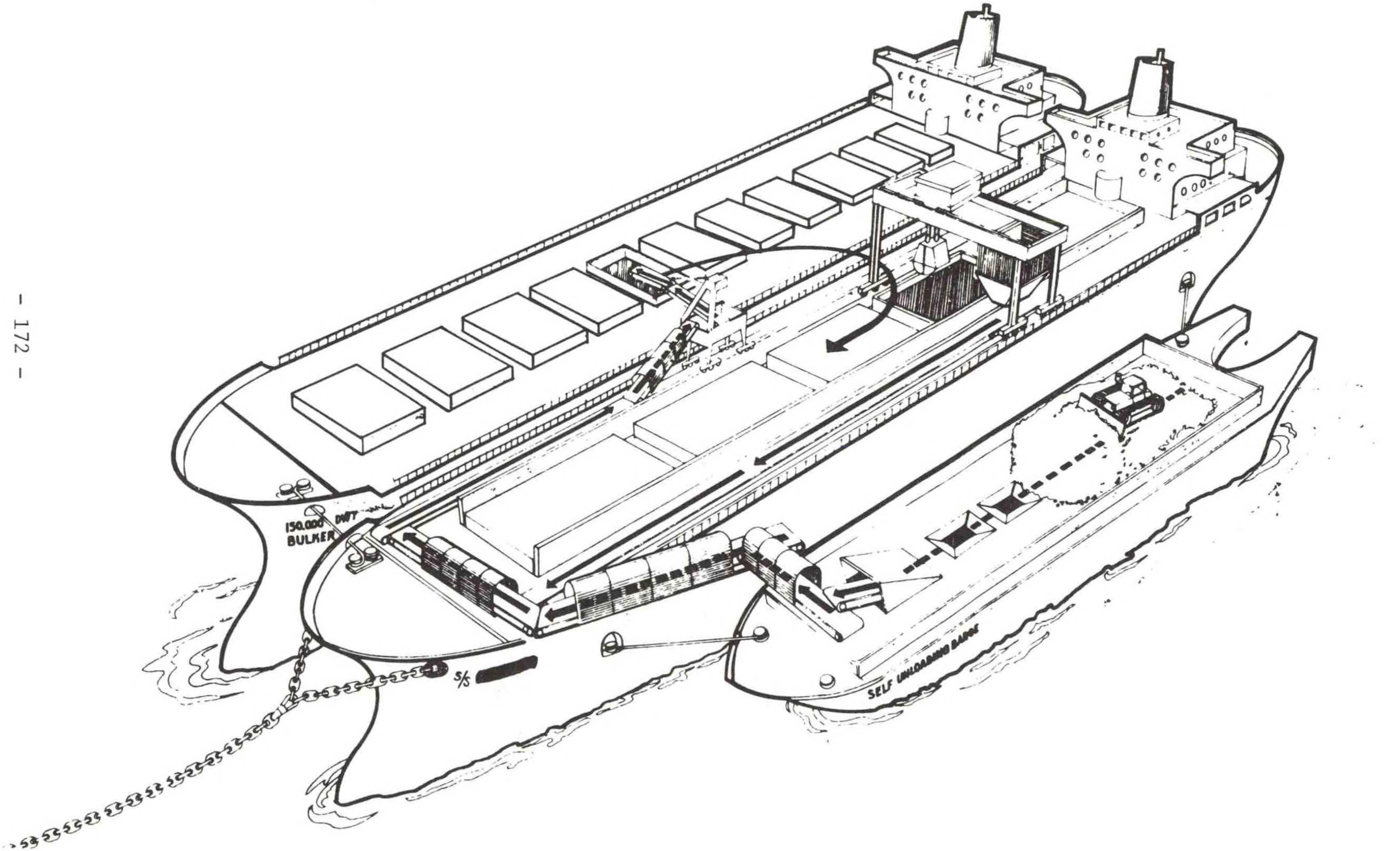


FIGURE 10

A Deep Draft Coal Transfer Facility Concept



THE STATUS OF WAVE ENERGY CONVERSION TECHNOLOGY DEVELOPMENT IN THE UNITED STATES

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ABSTRACT

Wave Energy Conversion is viewed as a potentially significant renewable energy source for the U.S. In this paper, the current status of the U.S. Department of Energy's (DOE) wave energy conversion technology development program is discussed. A review of recent government funded projects is presented, followed by a discussion of the future direction of wave energy conversion technology development.

The principal U.S. effort in this area has been directed at the development of a pneumatic wave energy converter for potential use in a multinational wave energy demonstration test or an independent test program. Other projects have included support for development of several other innovative wave energy conversion concepts, and preparation of a systems engineering study that may be utilized to evaluate and classify wave energy conversion devices by their technical and economic potential.

INTRODUCTION

Formal U.S. government interest in wave energy conversion coincided closely with the initial development of the U.S. Ocean Thermal Energy Conversion (OTEC) program and the creation of the U.S. Department of Energy. Many concepts had been proposed by individuals prior to this period; however, significant development of most of those ideas was not realized until recently.

The first wave energy conversion concept to exhibit sufficient promise to warrant funding for fabrication and testing is a pneumatic device that utilizes an oscillating air flow to turn a turbine and its associated generator. This system was devised by McCormick (Reference 1) and designed for installation in a barge-shaped ship, located in the Sea of Japan, as part of an International Energy Agency (IEA) project. Other proposed ideas have received funding for initial concept development and small scale model testing. These concepts include:

- DAM-ATOLL - a concept utilizing a large dome that creates an artificial beach to cause wave breaking and subsequent harnessing of this breaking to turn a turbine generator

- Tandem Flap Device - a multi-barrier concept that has variable spacing to optimize wave energy extraction and reduce mooring system forces

Support efforts for the wave energy conversion program have been focused on developing a systematic strategy for wave energy device evaluation, preparing an analytical wave resource prediction model, and numerical and hydrodynamic modelling of wave energy conversion concepts. Each of these efforts will be addressed in greater detail in the following section.

STATUS OF PROJECTS

Pneumatic Wave Energy Conversion (PWEC) Device

This device was initially devised for the barge-like vessel, KAIMEI, as the proposed U.S. device for an IEA pneumatic wave energy demonstration program. Other countries providing pneumatic turbine devices for testing were Japan and the United Kingdom. The PWEC device consists of a bidirectional turbine that converts an oscillatory air flow produced by wave motion within a cavity into a constant direction rotary motion that can be utilized to drive a generator. A schematic diagram indicating how this device might be configured in a wave energy system is provided in Figure 1.

The objective of the device fabrication program was to construct a system that could have a natural frequency equal to the expected frequency of the exciting force, in this case, the wave. In this condition, called resonance, maximum air displacements may be expected, and enhanced power conversion achieved through the concept of impedance matching, which relates extracted power to air chamber velocity and geometry.

The principal mechanical components of the PWEC are depicted in Figure 2 and are listed as follows:

- Counter-rotating turbine with two sets of rotors and stators
- A combining gearbox that transmits the torque generated by the two turbine runners to a single shaft
- Oil lubricating system
- A 125 KWe self-excited, brushless, AC synchronous generator
- A control system that regulates speed and voltage

Initial fabrication of turbine components was performed by the Naval Ship Research and Development Center (NSRDC) with subsequent turbine assembly and balancing completed by General

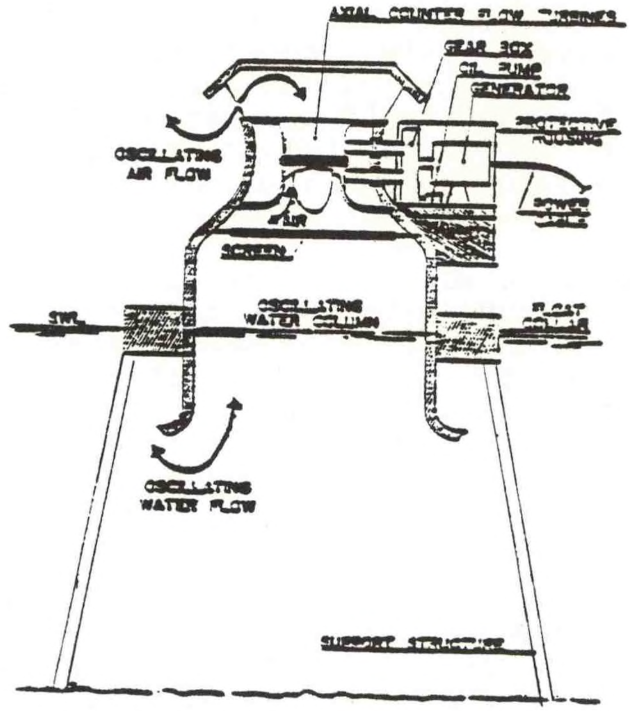

Figure 1. Possible Deployment of Pneumatic Wave Energy Conversion Device

PROTOTYPE WAVE ENERGY CONVERTER

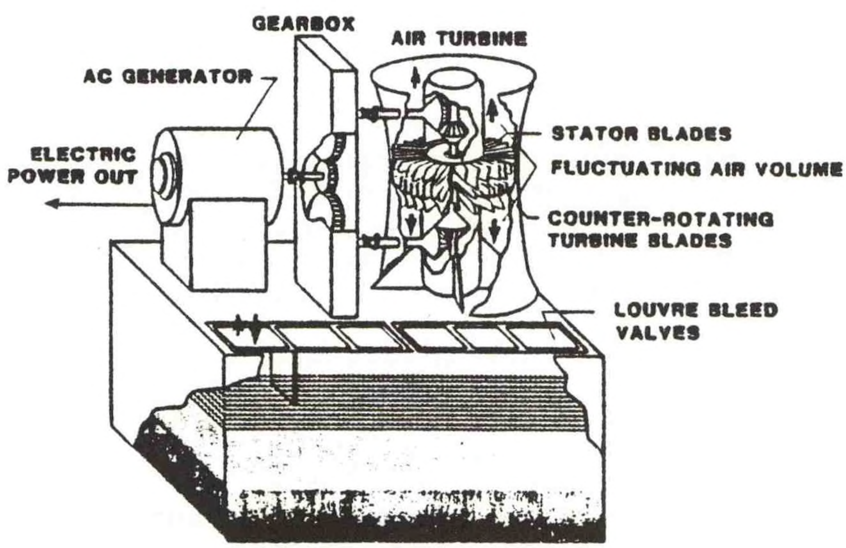

Figure 2. Major Components Of The Pneumatic Wave Energy Converter Device

Electric Company. Preliminary mechanical testing has been completed to identify inertial properties of the system and torque requirements of the generator. An estimated mechanical efficiency of the turbine itself was set at 53 percent (Reference 2). A comprehensive turbine testing program has been initiated that entails thermodynamic, hydrodynamic and dynamic modelling efforts, as well as physical testing (Reference 2).

A thermodynamic model has been developed (Reference 3) that relates the air volume within the cavity to the oscillating water surface and the turbine-generator system. This model can be utilized to assess the effects of altering air column dimensions on the power that may be extracted. Additionally, the effect of wave amplitude may also be examined with this model. The hydrodynamic model (Reference 4) is capable of estimating the time-averaged power available to the turbine by calculating wave and other hydrodynamic properties.

Physical tests are likely to be either aerodynamic in a wind tunnel; hydrodynamic in a wave flume tank; or at-sea on an offshore platform. An at-sea test is currently favored since an environment that more closely resembles that in which the device will be utilized should produce the most significant results.

DAM-ATOLL

DAM-ATOLL is a concept that utilizes the principles of wave refraction to focus wave energy into a turbine-generator system. Small scale model tests performed by Lockheed Missiles and Space Company, Inc., have indicated that the approach is technically feasible. Subsequent efforts have been directed at providing a design data base for larger scale model tests and an initial assessment of capital costs of full scale operational units (Reference 5).

The concept, as depicted in Figure 3, is situated at a site that permits waves to encounter the dome structure, causing them to be refracted around the central portion of the dome. The waves are then captured by a set of vanes and guided into the central core at the top of the dome. This rotating water mass acts as a vertical "fluid flywheel," which turns a turbine, thereby driving an electrical generator.

The recent study has investigated the following areas:

- Dome shape characteristics
- Internal flow characteristics
- Structural-design concepts
- Construction, deployment and installation techniques
- Preliminary costs and economics

These studies have resulted in optimizing the dome shape and analysis of the central core characteristics. Projected

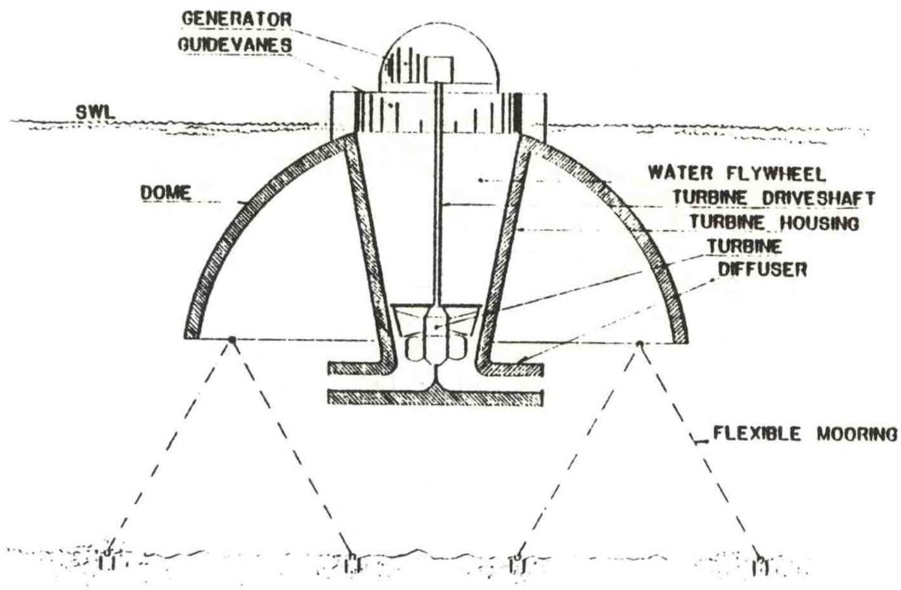

Figure 3. Proposed Configuration For The DAM-ATOLL Concept

structural configurations are concrete or steel, with concrete being the most likely material. Construction and installation techniques will depend upon whether the device is to be a bottom-mounted gravity structure or a free floating moored structure; however, it is likely that, in either case, it would be constructed on special purpose barges, then floated out and ballasted down at the installation site. Initial system conversion efficiencies were estimated to be between 35 and 45 percent, yielding projected capital costs of approximately $6,000/KW to $10,000/KW.

Future efforts are expected to entail refinement of major systems through model testing and further analytical studies.

Tandem Flap Device

Work on this wave energy conversion concept has been concentrated on a program that includes a balance of analytical effort and physical model tests. This concept, as depicted in Figure 4, essentially consists of two flaps in which the first flap is considered a "power" flap and the secondary flap is positioned for operation in several modes, depending upon wave conditions. The advantages of this concept are projected to include:

- Simple construction with attendant low capital costs
- Small physical displacement
- Reduction of surge mooring forces
- High efficiencies of operation

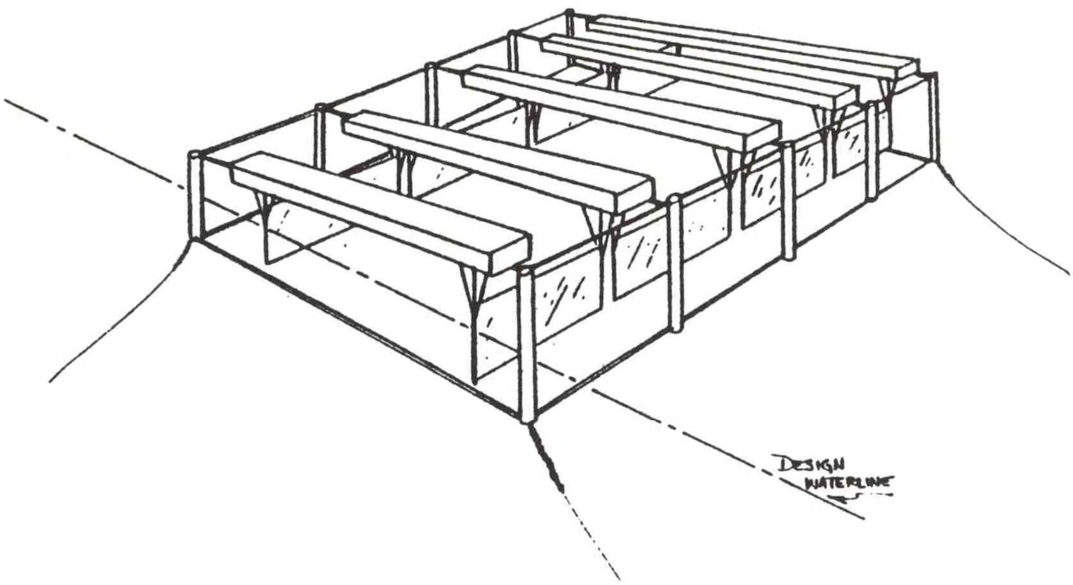

Figure 4. Deployment Configuration Of Tandem-Flap Device

Preliminary empirical tests have provided promising results, yielding single flap wave energy extraction efficiencies approaching 50 percent and tandem flap extraction efficiencies greater than 90 percent. Future efforts are expected to be directed at developing improved tuning techniques, completion of twin flap testing, developing construction and deployment scenarios, and economic evaluation.

Systems Engineering Effort

The systems engineering study, an ongoing project, is being conducted to provide a method by which proposed wave energy concepts may be evaluated. Principal tasks of this study have included development of a set of top level requirements for wave energy conversion devices and a work breakdown structure for classifying and identifying major wave energy conversion system components. A wave power resource scenario for coastal U.S. areas that are representative of typical high-resource zones was also prepared. Further, a task was performed that entailed compilation of an extensive bibliography on wave energy conversion.

The primary task of the study involved preparation of a performance evaluation of generic wave energy conversion concepts (Reference 6). This effort provided a methodology by which wave energy conversion ideas can be ranked by their technical merit, based upon the overall electrical and mechanical efficiencies of their extraction, conversion, and transmission systems. A summary of the performance figures for a representative generic device is provided in Figure 5. Identification of major ocean engineering systems associated with a wave energy conversion device and projections of component costs are the significant elements of a task still to be completed. With the availability of this data, figures of merit may be developed to facilitate comparison of costs per unit power produced for each of the generic concepts.

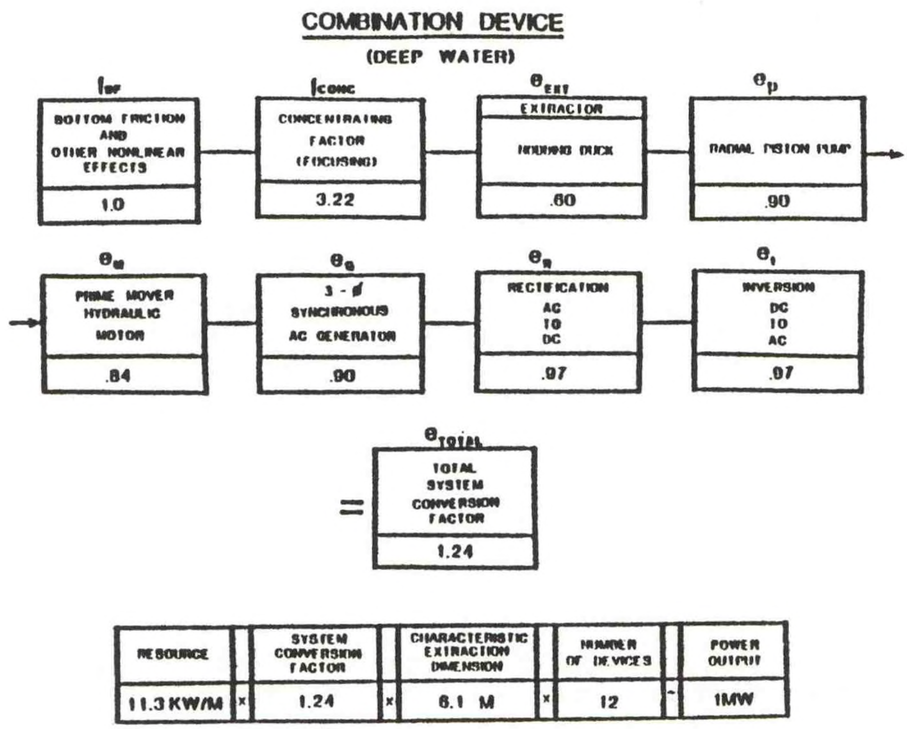

Figure 5. Summary Of Performance Factors For A Generic Wave Energy Conversion Device

Wave Resource Estimation Study

This project was initiated to augment the environmental data gathering effort of the U.S. OTEC program in order to provide detailed wave parameter data. A computer model, the Spectral Ocean Wave Model, has been developed to process raw meteorological data supplied by the U.S. Navy's Fleet Numerical Weather Center in order to provide directional wave spectra data for a number of coastal U.S. sites (Reference 7).

The code converts meteorological parameters such as atmospheric pressure data or wind information to derive wave spectral data properties. Incorporated in the model is an algorithm that removes incorrect data points because of inaccuracies in the unprocessed data. No follow-up effort is expected.

FUTURE DIRECTION

Future U.S. DOE wave energy conversion technology developments will be focused on testing and enhancement of the PWEC device in order to retain the capability of participating in a future full-scale multi-national demonstration test, such as may be sponsored by the IEA. Additionally, development of other concepts and an overall program support function will be pursued as opportunities develop. Funding of projects through areas other than federally supported programs will also be investigated, in order to ensure a continued U.S presence in this potentially viable technology.

REFERENCES

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STATUS OF THE U.S. DEPARTMENT OF ENERGY'S OCEAN THERMAL ENERGY CONVERSION PROGRAM

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ABSTRACT

Ocean thermal energy conversion (OTEC) is viewed as a potentially significant renewable energy resource for the United States. This paper presents an overview of ongoing research and recent developments in the U.S. OTEC program under the direction of the U.S. Department of Energy (DOE). Major research areas covered are power systems, ocean engineering, undersea power cable, ocean energy products and environment. The history and current status of DOE's OTEC proof-of-concept experiment are also reviewed, together with associated system integration efforts.

INTRODUCTION

Ocean thermal energy conversion (OTEC) utilizes the temperature difference between sun-warmed surface waters of the ocean and the deep, uniformly cold waters that maintain a nearly constant temperature of 4°C at depths 1,000 m below the sea surface. This temperature difference averages 20-24°C annually in the tropics and is available as far north as 30°N in the western parts of major ocean basins. Thus, both Japan (Kyushu) and the continental United States (Gulf of Mexico) have direct access to this renewable energy resource, and it is natural that the governments of both countries should encourage its development.

A typical OTEC plant contains a number of subsystems that must function together in an integrated fashion to effectively utilize the ocean thermal resource. These include the power system, platform, cold water pipe (CWP), mooring or positioning system and an energy transfer/utilization system. Electrical energy produced by the power system may either be transmitted directly to an existing power distribution grid or may be utilized on the platform to produce transportable fuels or energy-intensive industrial products. Environmental concerns which must be addressed include the magnitude and availability of the thermal resource, the acquisition of oceanographic and geotechnical design data, and the potential environmental impacts of plant construction, deployment and operation. Finally, like most solar technologies, OTEC is up-front capital intensive, and it is presently assumed that to be economically successful, an OTEC plant must operate at 80% availability for 30 years. Adequate inspection, maintenance and repair of the various plant subsystems is thus an essential ingredient in any OTEC venture.

The U.S. Department of Energy (DOE) has been involved with OTEC development since DOE's inception in 1977. During this period, DOE has conducted an extensive subsystem research and development program as well as sponsored a number of design studies for fully integrated plants ranging in size from 1 to 400 megawatts electric (MWe). In addition, DOE has initiated a proof-of-concept experiment, designed to demonstrate the economic feasibility of OTEC at a scale representative of commercial application. This paper reviews the current status of DOE's OTEC program and recent developments in each of the above areas.

POWER SYSTEMS

Two basic power cycles have been proposed for converting the ocean thermal resource into useable electric power (Figure 1). In the closed cycle concept, warm seawater is pumped through an evaporator, where a low boiling point working fluid, such as ammonia, is vaporized. This vapor expands through a low pressure turbine and is condensed by cold seawater pumped from the depths. The working fluid condensate is then collected and returned to the evaporator to complete the cycle. In the open cycle concept, a small fraction of the warm water stream is vaporized under a partial vacuum. Expansion of this water vapor is used either to power a low pressure turbine (Claude cycle) or to lift the vapor and associated liquid to a height where the liquid can fall through a hydraulic turbine (lift cycles). If a direct contact condenser is used, the condensate is discharged with the cold water stream. If a surface condenser is used, the condensate will be freshwater, which can be collected as a marketable by-product.

Two baseline closed-cycle power systems were developed early in the OTEC program, one incorporating shell-and-tube heat exchangers, and the other incorporating flat plate heat exchangers. Because of the low temperature differences involved in OTEC, heat transfer efficiencies are low, typically 2-3%. Recent research and development has therefore concentrated on improving the thermodynamic performance of heat exchangers and preventing the accumulation of biofouling films that seriously degrade their performance. Three major DOE projects completed in 1981 were: the evaluation of 13 different heat exchanger designs at the Argonne Heat Exchanger Test Facility (1), a single-tube heat-transfer monitoring program to assess the effectiveness of various biofouling countermeasures in temperate coastal waters (2), and a three-month heat exchanger test program carried out aboard the pre-operational test platform, OTEC-1, moored off Keahole Point, Hawaii (3). In addition, DOE and the Natural Energy Laboratory of Hawaii have jointly funded the construction of a permanent shore-based facility at Keahole Point, which will enable long-term heat transfer experiments in an actual OTEC environment (4).

Open-cycle power systems require research and development in a number of areas before a baseline design will be feasible. Emphasis is presently placed on the Claude cycle, with research concentrating on large-diameter turbine design, falling film evaporators and direct contact condensers, and non-condensible gas removal to prevent vacuum degradation and maintain power system performance (5).

OCEAN ENGINEERING

Ocean engineering technology development covers four general areas: platform design, cold water pipe design, mooring systems and foundations, and inspection, maintenance and repair. The most active DOE projects are presently in platform design and foundations for shelf-based OTEC systems and at-sea testing of a 1/3-scale cold water pipe.

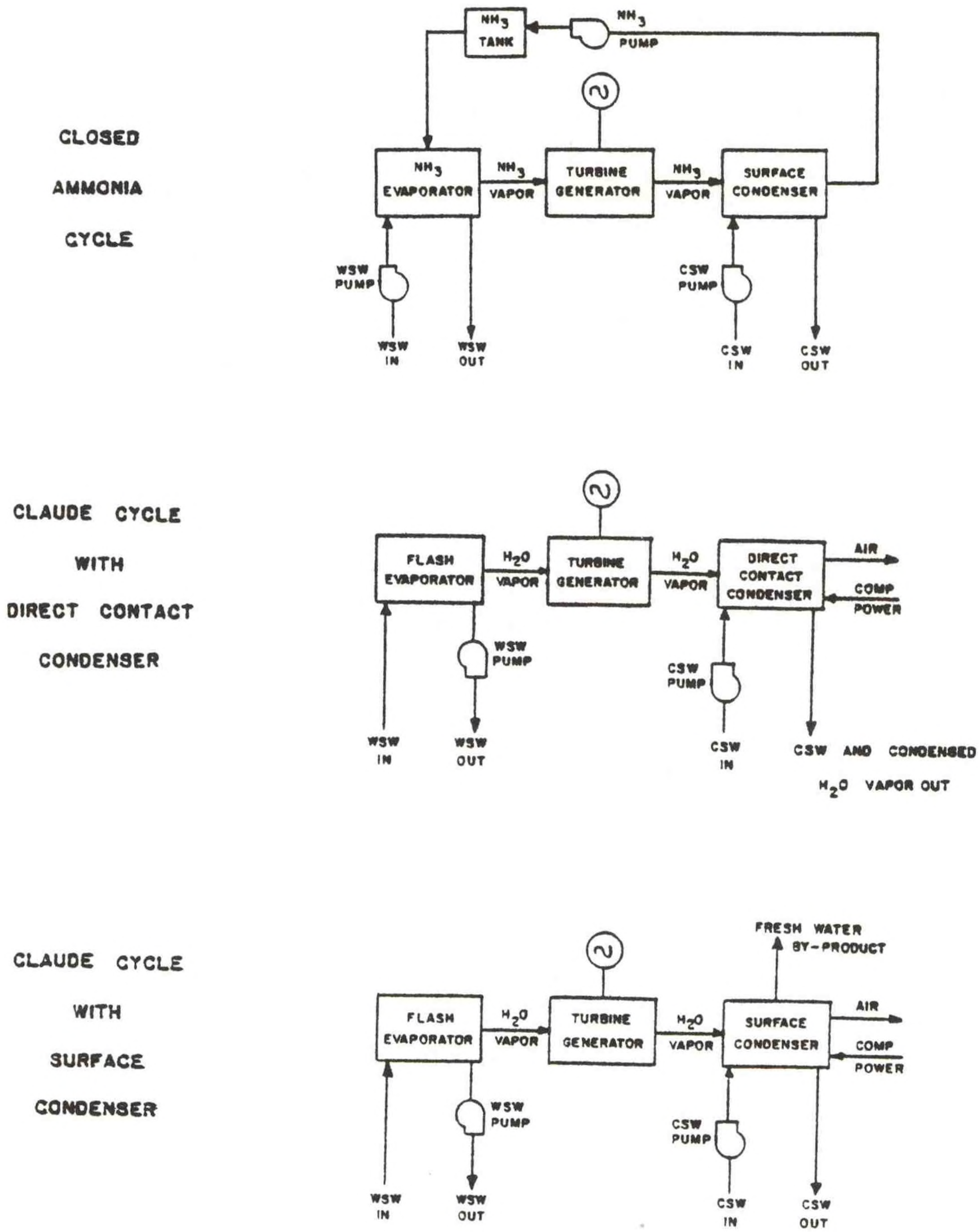

Figure 1. OTEC power cycle concepts having the greatest potential for near-term application. Closed cycle power systems may utilize working fluids other than ammonia.

Platforms

DOE has initiated two research projects to support the development of shelf-based OTEC systems. The first of these is a comprehensive study to develop foundation design procedures and foundation performance models for fixed-tower OTEC platforms, to prepare a detailed site survey plan and to perform a preliminary bathymetric survey of a candidate OTEC site. The second project is to obtain laboratory model test data on hydrodynamic loading of fixed-tower OTEC plants, concentrating on the loading experienced by large off-bottom block structures, such as heat exchanger modules, which will be contained within the submerged portions of these platforms.

With regard to floating platforms, DOE has recently completed an ocean engineering study on the feasibility of a moored pipe, mobile platform $(MP)^2$ concept, where the platform would be detached from the cold water pipe and its mooring system during extreme storms. Although this concept appears feasible from an ocean engineering point of view, a number of systems integration issues remain to be addressed, including platform propulsion, subsystem transition and connect systems, and platform detachment scenarios, particularly with regard to impact on life-cycle economics.

Cold Water Pipe

Early CWP baseline design studies funded by DOE resulted in fiber reinforced plastic (FRP) emerging as the leading pipe material, particularly when combined with a syntactic foam core in a sandwich wall construction. This construction offers flexibility in choice of material properties, ease of deployment, and relatively low cost. A series of model tests completed last year verified, at laboratory scales, that a single piece FRP/syntactic foam CWP can be deployed by horizontal tow-out and vertical upending, and that the structural responses of this pipe, when attached to a moored floating platform in operational and extreme sea-states, was well within design limits (6). Through DOE, the National Oceanic and Atmospheric Administration (NOAA) has sponsored the development of three analytical computer models to predict CWP responses to hydrodynamic loads and platform motions. Two of these codes, NOAA/ROTEC and NOAA/DOE, operate in the frequency domain, while the third code, NOAA/TRW, is a time-domain model.

The next step in the cold water pipe (CWP) development program is the at-sea testing of a 1/3-scale CWP. This program is intended to verify a complete CWP design methodology, including materials performance, fabrication, deployment, operation and retrieval. The pipe test article will be 10 feet in diameter and of FRP/syntactic foam sandwich wall construction. The pipe will be mounted via a gimbaled interface to a steel barge moored at a test site off Honolulu Harbor, Hawaii. The materials testing program is nearly complete and fabrication and preliminary deployment plans have been prepared.

The CWP studies mentioned thus far have focused on free-hanging CWP's attached to floating platforms. A number of studies have also investigated slope-mounted CWP's for land or shelf-based OTEC plants. Although slope-mounted pipe systems need not be designed to withstand loads induced by platform motions, deployment and installation of these pipes and their foundations is currently perceived as the highest risk area for land and shelf-based OTEC plants. DOE, therefore, plans to conduct the at-sea CWP test in two phases. During the second phase, the CWP test article will be retrieved from the barge and installed on a previously deployed foundation system, thereby enabling data collection on deployment, hydrodynamic loading and structural response of slope-mounted cold water and discharge pipes.

Mooring Systems

For floating OTEC plants that transmit electrical power to an on-shore distribution grid, mooring systems are a critical design element. In order to prevent excessive fatigue of the power cable between the platform and the seafloor, operational platform excursions should be limited to a watch circle radius equal to 10-30% of total water depth. Although catenary and tension anchor leg systems, as well as dynamic positioning, have all been considered for OTEC station-keeping, multiple catenary anchor leg mooring systems appear to provide the nearest term, lowest risk approach to the position control problem.

It is anticipated that floating OTEC plants of 40-100 MWe net capacity will require eight to twelve anchor legs. Each anchor leg will consist of five basic components: winches, windlasses and other platform equipment, transition hardware, such as chafing chains or spring lines, a wire rope segment (typically 11-18 cm in diameter, 1000-1800 m in length), a chain segment (typically 10-15 cm in diameter, 600-1200 m in length), and a seafloor anchor (large deadweight, high capacity drag embedment or pile). The DOE/NOAA mooring system development program is presently investigating a number of areas, including fatigue and service life data for large-diameter wire rope, analytical models of mooring system performance, particularly in response to wave drift forces, installation of anchors, and inspection, maintenance and repair requirements for mooring systems (7). Of recent concern is the fact that regulatory agency inspection requirements and replacement schedules for certain anchor leg components may contribute significantly to mooring system life-cycle costs.

Inspection, Maintenance and Repair

A recently completed, comprehensive investigation of inspection, maintenance and repair (IM&R) requirements evaluated typical OTEC plant materials and structures as to their susceptibiity to failure and deterioration, and identified means of IM&R, based on water depth and accessibility (8). IM&R at depths greater than 200-300 m will require development of special equipment and modification of manned/unmanned submersible technology, as divers cannot routinely operate below these depths. Repair of many components, particularly anchors and CWP, may not be possible while these components are in service. In-situ material repair capabilities are limited, particularly for concrete and plastics, emphasizing the need for constant monitoring to detect damage before it assumes major proportions. It has, therefore, been concluded that inspection accessibility be incorporated in the earliest phases of OTEC plant design.

UNDERSEA POWER CABLE

Construction of submarine bottom power cables and power conditioning equipment (e.g., switchboards, transformers) for OTEC plants of 40-400 MWe net generating capacity is well within the capabilities of existing technology. The riser cable between the bottom cable and floating OTEC platforms will experience cyclic environmental loads of a magnitude and frequency not previously encountered in high-voltage submarine power cable applications. Of primary concern is fatigue and associated stress-induced corrosion of the riser cable armoring material. A series of laboratory and at-sea tests have recently been completed on samples of the leading candidate material, AL-6X stainless steel. Although crevice corrosion was observed on the test specimens, no significant enhancement of fatigue was noted (9).

Three riser cable configurations have been proposed for floating OTEC plants: a vertical riser system attached to the CWP, a direct catenary riser system and a catenary riser system supported by a submerged stand-off buoy. Each of these configurations is associated with different system integration requirements, deployment methods and life-cycle costs (10). Ongoing DOE investigations of the riser cable system include the development of an analytical model to predict system response to hydrodynamic loading and platform motions and a baseline survey of corrosion protection problems and strategies for metallic riser cable components, as well as platform and bottom cable interfaces. Two studies funded by DOE were recently completed with regard to deployment and protection of the bottom power cable (11, 12). Environmental hazards were characterized as to type, depth of applicability and protection strategy for four generic OTEC sites.

OCEAN ENERGY PRODUCTS

Alternatives to transmitting OTEC-produced power directly to shore are the production of transportable fuels and energy-intensive industrial products. These alternatives do not require the OTEC plant to be located at a permanent site, and have given rise to the concept of a mobile plantship. Plantships would operate in a "grazing" mode, searching out the best thermal resource areas in which to carry out on-board production activities. Aluminum refining (13) and ammonia production (14) have both been considered for plantship applications. Through the Applied Physics Laboratory of Johns Hopkins University, DOE has recently completed investigations of the market potential for two OTEC-produced synthetic fuels: ammonia (15) and methanol (16).

ENVIRONMENT

Environmental research in support of the DOE OTEC program has recently been active in three major areas: the evaluation of potential environmental impacts, the collection of environmental data from proposed OTEC sites, and the development of numerical models to predict circulation patterns in the vicinity of OTEC plants.

In early 1981, a generic Environmental Assessment (EA) was prepared for the operation of a 40 MWe OTEC pilot plant as part of DOE's proof-of-concept experiment. Significant environmental, health and safety, and regulatory issues were identified, together with data requirements for resolving these issues during the preparation of future site- and design-specific EA's and Environmental Impact Statements (17). A programmatic Environmental Impact Statement was also prepared to evaluate the potential impacts of commercial OTEC development within the United States through the year 2000 (18).

To provide documented information on existing oceanographic conditions at proposed OTEC sites, DOE has supported an extensive environmental monitoring program, managed by Lawrence Berkeley Laboratory at the University of California. This program consists of archival studies, serial oceanographic cruises, measurements from various fixed platforms and the compilation of data for appropriate legal compliance and permit requirements (19). One-year monitoring programs have been completed at benchmark sites in the Gulf of Mexico, Puerto Rico, Hawaii, and the equatorial South Atlantic Ocean off Brazil (plantship operations). Archival and preliminary field data have also been collected for Guam and the U.S. Virgin Islands. In addition, on-board and oceanographic sampling programs were carried out during the deployment of OTEC-1 (20).

Prediction and analysis of physical transport and mixing processes in the vicinity of OTEC plants are required to provide a basis for assessing chemical and biological environmental impacts, as well as characterizing ocean thermal resource utilization. Such studies form an integral part of DOE's OTEC environmental assessment program. Recently completed investigations have focused on the modeling of thermal discharge plumes and the development of discharge design and plant siting strategies to avoid recirculation effects and minimize environmental impacts (21, 22).

PROOF-OF-CONCEPT-EXPERIMENT

The primary goal of DOE's OTEC program is to demonstrate the economic feasibility of OTEC at a sufficiently large scale to encourage the development of privately financed OTEC ventures within the United States. To this end, proposals were solicited on a competitive basis for one or more pilot plants, whose design, construction, deployment and initial operation will be cost-shared by the Government as a proof-of-concept experiment. It is anticipated that Government funding will be provided only so far as is necessary to develop sufficient confidence in the technology to encourage private investment in OTEC.

In September of 1980, a Program Opportunity Notice (PON) was issued to approximately 325 firms and industry representatives, soliciting proposals for a 40 MWe closed-cycle OTEC pilot plant. The PON advised potential offerors that the project would be divided into six phases, commencing with Phase I, Conceptual Design, and ending with Phase VI, Transfer of Ownership and Contractor Operation. Contractors were expected to share 15 to 40 percent of the total cost of the project.

Two awards were announced by DOE in February of 1982. The first was to General Electric (GE) for a shelf-based plant of conventional offshore fixed tower construction, located in approximately 100 m of water off Kahe Point, Oahu, Hawaii. The second award was to Ocean Thermal Corporation (OTC), also for a shelf-based plant off Kahe Point. The OTC concept differs in a number of ways from that proposed by GE. The two most significant differences are that the OTC plant is to be sited on an artificial island in approximately

9 m of water and that the warm water supply is to be enhanced by the condenser discharge from an existing shore-based, fossil fuel power plant. Details regarding the selected proposals are given in Table 1.

In order to provide a design data base for evaluating the technological risks and cost reasonableness of the PON responses, DOE funded the development of a series of 40 MWe OTEC Pilot Plant Reference Baseline designs. These designs also provide a basis for determining critical areas where further research is required to reduce risks to an acceptable level and to adequately support cost estimates. Platform configurations included in the DOE Reference Baseline series are a tension-moored spar buoy (23), a catenary-moored floating barge (24), and a shelf-mounted fixed tower (25). These designs are continually updated to incorporate new findings from the research areas discussed previously, and to reflect additional concerns raised as the program develops. To determine how the experience gained during the proof-of-concept experiment will apply to larger platforms, DOE has also funded conceptual design studies of a 100 MWe shelf-mounted platform (26) and 100 MWe and 400 MWe catenary-moored floating platforms (27).

Table 1. Proof-of-Concept Experiment, Phase I Proposed Designs

PRIME CONTRACTOR:	General Electric Company	Ocean Thermal Corp.
SITE:	1600 m offshore Kahe Point, Oahu 100 m water depth	180 m offshore Kahe Point, Oahu 9 m water depth
PLATFORM:	Steel tower supported by pile foundation	Reinforced concrete plant on artificial island
POWER SYSTEM:	40 MWe net capacity Tower sized to accommodate 100 MWe	40 MWe net capacity Warm water supply enhanced by thermal effluent from existing fossil fuel plant
HEAT EXCHANGERS:	Flat plate aluminum construction	Horizontal shell-and-tube titanium construction
WORKING FLUID:	Freon R-22	Ammonia
COLD WATER PIPE:	10 m diameter 3000 m long Steel	10 m diameter 5700 m long Lightweight concrete
POWER CABLE:	Buried	Overhead

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OCEAN ENERGY FACILITIES: MINI-OTEC AND DAM-ATOLL WAVE ENERGY SYSTEM

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Introduction and Objectives

Man has coexisted with the oceans for many centuries, and while it has provided some benefits-- such as food, recreation and an avenue for transportation--we have not yet begun to utilize fully the tremendous resources that exist within the ocean. As my part of our joint panel meeting, I shall address only a small part of the total marine resources--ocean energy.

Extraction of power from the oceans may be classified as mechanical (waves, tides, current), thermal (temperature gradients), and chemical (salinity gradients and biomass). Lockheed's activities in ocean energy have been in the mechanical and thermal areas, and I would like to review with you two of our more important programs--the Dam-Atoll wave energy conversion system, and our Mini-OTEC system. I know that Japan is also interested in both thermal energy and wave energy from the ocean. We have some general knowledge of the Tokyo Electric Company OTEC installation at Nauru, and also your Kaimei wave energy project. Several Japanese groups have visited us for Mini-OTEC discussions in California and Hawaii. Time does not permit broad discussions, but we must be cognizant of ocean energy activities by other nations, such as the United Kingdom, France, Holland, and Canada.

For convenience, I will discuss our Mini-OTEC program first and then our Dam-Atoll program. The objective for Mini-OTEC has been to demonstrate that a floating plant in the open ocean can generate net electricity from the thermal gradient. The Dam-Atoll concept is more recent than OTEC and our objective is to acquire scale model tests in the laboratory to obtain quantitative data for further design work and more refined systems analyses.

At the conclusion of my talk, I will show a short movie on each of the ocean energy systems that I will discuss.

MINI-OTEC

Description of Project

The Mini-OTEC project was initiated in 1978 with the purpose of demonstrating that an OTEC plant at sea could produce net electrical power. It was decided that an integrated system would be built using off-the-shelf hardware components to vividly portray that OTEC is a present reality and not a distant, future possibility. The OTEC concept was almost 100 years old, but no one had ever built an OTEC plant which could produce net electricity. Fig. 1 is a picture of Mini-OTEC on station just off the coast of Hawaii.

A consortium was formed to finance the project without any funding from the U.S. Federal Government. The effort was led by Lockheed and the State of Hawaii, with support from Dillingham, Alfa Laval, and others. The time from the start of the project to the date of producing net OTEC power was only

15 months--a remarkably short time which is a credit to all the consortium participants.

The three major subsystems are the platform, the power plant, and the cold water pipe/mooring system.

A navy hopper barge was loaned to the State of Hawaii via the Department of Energy and then modified for installation of the OTEC system. The barge has a beam of 10 meters, length of 32 meters, and displacement of 270 tons.

The OTEC power plant utilizes a closed loop ammonia cycle that powers a turbine driven electric generator. Warm surface water of about 80^{o}F. is used as the heat source to vaporize the ammonia. The expanded vapor passes through the turbine and then into a condenser, where the cold water is used to condense the ammonia vapor back to a liquid.

Alfa Laval plate type heat exchangers were used in the heat exchangers for vaporizing and condensing the ammonia. Both heat exchangers operate with mixed phase flow in the ammonia passages.

The cold water pipe and mooring were an integrated system in which the cold water pipe was used as a tension leg member in the mooring system, Fig. 2. Twelve meter segments of a .6 meter diameter high density polyethelene pipe were butt welded together to form an integral cold water pipe 670 meters long. The cold water pipe had a polypropylene line and clump anchor attached to the bottom of the pipe; and the entire pipe was supported by a surface buoy. At a depth of 30 m, the cold water pipe was connected to a crossover hose which was attached to the bottom of the cold water sump in the barge.

The mooring clump anchor, which was at a depth of about 1000 meters was restrained from sliding down the bottom slope by a restraining line that was anchored just off shore.

The Mini-OTEC barge was connected to the surface buoy by a mooring hawser.

Results

During Mini-OTEC's four months deployment in the latter half of 1979, it was conclusively demonstrated that net OTEC power could be generated from the ocean thermal gradient. After initial operational problems were resolved, the OTEC plant was able to operate continuously night and day. Several hundred hours of power generation were achieved, and even when the entire OTEC plant was not operating, the auxiliary diesel generator provided power to keep a continuous flow of cold water.

The OTEC plant produced approximately 50 KW, which provided 15 KW net after extraction of 35 KW for parasitic power requirements associated with the seawater warm and cold water pumps, ammonia pump, and auxiliaries.

The low ratio of net power to gross power was in accordance with calculations, but should not be used as typical of large, optimum designed plants. Recall that the objective for Mini-OTEC was to demonstrate net OTEC power in a short time period at low cost. Large scale, optimum design OTEC plants will have net power be about 2/3 of the gross output.

Conclusions and Recommendations

Significance of the Mini-OTEC success has been widely used as an indication that OTEC power is feasible, and therefore normal business, commercial activities will cause the implementation of large OTEC power plants. It is true that the success of Mini-OTEC has gained world-wide recognition and has provided adequate proof of the OTEC concept. Recognition must also be given to Tokyo Electric for the OTEC plant at Nauru which began producing net OTEC power last year.

However, work remains to be accomplished on factors such as reliability, optimum design, specific site locations, and system economics before large plants will be built with private capital. Economies of scale will benefit large, several hundred MW, OTEC plants, but the large size plants will cost several hundreds of millions of dollars. Before very large OTEC plants will be built, we believe OTEC must prove itself economically competitive for small plants (few MW), and therefore we believe that Mini-OTEC, and other small plants, will provide a useful role in further testing and demonstration. Further, the total funding required for small plants provides an opportunity for consortiums of companies to further their interests without excessive participation by Government bureaucracies.

We recommend a continuation of OTEC development and testing, and would be pleased to have Mini-OTEC be an integral part of any further activity.

DAM-ATOLL

Description of Project

Numerous concepts and mechanisms have been envisioned to extract energy from ocean waves. Serious obstacles that must be overcome by any competitive wave energy system is recognition that wave energy tends to be diffuse or of low density; and any movable mechanism that "rides" the waves, or is on top of the water, is forced to operate in a most hostile environment. The Dam-Atoll concept is able to cope with both of these obstacles.

As shown in Fig. 3, a Dam-Atoll is a large, dome shaped structural shell located just below the neutral level of the sea. The shell is built over a central core which houses the turbine and generator. The special dome shape acts as a concentrating device, and thus accommodates the low density of wave energy, to concentrate the energy in both horizontal and vertical directions. The energy in the vertical direction is concentrated in a manner like a typical beach; and in the horizontal direction, the energy is refracted or turned toward the center of the dome. The concentrated wave energy is directed to a central core in a manner to create a vortex flow in the core. This vortex, or fluid flywheel, acts as an energy storage device to permit continuous output power from massive pulses of wave energy input power. Thus, the vortex in the central core serves as a fluid flywheel from which energy is continuously withdrawn by a turbine. When the turbine drives an electrical generator, the nominal output of an 85 meter diameter Dam-Atoll is in the order of 1 to 2 MW depending upon the input wave energy.

Other than the turbine-generator drive shaft, the Dam-Atoll system has no moving parts and is a static, structural shell maintained just below the surface of the water. Thus, to a very large degree, it avoids the very hostile air-sea interface environment.

The Dam-Atoll concept was developed by Lockheed in the late 1970s, and a patent was issued in May 1979.

Findings

A 1/100 scale model has been built and used as the proof-of-concept. Limited quantitative data have been obtained, but the tests and subsequent systems studies have provided encouragement to continue the program development.

Lockheed conducted a one year design and system study, which was completed in 1981, for the Solar Energy Research Institute. During that study a methodology was developed to optimize the configuration of the refractive dome shape. Analysis indicates that wave capture efficiencies up to 70% can be achieved. Some insight has been obtained about the internal flow characteristics in the central core, but additional research is needed to understand the flow characteristics so that maximum power extraction by the turbine can be achieved.

Design studies have been conducted for Dam-Atoll domes which are fixed in the ocean by bottom mounting, and for floating domes which must be appropriately moored. The floating system has the obvious advantage of accommodating tidal variations, which can be large in certain areas. The concentrating feature of the Dam-Atoll dome is a function of the decreasing depth for each streamline, so the mooring system in conjunction with the dome inertia must not degrade the potential high wave capture efficiencies. Preliminary designs have been made for bottom mounted, or fixed, installations which permit the dome to be "tunable", or maintain a fixed relationship to the average water surface level. Fig. 4 presents a cut-away, artist sketch of a Dam-Atoll unit.

Ecomonic studies indicate that even though the initial cost is high, Dam-Atoll can provide cost competitive electricity in the late '80s and early '90s. Three factors are the key to future Dam-Atoll competitiveness; 1) oil prices will tend to increase even though there may be short periods of oil price stability or temporary reversal, 2) multiple Dam-Atoll units will be built so that a "learning curve" benefit will accrue to the capital cost of each unit, and 3) systems will be installed in areas which have good wave resources a large percentage of the time, say a minimum of 30 to 40 KW per meter of wave front. With each Dam-Atoll unit producing 1 to 2 MW, the cost of electricity is expected to be about 10 cents per KWHr.

Conclusions and Recommendations

In consideration of the tremendous amount of renewable wave energy that is now dissipated on the shore, we endorse continued development of the more promising wave energy systems. We believe Dam-Atoll has great potential and would expect to see that more laboratory test results be obtained so that the true potential of a refractive wave energy concentrator can be developed.

In summary, I have described two solar energy conversion systems which utilize the ocean as a medium for providing an energy source to two different types of energy extraction systems. We have a facility available--Mini-OTEC--which can be used to further the OTEC principle; and we have a demonstrated concept--Dam-Atoll--which can be further tested and quantified. Successful introduction of solar energy devices will require coordinated efforts by all of us.

Thank you.

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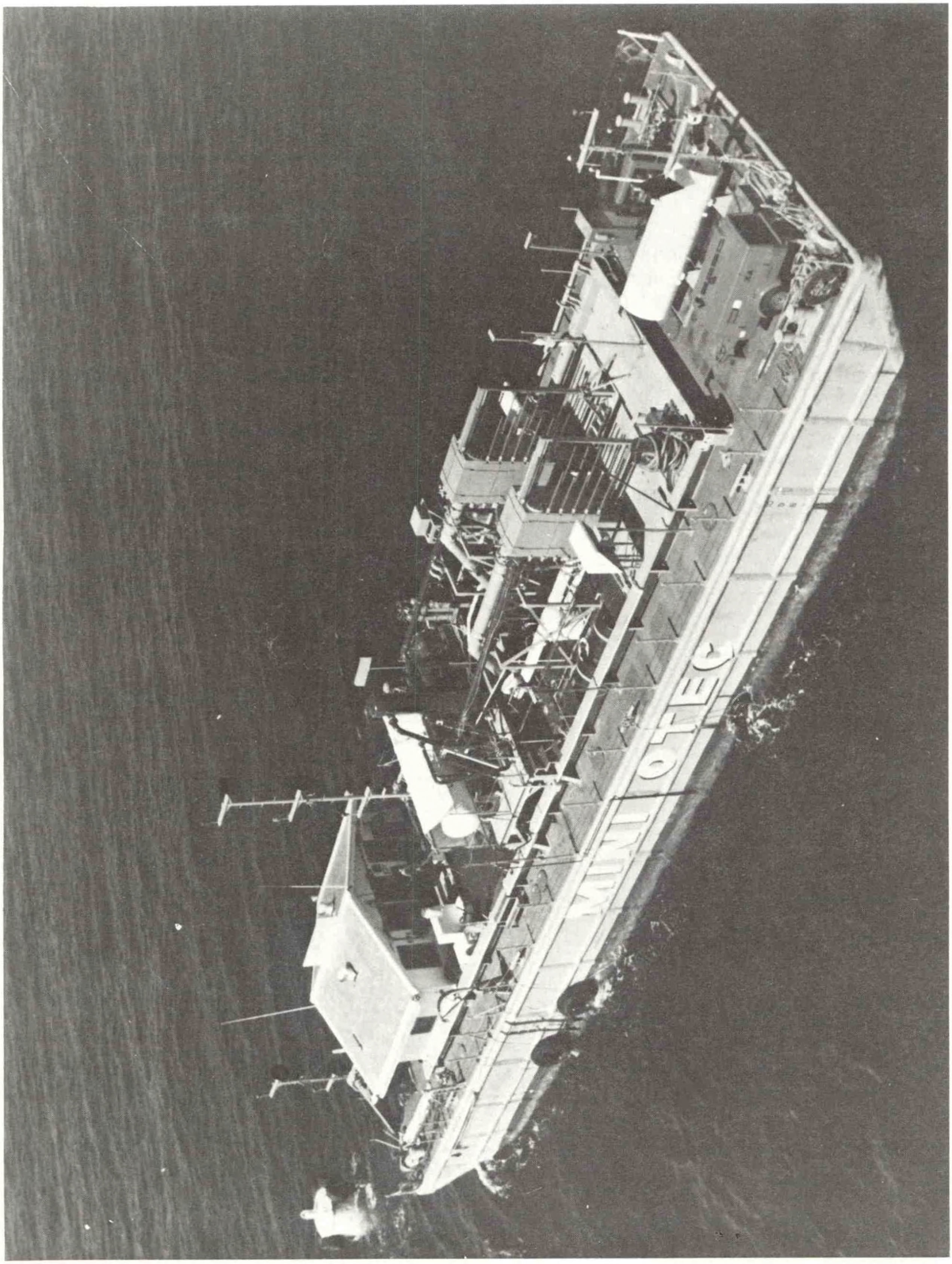


Fig. 1, Mini-OTEC On Station

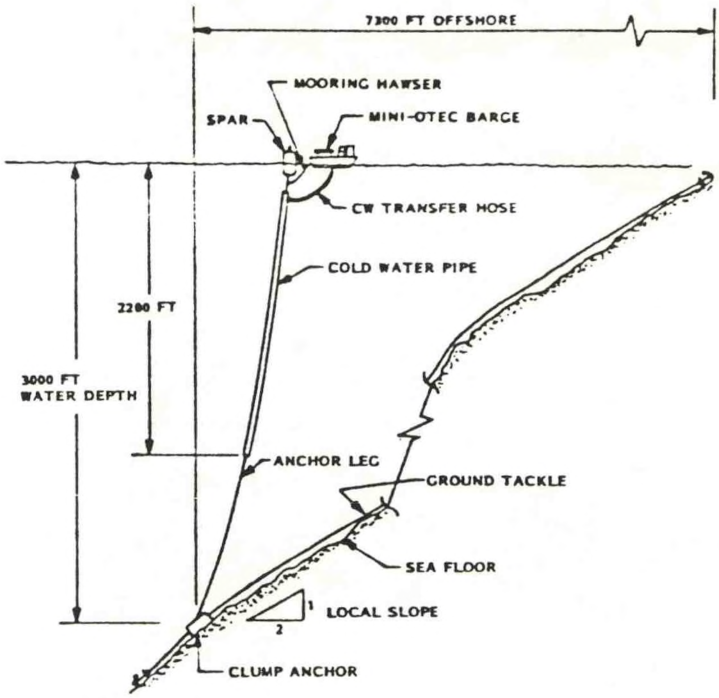


FIG. 2, Mini-OTEC Mooring Profile (Single Point Moor)

DAM-ATOLL™

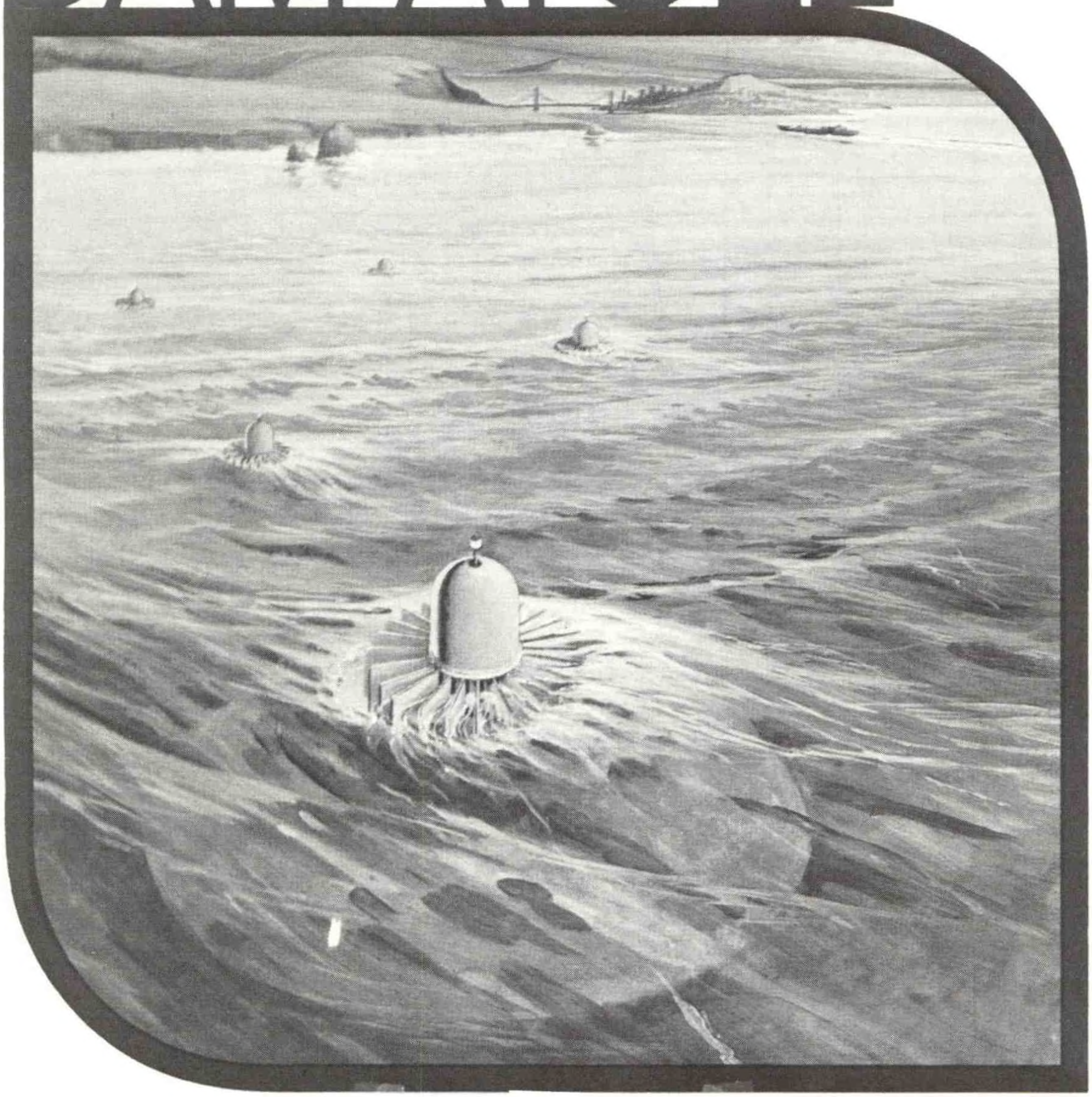
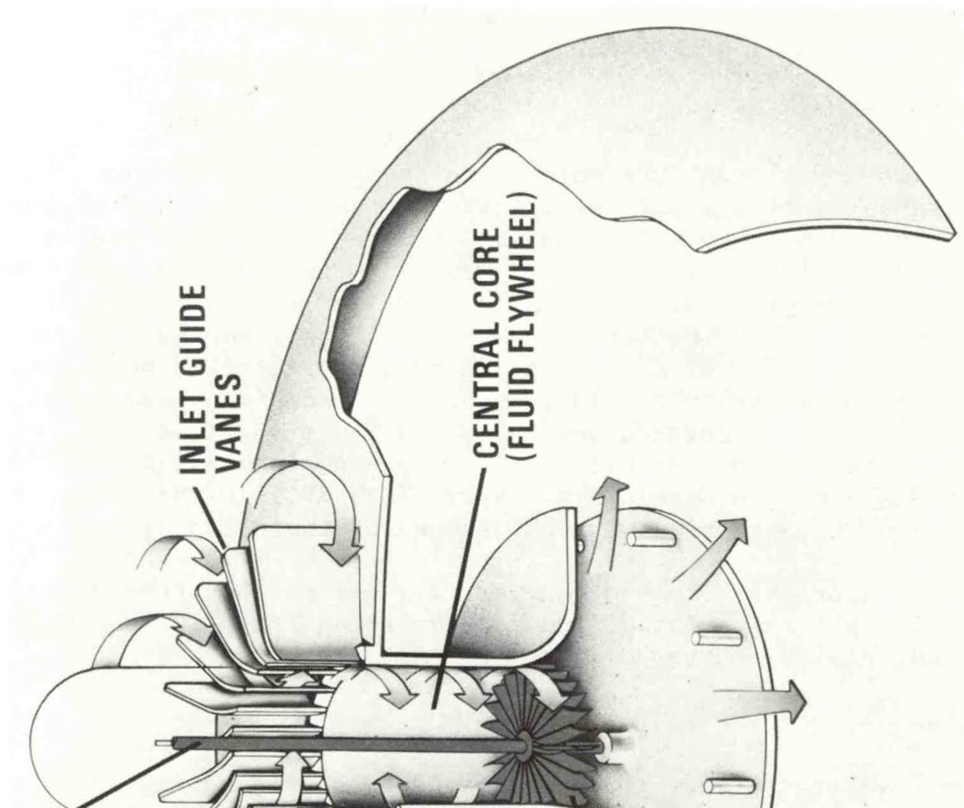


Fig. 3, Dam-Atoll

LOCKHEED'S PATENTED NEW CONCEPT FOR HARNESSING THE UNLIMITED ENERGY OF WAVES


WAVE
DIRECTION
WORK SYSTEM DRIVE SHAFT
INLET GUIDE
VANES
CENTRAL CORE
(FLUID FLYWHEEL)
TURBINE

EFFECT OF SHIP WAVES ON VESSELS AND OCEAN STRUCTURES

by

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Introduction and Objectives

A ship moving through the water generates a train of waves which spread out and eventually decay. If these waves encounter a small vessel or floating ocean structure, they will cause it to move in a manner similar to its response to naturally occurring ocean waves. Depending upon the specific circumstances, damage to or loss of the vessel or injury to persons on the vessel may occur. Thus two questions arise: first, how to prevent such damage by proper design of marine facilities, by selection of operating conditions, ship routes, etc., and, second, if a claim is made that such damage or injury has occurred, how to assess the probability that the ship claimed to be responsible actually was. The experience of the David Taylor Naval Ship Research and Development Center (DTNSRDC) in this area over the years has been in connection with the second of these topics.

In this paper, the state-of-the-art for estimating these effects, both for predicting potential damage and for assessing liability for damage which has occurred, will be surveyed.

Description

In deep water the wave train generated by a ship moving at constant speed on a straight course is in the form of a vee-shaped disturbance aft of the ship. Away from the local disturbance in the immediate vicinity of the hull the dominant divergent waves lie near a theoretical cusp line which is at an angle of approximately 19.5 degrees on both sides of the ship path. These waves appear locally to be nearly regular, with crests at an angle of approximately 54.75 degrees to the ship path. There is a second set of (transverse) waves, with crests which lie at an angle of approximately 90 degrees to the ship path, which are generally smaller in height than the divergent waves, and which extend to approximately the 19.5 degree cusp line.

In shallow water, as the depth Froude number* increases to a value of unity, the angle of the cusp line increases to 90 degrees. Above this critical Froude number, the transverse waves disappear and the divergent waves tend to have long, straight crests and the angle of the cusp line becomes smaller with increasing speed.

When a ship or other object floating in the water is subjected to an incident regular (sinusoidal) wave, the ship will move in a sinusoidal manner in response. The motions depend in a complicated manner upon the shape of

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* $U/\sqrt{gd}$, where U is the ship speed, d is the water depth, and g is the acceleration due to gravity.

the ship and the direction and wave length of the incident wave, but are generally (except for roll) proportional to the height of the incident wave for moderate waves. For heave, pitch, and roll there exist (usually different) natural or resonant periods at which the response per unit wave height or wave slope can become quite large, particularly for roll, which is poorly damped. For long waves the ship tends to follow the wave elevation while for short waves with periods considerably less than the respective natural periods, the response becomes small.

For the case of ship generated waves in deep water, at a fixed point the wave elevation appears to be an oscillation with an envelope which starts from nothing, rapidly increases to a maximum, and then slowly decays, with perhaps another local maximum. Thus, the waves appear with almost no warning. If the natural period of one or more motions of the vessel is close to the period of the incident waves, very large amplitudes of motion may be rapidly built up and the vessel may capsize. This is particularly serious in the case of roll motion, as the ship generated waves may be quite steep, although not excessively high, due to their shortness.

The discussion above concerns waves in an infinite ocean. Actual situations typically encountered in practice are much more complicated. In addition to the shallow water effects, uneven sea bottom contours, currents and nearby shore line and structures such as seawalls can seriously distort the wave pattern. Moreover, the speed and course of the ship are often not constant.

As examples of the complications which can occur in practice, consider certain cases for which DTNSRDC was asked for advice. In one recent case, waves from three patrol boats moving down Long Island Sound at speeds of up to 18 knots were claimed to have damaged a sailboat moored to a barge. This involved not only irregular bottom effects, but also the presence of a nearby island, reflection of waves from the barge, motions of the barge, the dynamic effects of the mooring, and possible adverse interference effects of the three sets of ship waves. Wave height estimates for a simplified physical situation were provided.

A more complex physical situation was a case in which waves from a slowing and turning tugboat were claimed to have violently disturbed a small work float under a nearby pier, injuring a man working on the float. The complications included not only the shallow water and the unsteady speed and course of the tug, but also the presence of ships moored on both sides of the pier, which reflected and channeled the waves, and the effect of the pilings supporting the pier. Disturbances of this type were a routine occurrence, and on previous occasions tools had been lost from the float and on one occasion a man had been thrown into the water. It was not possible to provide sufficiently accurate estimates of the magnitude of the local wave action in this case without extensive research (which was not done).

More typically, in the case of a destroyer running back and forth at high speed on a measured mile for speed trials, estimates of amplitude and time of arrival of waves on the nearby shore can be provided.

There are interaction effects in the close proximity to moving ships, but these will not be considered here as they are not wave phenomena. In fact, this problem is generally treated as one in which displacements of the water surface can be ignored, i.e., it is represented as a rigid waveless surface.

Findings

The problem of calculating the responses of vessels--stationary or moving--and ocean structures to waves generated by passing ships is a generally neglected but sometimes important subject in ship hydrodynamics. To take just one example, at the 16th International Towing Tank Conference (ITTC), the extensive report of the Seakeeping Committee[1] did not mention the topic. For ocean going vessels this neglect may be justified, as naturally occurring ocean waves are often much larger than ship generated waves. Even so, it has happened that a small yacht was hit by a significant wave generated by a large high speed liner, there being a rare dead calm: the liner was out of sight beyond the horizon.

In sheltered waters there may be considerable danger from these waves to small craft and structures which either are not designed for the open ocean or whose operators may not be prepared for the sudden appearance of relatively large and regular waves during otherwise calm conditions.

Ship generated waves, which are closely related to wave resistance, and the response of ships to regular and irregular waves are two important problems of long standing, and consequently there is much theory as well as model and full-scale experimental data available.

Ship generated waves and the related problem of wave resistance have been a topic of investigation from the time of Michell[2] down to the present time. Wehausen[3] has reviewed this work in considerable detail. Sorensen[4] has reviewed a very extensive amount of detailed model scale and full scale measurements of ship waves. Much of this work was motivated by consideration of damage to channel banks. The report of the Resistance Committee[5] of the 16th ITTC surveys recent work in the area. Two papers of particular value for calculation of wave patterns are by Ursell[6] and Tuck, Collins, and Wells[7].

The prediction of the response of a ship to idealized regular waves and to random waves as found in nature has received extensive study over the years. Newman[8], Ogilvie[9], and Faltinsen[10] have prepared extensive reviews of various aspects of the theory. This research is continuing at a rapid pace and the report of the Seakeeping Committee[1] at the 16th ITTC contains an up-to-date review of experimental results as well as theory. The report of the Ocean Engineering Committee[11] of the 16th ITTC reviews the situation for floating ocean structures. It is possible to predict the motions of a ship or ocean structure in moderate regular waves to within reasonable engineering accuracy.

Assuming linear superposition, it is then possible to predict the response of a ship to an arbitrary incident wave system as the sum of the response to the individual regular waves composing the incident wave. While this is done routinely for random waves, it is not so for ship generated waves.

The wave propagation question is more difficult: important aspects are the effects of channels and shoaling, the diffraction, refraction and reflection of waves, the effects of moorings and so forth. Various idealized solutions for such pieces of the total problem exist and these topics are the subject of much active work.

Newman[12] has surveyed diffraction effects, and Mei[13] has surveyed numerical methods applicable to this problem. Meyer[14] has reviewed refraction effects and Peregrine[15] has reviewed the effect of currents. These authors generally discuss effects on regular waves, but these results can be applied to the components of the wave field generated by the moving ship. Beck, Newman, and Tuck[16] have developed a theory for the steady longitudinal motion of a ship in a dredged channel. Van Oortmerssen[17] has developed a detailed mathematical model for the motion of a ship moored to a pier. Similarly, Webster and McCreight[18] have developed a mathematical model of the motions of a moored ship in the open ocean.

Two researchers have explicitly considered the present problem. Gadd[19] proposes the use of wave prediction methods as a tool for judging the possibility of damage due to waves generated by a ship of a new design. He suggests comparing predicted waves for the new ship with predicted waves for an existing ship whose waves are known to be large but tolerable in the area of interest. If the predicted waves for the new ship are no larger than those for the existing ship, the new ship is also likely to be acceptable. He argues that for similar ships the effects of the irregular sea bottom on the waves should be similar and consequently analytical predictions of waves in unrestricted deep water will be a useful guide to the acceptability of the new ship.

Lee[20] conducted an extensive series of full-scale measurements of waves generated by two ferry boats operating in Pearl Harbor at several speeds along the course to and from a proposed new ferry terminal. The resulting motions of several small craft located in a nearby marina also were measured. The motions were found to be acceptable and a wave energy dissipator was considered to be unnecessary.

However, it is frequently beyond our capabilities to fully address the general practical situation: techniques have not yet been developed to represent the combined influences of non-analytical forms in a useful way.

Usually, in assessing responsibility for damage, it is necessary to rely on rough estimates of wave height and times of arrival at the site of the damage. The theory of Stoker[21] has been found useful in making estimates of this nature. An additional difficulty is that conditions such as ship speeds, and time of passage, as well as the time of the incident are often not known exactly.

Conclusions and Recommendations

There exists an extensive and growing body of work in two separate areas of ship hydrodynamics, ship generated waves and ship and floating ocean structure response to waves, which are directly related to the problem of predicting the motion of vessels and ocean structures due to ship generated waves. There is also a growing literature on the wave propagation problems. However, there exists only a meager amount of information on the combined problem itself.

The methods which need to be developed to predict these effects are: first, for calculating the waves generated by a ship moving with varying speed along an arbitrary course; secondly, for calculating the response of a vessel to an arbitrary transient incident wave; and thirdly for accounting for bottom effects (including channels), currents and obstructions, and combinations thereof both in the wave propagation and in the response.

Such methods should be validated by model tests and full-scale experiments to establish adequate confidence in the predictions: unfortunately the establishment of a sufficiently broad data base to cover many practical situations will be relatively expensive.

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APPLIED MARINE RESEARCH IN U. S. UNIVERSITIES

by

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1.0 Introduction

Marine research as a organized field of study is a relatively recent development within the world's academic institutions. This may seem rather strange since the oceans cover nearly three-fourths of the surface of the earth and have enormous resource potential; but, in fact, until recently there was really little incentive to look seaward except as a means to get from one point on land to another. Terrestrial resources were both plentiful and relatively simple to harvest for the small numbers of people who inhabited the earth prior to the twentieth century. Thus the earliest uses of the sea had little to do with resource exploitation but a great deal to do with trade, commerce, and the conquest of territory. The population explosion of the past century with its concomitant depletion of terrestrial resources and increased competition and conflict among developing nations has forced an increasing exploitation of marine resources of food, fresh water, energy, and minerals. This growing dependence upon the seas to meet human needs and the related exercise of sea power among coastal states has been the forcing function for the rapid development of marine studies within academic institutions; for as the resources needs have become more intense so has the need for improved knowledge and technological expertise to exploit these resources. This paper will outline the major thrusts of these marine studies efforts within U. S. universities.

2.0 Oceanographic Institutions

The first major oceanographic institutions to be established in the United States were the Scripps Institution of Oceanography (1903) and Woods Hole Oceanographic Institution (1930). Interestingly enough, both of these institutions were established with private rather than public funds. This probably reflects the fact that, at least within the U. S., there was little recognition, at the national level, of the need for exploitation of marine resources at least through the first part of this century.

With the advent of World War II, the science of oceanography in the United States expanded dramatically in importance. National support for research in this interdisciplinary field of science grew rapidly within the nation's colleges and universities and, within the next three decades, over 150 of them had at least some program offering in the marine field. Most of these institutions started in the ocean business by offering courses in marine biology and geology. Only a few developed the resources, facilities, and base of scientific skills sufficient to offer advanced degrees and conduct research in the field of oceanography. These latter institutions include Woods Hole, Scripps, MIT, Texas A&M, and the University of Washington. More recently, additional universities have emerged as major oceanographic institutions. These include the University of Southern California, Oregon State University, University of Rhode Island, University of Alaska, and the University of Hawaii. Much of the applied marine research in U. S. universities is conducted by this core of institutions with a solid academic base and research facilities.

3.0 Research Funding, Facilities, and Equipment

Applied oceanography is "big" science. It requires the coordinated efforts of scientists from a number of disciplines, and it requires expensive laboratories, equipment, and ships. Massive government support has necessarily been the mainstay of this activity; and, as a result, the applied research has principally followed the course of governmental concerns. During World War II, acoustics was a dominant research field. Offshore oil and gas related research emerged in the 1940's. With the reduction in various fish stocks, aquaculture and fisheries related projects increased. Environmental concerns have, more recently, been responsible for an influx of applied research funding. With the projected declines in terrestrial supplies of energy and minerals, the trends in applied research is now leaning in those directions.

Marine research dollars flow principally from the National Science Foundation (facilities support and basic research), the National Oceanic and Atmospheric Administration, and U. S. Navy, with a smaller amount coming from other federal, state, and local agencies, industry, and foundations. Total funding for this research in U. S. universities amounts to about $550 million annually.

Marine research facilities and equipment are expensive to build and expensive to operate. The U. S. university fleet currently consists of 25 research ships (over 25 meters in length) costing $25 million annually to operate. These operating costs represent about 25 percent of each seagoing research project. The equipment installed in the research fleet is also expensive, with towed arrays costing up to $500,000 each, precision echo sounders $750,000 and equipment handling systems up to $1,000,000. Manned submersible research vehicles compound the costs since each of these has an associated surface support ship.

Oceanographic facilities on land are also expensive, with operating costs running in the millions of dollars annually at each major oceanographic institution. Few academic institutions engage in significant ocean engineering research because here the costs are even higher, with experimental towing tanks, wave flumes, and other facilities costing in the millions of dollars each. Substituting computer analysis for experiments, while less expensive, yields less reliable results.

4.0 Applied Research Programs

Applied marine research in U. S. universities can be place into the following categories:

A. Living Marine Resources
B. Non-Living Marine Resources
C. Socio-Economics
D. Ocean/Coastal Engineering

Projects within these categories range from the culturing of shellfish to the design of breakwaters. A very representative listing of current applied marine research projects undertaken by U. S. universities can be obtained through the National Sea Grant Depository at the University of Rhode Island. The current index published by the Depository contains a listing of over 4,000 technical reports resulting from current applied research funded by the National Sea Grant Program at all of the major universities in the U. S.

The founding principle of the Sea Grant Program is of particular interest in a discussion of applied university research since it gets at a basic problem of many academic institutions. Sea Grant was conceived as a mechanism for bringing the skills represented by the academic community to bear on relevant questions concerning the development of marine resources and also as a means by which marine resource problems and opportunities of the nation might be introduced to a university for study. The mechanisms established by the government to encourage university participation included funding for three elements at each selected institution:

1. a marine education program;
2. applied research program; and
3. a marine advisory services program.

The education component is designed to encourage graduate study in the marine field and to help create an improved understanding of the oceans among the citizens of the country; the applied research program provides funding for the study of marine resource problems and opportunities of local, state, or national interest; and the marine advisory services component is the transmission belt by which research results are translated to those who might be interested and by which new problems or opportunities might be translated to the faculty for resolution. The University of Southern California is one of about 30 academic institutions in the United States with a major Sea Grant Program.

5.0 Conclusions

Applied marine research projects at academic institutions in the U. S. are principally government funded, and the funding is dependent upon national priorities. The current direction of the research is toward living and non-living resources with a funding level at about $550 million and relatively constant over the past several years. With an increasing population density along our coastline, there is an increased research emphasis on socio-economic and environmental problems.

OVERVIEW OF MARINE TRANSPORTATION IN THE UNITED STATES

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I. Introduction: Policies vs Technologies

The U.S. marine transportation 'industry' has seven major components:

1.) U.S. flag oceangoing shipping in international trade (about 294 privately-owned vessels).

2.) U.S. flag oceangoing shipping in domestic trade, between U.S. ports under the Jones Act, (about 242 vessels).

3.) The U.S. flag Great Lakes fleet (about 145 vessels).

4.) U.S.-owned shipping under flags of convenience (about 687 vessels).

5.) The U.S.-owned and operated offshore services fleet (crewboats, supply vessles and tugs) in support of gas and oil exploration and production (about 2100 vessels).

6.) There are 59 privately-owned vessels laid up which can be put into service on short notice.

7.) The government-owned merchant fleet assets are 281 vessels. Only 17 are active, 264 are inactive.

Because of the breadth of the topic and the amount of time and space available for its presentation, I have chosen to focus on the most troubled segment of this industry: U.S. flag shipping in international trade. This is also what most of us mean when we use the term, "The United States Merchant Marine." I will also address the related shipbuilding base.

The U.S. Merchant Marine is in poor shape. U.S. flag ships carry only about 4% of U.S. import and export cargo tonnage. Not surprisingly, most U.S. shipyards face an uncertain future in the construction of commercial vessels.

This situation results from several decades of inattention on the part of the U.S. government. For example, in 1950 the U.S. Merchant Marine ranked second in the world in size, consisting of some 1170 vessels. It carried, roughly, 50% of our nation's overseas trade tonnage.

This was a valuable national asset, but one which derived from the buildup of merchant shipping assets during World War II. At present, the U.S. Merchant Marine now ranks 11th in numbers of ships with 580 in service.

Since the early 1950s, the U.S. has 'used up' its merchant navy by failing to maintain a large and modern fleet. Ironically, this happened at a time of great U.S. progress in naval architecture and marine engineering. Nuclear power first went to sea in an American submarine and its first merchant vessel application was the U.S. built N.S. SAVANNAH. In the movement of cargoes, Americans were heavily involved in the development of the new technologies such as containerization, modular barges aboard ships (LASH) and the roll-on/roll-off (RO-RO) vessels.

The real problem is with failed government policies rather than proper implementation of new technologies. This will be the theme of this paper.

This is a technical meeting in which engineers and scientists exchange ideas and experiences. My intent is to show how chronic, poor planning together with short-term management objectives can override technological advantage. It is a lesson that all technical people should understand; that is, they must maintain an active, vital relationship with the policy making process.

II. The Reagan Administration and Congress: A New Start?

In January, 1981 President Reagan took office. During his first two years, he has primarily addressed himself to reductions in the federal budget, taxes and the size of government. However, he has, also, taken some actions that could help arrest the decline of the American Merchant Marine.

In campaign statements made in September, 1980 (before his election), Mr. Reagan declared the following points:

"1.) Provide a unified direction for all government programs affecting maritime interests in the United States, insuring active cooperation between the Navy, the merchant marine and governmental departments responsible for each.

2.) Improve utilization of military resources by increasing commercial participation in support functions, thus saving taxpayers dollars and releasing naval crews to man the growing naval fleet.

3.) Recognize the challenges created by cargo policies of other nations and insure that American-flag ships carry an equitable portion of U.S. trade.

4.) Restore the cost competitiveness of U.S.-flag operators in the international marketplace, making certain the American merchant fleet and shipbuilding industry survive and grow.

5.) Revitalize the domestic water transportation system.

6.) Reduce the severe regulatory environment that inhibits American competitiveness in shipping and shipbuilding.

7.) Insure that the vital shipbuilding mobilization base is preserved by undertaking sufficient naval and commercial shipbuilding.

The next month, October, 1980, he added an eighth point:

8.) The preservation of coastal trade, presently embodied in the Jones Act, has been a part of this nation's maritime policy since its beginning. The Reagan Administration will not support legislation that would jeopardize this policy."

Since taking office, the President has implemented these points by the following actions:

1.) The Maritime Administration (MARAD) was moved from the Department of Commerce to the Department of Transportation. This was in August, 1981, as the first major marine transportation transaction of the new administration.

2.) In December, 1981, Secretary Drew Lewis, of the Department of Transportation, announced that the President would support a six point program for stimulating competitive operations of U.S. liner companies, largely through enhanced anti-trust immunity. This proposal had many elements similar to bills proposed in the Senate in the 96th (1979-80) and 97th (1981-82) Congresses. The Administration proposal was similar to the provisions of the nearly identical Senate bills adding a provision providing for shipping conference members to set tariff rates among themselves without filing them with the Federal Maritime Commission.

3.) The Economic Recovery Tax Act of 1981 reduced the depreciation period for full write-off of a ship from 14.5 years to 5 years. This moves the U.S. much closer to the practices of other major maritime nations.

4.) The President's build-up of the defense establishment was reflected in the Navy's program to build a 600-ship Navy. At present, the Navy has about 450 ships; some of these will need to be replaced in the next few years, giving U.S. shipyards a building program of well over 150 ships. While most of these are warships, some will be logistic support vessels built along the lines of commercial ships.

5.) The President has resisted attempts to roll back provisions of the Jones Act to permit foreign ships in U.S. coastal trades.

6.) The Administration maintains strong support of the Cargo Preference Act of 1954, so that not less than 50 percent of U.S. Government cargoes are carried in American flag ships.

7.) Proposals to ship Alaskan oil to Japan in foreign flag vessels have been denied.

8.) New policies of the Defense Department's Military Sealift Command favor increased use of long-term chartered shipping for military cargoes and logistic support.

9.) The Regulatory Reform Task Force, chaired by Vice President Bush, is reviewing a large number of federal regulations. Many of these affect the marine transportation industry. It is probable that many will be amended or terminated, resulting in considerable cost savings.

10.) The President's general philosophy of getting the government out of private sector businesses will, also, have a positive downstream effect for the maritime industry.

But Congress has not simply waited for the President to act. For its part, both the House and Senate have proposed some similar actions that could help facilitate the President's program. There seems to be agreement that prompt action is needed.

While there has been significant, positive movement, there have also been some disappointing aspects of the Administration's activities. Some examples are:

1.) The proposals to drop the Construction Differential Subsidy (CDS) program and to greatly reduce the Operating-Differential Subsidy (ODS) program will cause problems. Many agree these programs for U.S. flag shipping should be phased out if offsetting remedial measures were simultaneously applied. This cutback should not be done instantly. The industry might have major problems if these subsidies are abruptly terminated or significantly curtailed. Careful phasing out must be considered.

2.) The user fee issue is troublesome. These charges are being considered for a wide range of services formerly provided 'free' by government. Proposed fees range from charges for federal dredging maintenance in ports to Coast Guard licensing services for seamen. An equitable fee system serving the purposes of government while not imposing an unfair burden on certain segments of the U.S. maritime industry will be difficult to develop.

3.) Reductions in Coast Guard budgets will reduce services to mariners. From safety of life at sea to in-port vessel safety inspections, the USCG will be less effective than at present.

4.) Most of the Navy's ship construction program will involve shipbuilding techniques that may not have much in common with the production of merchant shipping. Some shipyards which are not equipped for, or cannot convert to, naval vessel construction may be forced to shut down due to lack of merchant ship orders. Or, they may be forced out of new construction into the repair business. An added problem is the gap between present shipyard work activities and actual startup of the Navy program. This may result in 2-3 years of little or no work until the Navy program is implemented. In the interim, yards may have to reduce skilled personnel in their labor force. These people might not return to the yards when work resumes.

5.) The Administration's Special Trade Representative strongly promotes "free trade in free markets." His organization must gain full understanding about the real nature of the international marine transportation market. They should resist applying these notions to this area, which is distinctly not "free."

6.) Reduction of the Maritime Administration's research and development budget is bad. It mortgages future ability of the U.S. maritime industry to find new, productive technologies in partnership with the government.

7.) There is an indication that the Office of Management and Budget (OMB) may reduce the Title XI ship mortgage guarantees as part of an overall reduction of Federal credit programs. This program has been self-supporting, without burden on the U.S. Treasury, and has helped stimulate investment.

III. Conclusions: Cautious Optimism

On balance, the Reagan Administration, so far, has been a positive force with respect to improving the U.S. maritime posture. There is, however, some disappointment about the slow progress being made to develop a national maritime policy. There is also concern that not enough attention is being paid to the state of our commercial shipbuilding base. Finally, the general tendency to remove all subsidies is troubling if offsetting remedies are not given a chance to work. This will take time.

The naval shipbuilding program will provide stimulus to the U.S. shipbuilding industrial base. It will facilitate modernization of yards, development of new production technologies and will keep a skilled labor force intact.

But, attention also must be given to keeping the civil sector shipbuilding base intact. Incentives (i.e., taxation, anti-trust immunity, regulatory reform, etc.) that are beginning to emerge from government actions should stimulate investment by shipowners. But the U.S. Maritime Administration must insure that U.S. shipbuilders are reasonably protected, if this sector is to be maintained for the future.

With respect to new technologies in the U.S. shipping industry, there are some promising areas. The offshore support fleet for oil and gas operations continues to grow and is largely of U.S. design, construction and financing. Innovative designs and construction techniques keep this special segment of shipbuilding healthy. Short-term variabilities of offshore oil and gas development do put up-and-down swings in the upward trending growth curve.

Development, refinement and use of integrated tug-barge combinations for longer trade routes is very encouraging. Greater efficiencies can be achieved over conventional vessels in certain trades providing significant savings in initial investment, manning costs and fuel.

On the Great Lakes, advanced technology has put into operation large, self-unloading U.S. flag bulk carriers which can unload up to 10,000 tons of cargo an hour. Hopefully, such an advancement will find its way into the seagoing bulk fleets for handling of grains, ores and coal.

Technological progress is only insured through an active R&D program supporting our merchant shipping industry. Therefore, it is somewhat disappointing to note that the R&D budget of the U.S. Maritime Administration has been cut by over 50% in the last two years. In addition, the R&D budget of the United States Coast Guard (which has some maritime transportation aspects) has also been scheduled for a 50% reduction. Of course, industry must be encouraged to make its own R&D investments, but the guidance and partnership roles of the federal government are critical to effective progress.

To conclude, there are indications of positive movement in the formulation of new policy directions for the U.S. Merchant Marine. Many of the remedies proposed are innovative and they address the real problems. Certain sections of this industry are enjoying modest, positive progress but much more needs to be done.

Perhaps when this topic is addressed again at a UJNR/MFP meeting, the theme will be mostly technology and very little policy. But, policy must come first to set priorities and to allocate resources which will then facilitate the next step of implementation.

1981 UNITED STATES SUBMERSIBLE ACTIVITY AND ROBOTICS AND UNDERWATER WORK

by

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INTRODUCTION

This paper will cover two topics; first, the activity of fifteen manned submersibles operated by seven United States organizations. The second topic to be covered will be a brief discussion on the application of robotics to underwater work tasks.

SUBMERSIBLE ACTIVITY

During 1981 fifteen manned submersibles operated by U.S. organizations made 861 dives. These dives ranged in depth from 90 to 4000 meters and from the Mediterranean Sea to the Western Pacific Ocean in location. Many of the dives took place in waters adjacent to the United States. The purpose of the dives ranged from crew and system training to scientific research, object recovery and commercial offshore oil drilling and production support.

The submersibles that made these dives were:

* ALVIN - Operated by Woods Hole Oceanographic Institution, Woods Hole, Massachusetts

Crew - 3, Depth - 4000M, Weight - 15.4T

Support Ship - Lulu, catamaran with center elevator

1981 Dives - 81

LOCATION	#	DEPTH	ACTIVITY
Off St. Croix	18	900 to 4000M	Test - Training
Off New Jersey Coast	13	500 to 4000M	Env. Baseline Study
Off Galapagos Island	10	to 3000M	Sulfide Dep. Study
Panama Basin	14	to 4000M	Benthic Biology
Off Costa Rica	5	to 3600M	Mang. Nodule Exploration
East Pacific Rise	13	to 2600M	Geo. Chem. Hot Vents
Off Mazatlan Mexico	8	300 to 3000M	Benthic Biology

* DIAPHUS (PC-14) - Operated by Texas A &M University, College Station, Texas

Crew - 2, Depth - 366M, Weight - 4.5T

Support Ship - As provided - Handling with stern U frame

1981 Dives - 30

LOCATION	DEPTH	ACTIVITY
Gulf of Mexico	125-366M	- Pipe line inspection - Cathodic Protection Measurement

* JOHNSON SEA LINK I and II - Operated by Harbor Branch Foundation, Fort Pierce, Flordia

Crew - 2 + 2 (Lockout), Depth - 610M (Ready for 915M cert) Weight - 11.5T

Support Ships - R.V. Johnson (Primary) - Stern Crane
R.V. Sea Diver (Alternate) - Stern Crane

1981 Dives I - 168 Dives to date 1158

1981 Dives II - 95 Dives to date 660

LOCATION	DEPTH	ACTIVITY
Off San Salvador Island	200 to 600M	Fish & Benthic Survey
Off Bahamas Island	610M	Recovery of Cosmic Ray Chamber Equipment
Off Florida East Coast	200 to 600M	Fish & Benthic Survey
Off East Coast U S.	200 to 600M	Environmental Baseline Studies at Canyon Heads
Off Florida West Coast Dry Tortugas	100 to 200M	Lost Fish Trap Condition Survey

* NEKTON GAMMA - Operated by Nekton, Inc. San Diego, California

Crew - 2, Depth - 305M, Weight - 2.3T

Support Ship - Self Propelled Barge SEA HAVEN with stern elevator

1981 Dives - 100

LOCATION	DEPTH	ACTIVITY
Santa Barbara Channel and Off Pt. Concepion California	60 to 245M	- Environmental Assessments - Bottom Condition Baseline Studies - Color TV & Photo Camera Evaluation for Transit Survey

* USN DSRV (Mystic),(Avalon) - Operated by USN Submarine Development Group I, San Diego, California

Crew - 2 + 24, Depth - 1524M, Weight - 24.6T

Support Ship - Trans Quest (training)
ASR & SSN for rescue mission

1981 Dives Mystic - 20

1981 Dives Avalon - 26

LOCATION	ACTIVITY
Off San Diego, California	Crew and Operational Training for Rescue Readiness
Fly Away to Pearl Harbor	Training

* SEA CLIFF & TURTLE - Operated by USN Submarine Development Group I, San Diego, California

Crew - 3, Depth - Sea Cliff 2000M Turtle 3048M Weight - 23T

Support Ship - Energy Services I (Primary)
Trans Quest (Alternate)

1981 Dives Sea Cliff - 55

1981 Dives Turtle - 47

LOCATION	ACTIVITY
Off California	- Search and Recovery - Inspection Services for Navy Labs - Inspection of DSRV Deep Seat Training Fixture

* TRIESTE - Operated by USN Submarine Development Group I, San Diego, California

Crew - 3, Depth - 6100M, Disp. - 300T

Support Ship - Towed

1981 Dives - 3

LOCATION	DEPTH	ACTIVITY
Off California	1525M	Training at 4 Month Intervals

* PISCES VI - Operated by International Underwater Contractors, City Island, New York

Crew - 2, Depth - 2530M, Weight - 11.5T

Support Ship - Discoverer Seven Seas or Ship of Opportunity

1981 Dives - 100

LOCATION	DEPTH	ACTIVITY
North Atlantic off U.S. Coast	305 to 610M	Observation - Inspection and work for off shore oil exploration and drilling support.
South Atlantic off Africa	305 to 610M	Observation - Inspection and work for off shore oil exploration and drilling support.
Mediterranean off Italy	305 to 610M	Observation - Inspection and work for off shore oil exploration and drilling support.

* MERMAID II - Operated by International Underwater Contractors, City Island, New York

Crew - 2, Depth - 305M, Weight - 3.2T

Support Ship - R.V. Aloha with stern U frame

1981 Dives - 24

LOCATION	DEPTH	ACTIVITY
Gulf of Mexico	to 300M	Observation - Inspection and work for off shore oil exploration and production

* MANTIS 011 & 012 - Operated by International Underwater Contractors, City Island, New York

Crew - 1, Depth - 700M, Weight - 1.1T

Support - Ship or platform of opportunity

1981 Dives Mantis 011 - 28

1981 Dives Mantis 012 - 32

LOCATION	DEPTH	ACTIVITY
011 - North Atlantic off U.S. Coast - Gulf of Mexico - Pacific Off California	to 400M	Off shore oil support: - Inspection - Tool Recovery - Light Work
012 - Western Pacific South China Sea	to 400M	Off shore oil support: - Inspection - Tool Recovery - Light Work

* MAKALI'I (Star Two) - Operated by Hawaii Undersea Research Laboratory (Managed by University of Hawaii)

Crew - 2, Depth - 366M, Weight - 4.5T

Support Ship - Launch and Recovery Platform (LARP) towed by ship of opportunity

1981 Dives - 52

LOCATION	DEPTH	ACTIVITY
Eniwetok Atoll	91 to 366M	Biological and Geological research on residual nuclear effects

Recent construction activity by Perry Oceanographics - Riviera Beach, Florida

Submersible: PC1805 Crew - 2 + 2, Weight - 13T

Depth - 300M, Observation - 200M Lockout

Observation Manipulator Bell: Depth - 915M, Weight - 6T

2 Manipulators and 1 Holding Arm

Diving/Work Systems:		
	150M	SDC - DDC
	205M	SDC Only
	305M	SDC - DDC
	366M	SDC - DDC

ROBOTICS AND UNDERWATER WORK

INTRODUCTION

Before entering into a discussion of work and robotics it is appropriate to define what is meant by robotics. In the context of this paper robotics is the application of pre-programmed movement or activity used on a repeatable basis to accomplish a desired task.

It does not encompass the broader fields of "artificial intelligence" and "thinking machines".

DISCUSSION

From the definition of a pre-programmed movement or activity it means that we know before hand what we want to do and where we want to do it. Knowing what and where means that we can pre-program the machine or system to "How we want to do it". Thus for a given task or activity that has known repetitive segments, the system can be pre-programmed to do that portion of the task without operator control or in some cases without operator supervision.

Applications of robotics to underwater tasks can be most productive in that human bottom time is usually limited and permitting machines or automatic systems to do repetitive tasks can free human operators for tasks requiring his decision making capability.

Typical tasks that would be appropriate for robotic or pre-programmed activity would be:

1. Bottom mapping and area survey.
2. Bottom work involving assembly or disassembly tasks.
3. Manipulation tasks that require tool exchange or repeated work motion.

SPECIFIC EXAMPLES

1. Bottom Mapping. A manned or unmanned submersible can have pre-programmed navigation and control systems such that a desired compass heading is maintained for a certain distance or time. Then two 90° turns are made and the craft heads back in the opposite direction on a track parallel to the first but offset to one side so that new ground is documented on one side and over lapping coverage is obtained on the side toward the prior track. The mapping sensor could be side looking sonar, video camera, movie camera, or a sequenced still camera. The sophistication of the system would be dependent on the degree of precision desired in the resulting map or survey. The simplest system would monitor course and time and control the vehicles course. A more complex system could also monitor and/or control speed or distance, still more system complexity could be added with the monitoring of the actual course, speed and distance made good over the bottom. To this could be added initial and final geographic reference markers thus producing, a complete and well defined survey map.
2. Assembly/Disassembly Tasks. For large bolted pipe or structure flanges there are automatic wrenches that tighten or loosen bolt and nuts. Adding the robotic function of placing the wrench sequencially on each nut or bolt produces a system that can work its way around a large joint either tightening it up during assembly or loosening it up for disassembly.

The basic robotic function is that of tightening or loosening the bolts (or nuts). A more complex robot could make the initial installation of the bolts in the joint and start the nut on the bolt.

A fully programmed and motion capable robot would place pipe or valve sections in place and then make up the attachment joint.

3. Underwater work involving manipulator tool exchange tasks is well suited to robotic system control. For a particular inspection task, the manipulator could be cleaning off sea growth or corrosion products from a pipe. When a different tool or sensor is desired, a pre-programmed tool exchange program is executed. The manipulator system knows where it was working and it knows where the new tool is located in the tool rack.

   The control system thus retracts the arm - stows the old tool, picks up the new tool and re-extends the arm to the work site. This type of pre-programmed motion can be done faster and better than it could under human operator control.

   Manipulator work tasks that require area coverage or specific point location - one point from another - can also be done more efficiently using a pre-programmed robotic type of control.

CONCLUSION

A repetitive task that is done within known boundaries is well suited to robotic type pre-programmed control.

Many underwater tasks are being done within the stated constraints and thus are suitable for the application of robotic control concepts.

SEA CLIFF (20,000 FOOT) MODIFICATION PROJECT

John Freund
United States Navy

INTRODUCTION

The objectives of this project include modification of the DSV SEA CLIFF to allow for 20,000 foot operational capability and to demonstrate advanced technologies which have been developed in the Deep Ocean Technology (DOT) Program.

There is a Navy operational requirement to perform manned ocean bottom search and small object recovery at depths greater than 6,500 feet. The present capability is limited to the submersible ALVIN (12,000 ft) and the bathyscaph TRIESTE (20,000 ft). The DSV SEA CLIFF Modification Program is to provide an advanced operational capability and to be a focal project for the demonstration of present development efforts which include technology options and reliability requirements of many vehicle subsystems, components and materials. The development objective is to validate these technical options in an operational capability such that future Navy missions in the deep ocean can be safely and reliably performed. This program will provide new subsystems and components and the modification of existing components which are necessary to modify the existing manned submersible, SEA CLIFF, DSV-4, to extend the operating depth from 6,500 to 20,000 feet and retain the present work effectiveness and performance characteristics.

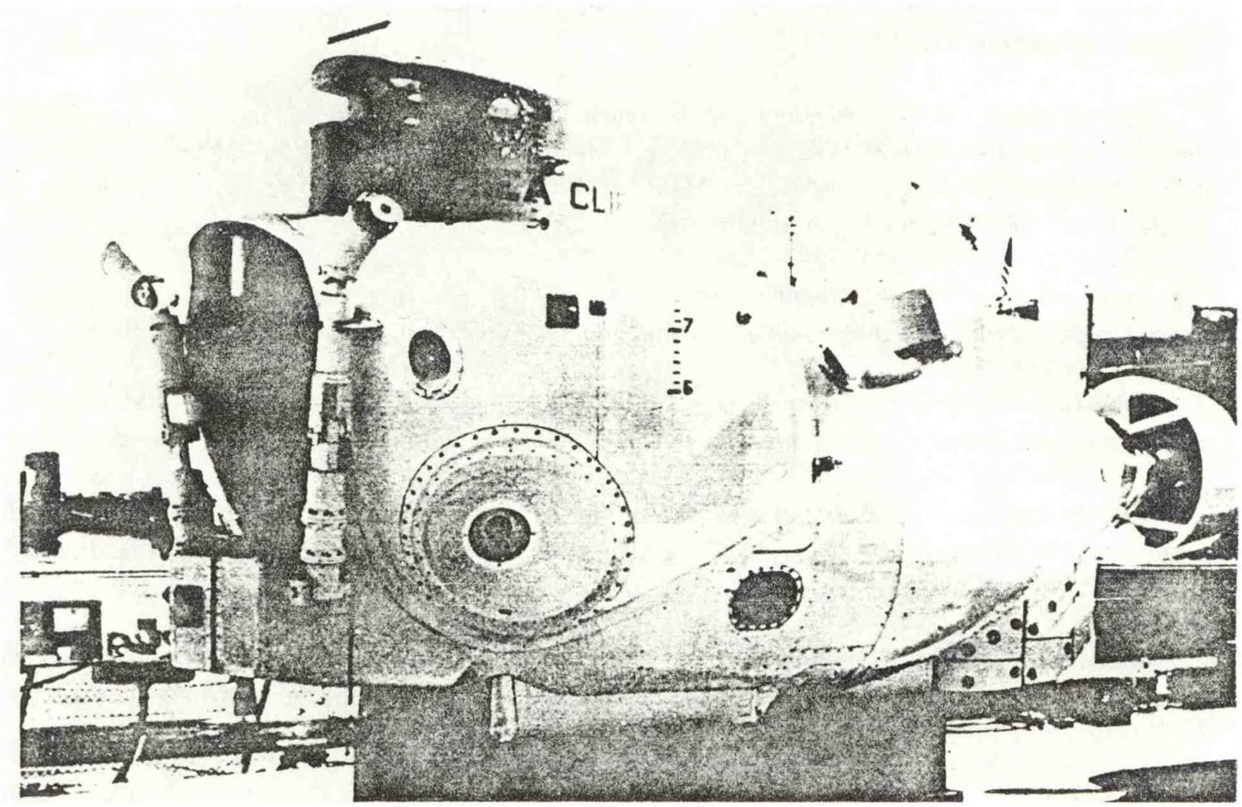
The successful modification of DSV ALVIN from 6,000 to 12,000-foot operating depth in 1974 has provided confidence in this approach and is an important milestone for the DOT program in developing a 20,000-foot test-bed vehicle.

The DSV TRIESTE II is the only deep submergence vehicle having 20,000-foot depth operational capability and it is scheduled to be inactivated. SEA CLIFF 20 is identified as the replacement for TRIESTE.

The present vehicle has demonstrated a wide variety of capabilities of proven value to the Navy. Therefore the requirements for the modified vehicle included retaining or improving these operational characteristics at 6,500 feet. The design maintained most characteristics such as payload life support, speed, etc. The changed characteristics are:

Depth	6,500 feet	to	20,000 feet (6096m)
Weight	48,000	to	55,000 pounds
Length	27	to	31 feet
Turning Diameter	10	to	12 yards
Bottom Time	3.5	to	3.25 hours

This SEA CLIFF R&D project will significantly improve Navy deep ocean operational capability and be a milestone in demonstration of safe and reliable manned vehicle technology. When the SEA CLIFF 20,000 is operational it will relieve the old, expensive and less maneuverable TRIESTE.



The 6,500-foot design of DSV SEA CLIFF which is shown here has provided a mix of capabilities of proven value to the Navy. The requirements for the 20,000-foot design are planned to make maximum use of these proven capabilities. This vehicle design (including DSV TURTLE) has made in excess of 500 dives during the past five years.

DESCRIPTION

The Navy has supported deep submergence R&D in the areas of materials and fabrication, electrical components, and propulsion and auxiliary machinery. This project utilizes the designs representing the best combination of technical feasibility, risk and cost resulting from these R&D efforts. The components and subsystems which have undergone preliminary development and are to be demonstrated in DSV SEA CLIFF to 20,000 foot depths include:

Titanium Pressure Hulls — The low weight-to-displacement ratio of titanium hulls is an important factor in the very weight sensitive 20,000 foot design. Construction of a personnel hull and ballast tankage will demonstrate the technology to produce and fabricate titanium in four inch thicknesses having a yield strength greater than 100,000 pounds per square inch.

Buoyancy Material — A light weight thrust (34 pounds per cubic foot), low cost ($50 per pound) systactic foam has been developed and qualified for manned submersible operations to 20,000 foot.

Electric Drive Systems — Electric motor and controller developments have provided the technology to specify and modify individual components for the propulsion, hydraulic and ballast subsystems.

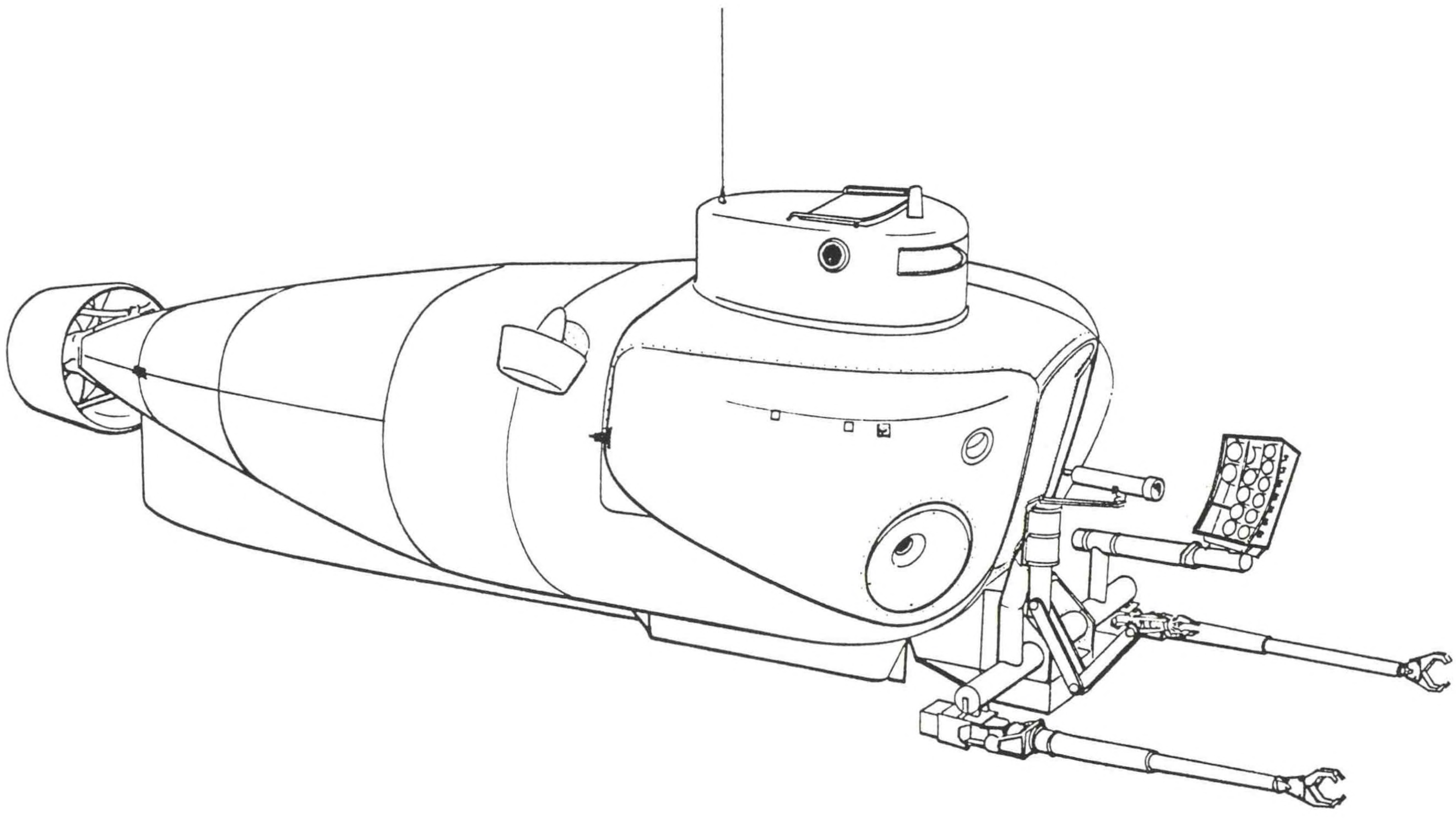
Seawater Variable Ballast Systems — A very high pressure seawater pump and hydraulic system will demonstrate advanced materials and component designs. A similar system has been operational on ALVIN to 12,000 foot depths since 1974.

Electrical Hull Penetrators — Development and qualification of through-hull electrical power and signal transfer devices have insured the safety of personnel and reliability for manned submersible operations to 20,000 feet.

Electrical Distribution Components — Development of pressure compensated electrical protection and switching devices and cable harnesses have significantly improved reliability and maintenance requirements. Definition of design requirements and component parameters for successful operation have been demonstrated and are incorporated into qualified prototype designs.

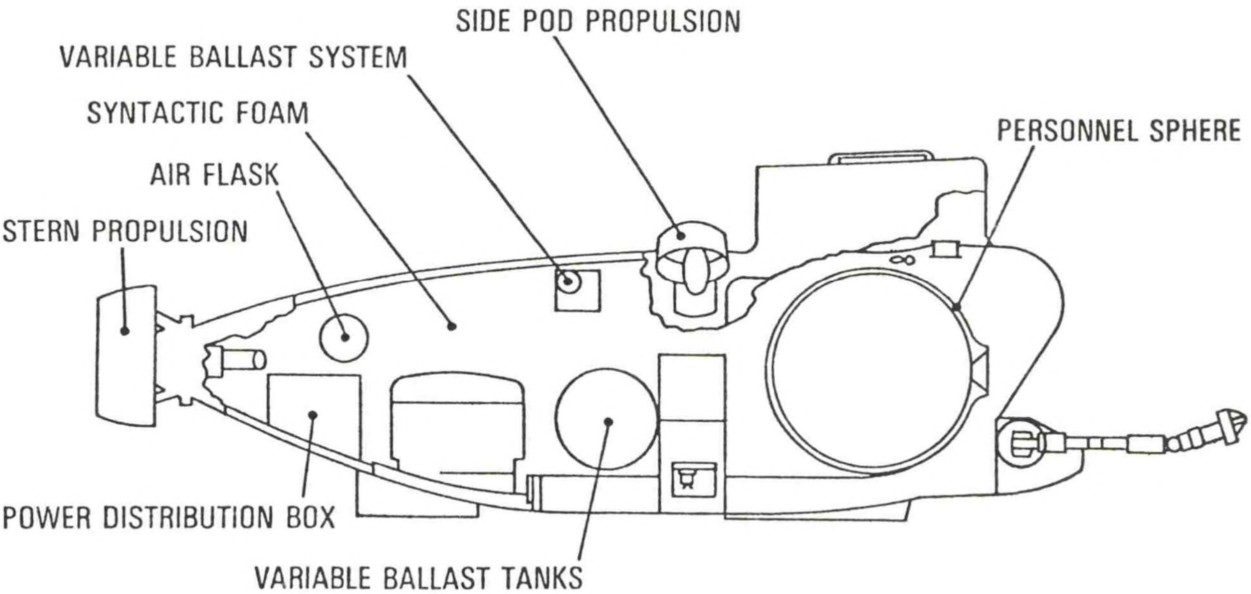
STATUS

The SEA CLIFF modification is planned for completion in 1984. The various subsystems identified above are products of the SEA CLIFF research and development program. These systems will be installed when the submersible is overhauled in 1984. A subsequent test program will include the audit and demonstration of design and construction as necessary to insure the safety necessary for manned submersible operations to depths of 20,000 feet.



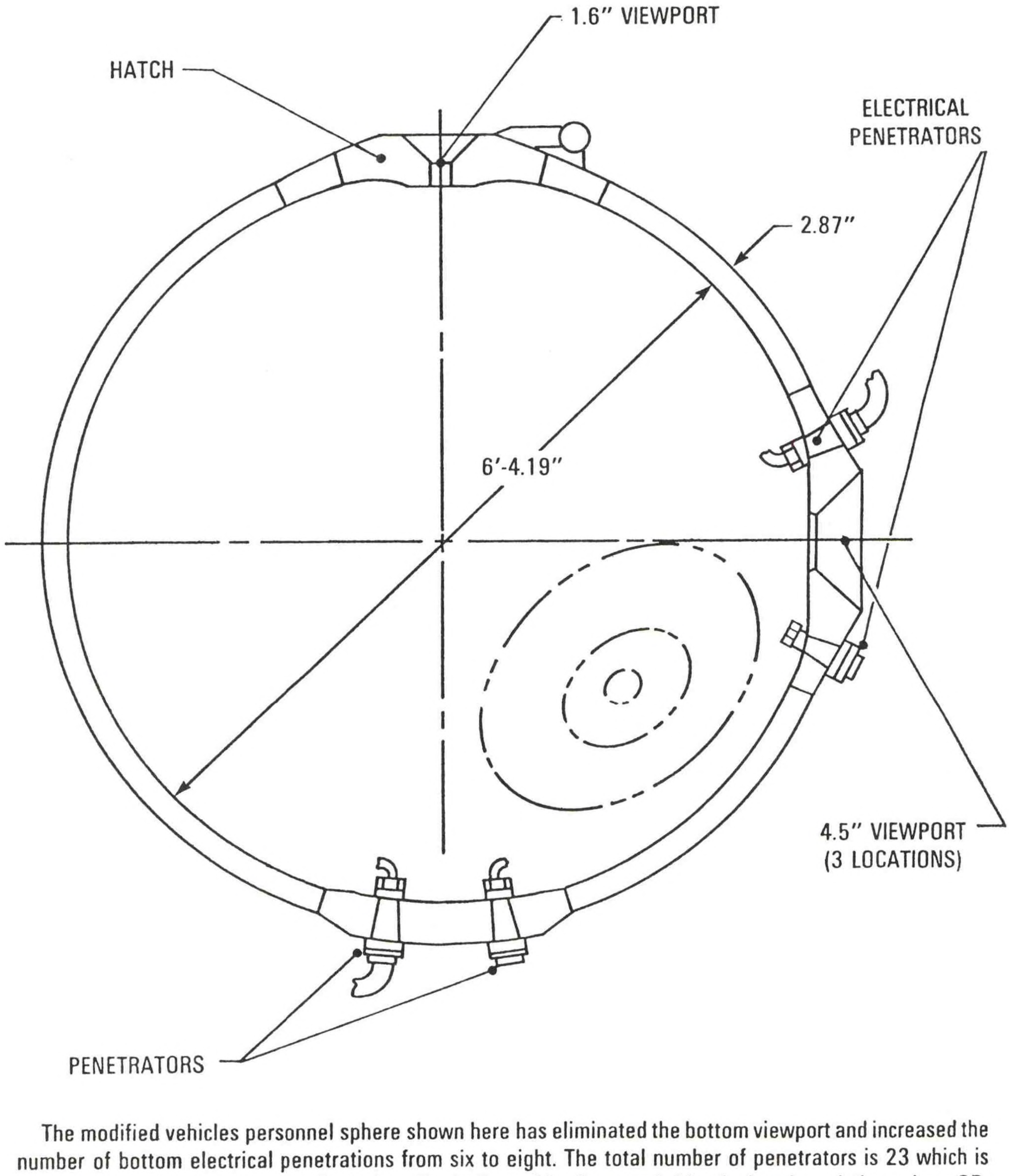
Modified DSV SEA CLIFF 20,000 equipped with an advanced work system

SEA CLIFF MODIFICATION



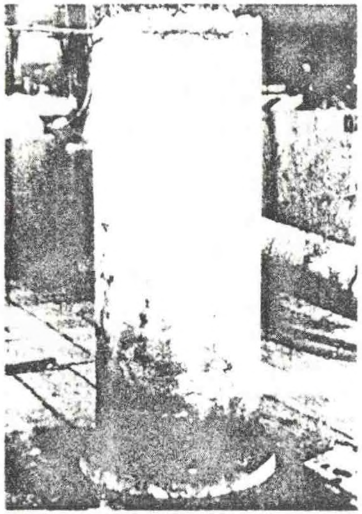
GENERAL ARRANGEMENT

SEA CLIFF MODIFICATION

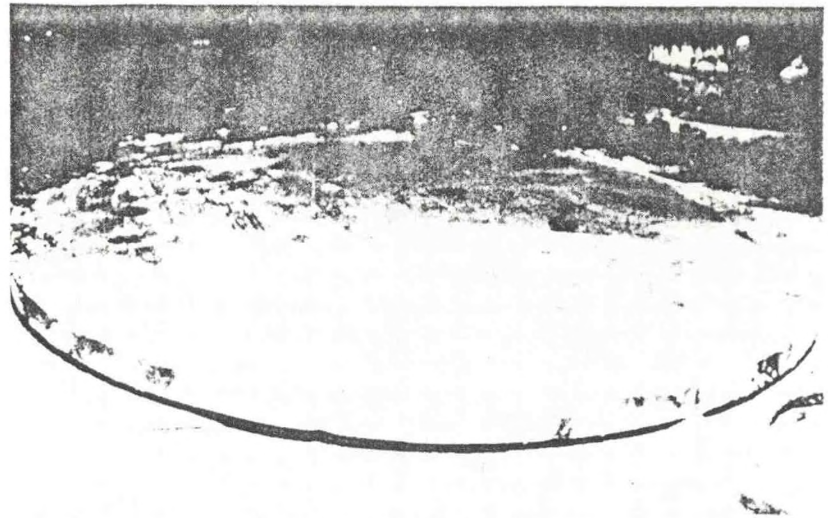


The modified vehicles personnel sphere shown here has eliminated the bottom viewport and increased the number of bottom electrical penetrations from six to eight. The total number of penetrators is 23 which is unchanged from the present configuration. The hull outside diameter is identical to the existing sphere OD.

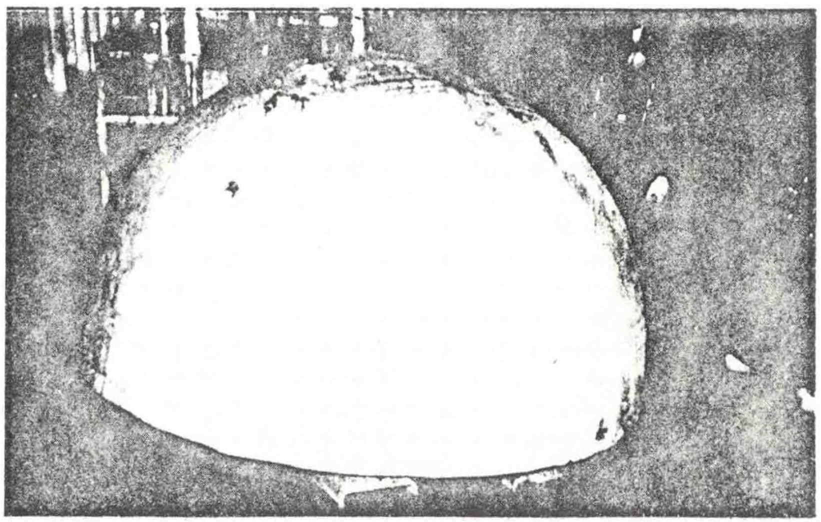
SEA CLIFF Ti-100 PRESSURE HULL



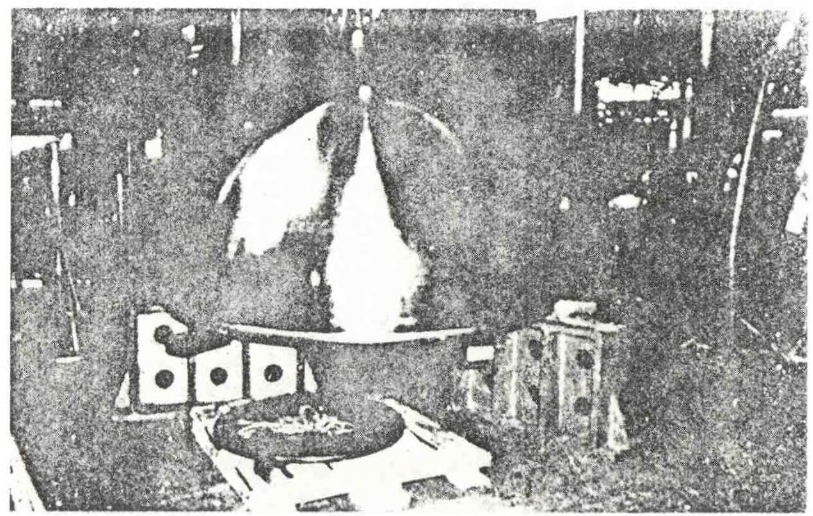
INGOT



CIRCULAR PLATE



FORMED HEMISPHERE

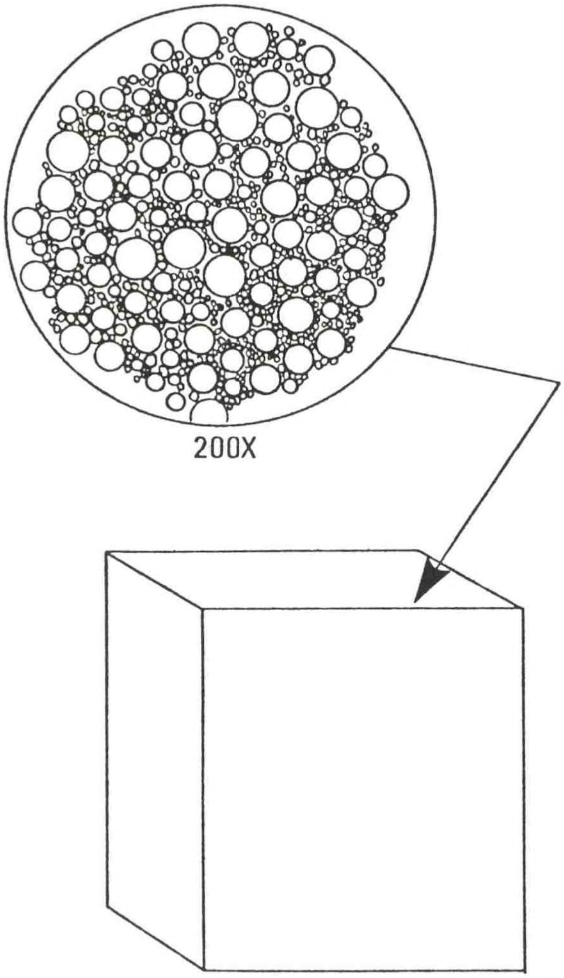


MACHINED HEMISPHERE

TITANIUM PRESSURE VESSELS

The various stages in the manufacture of the hull hemispheres for the personnel sphere are shown here.

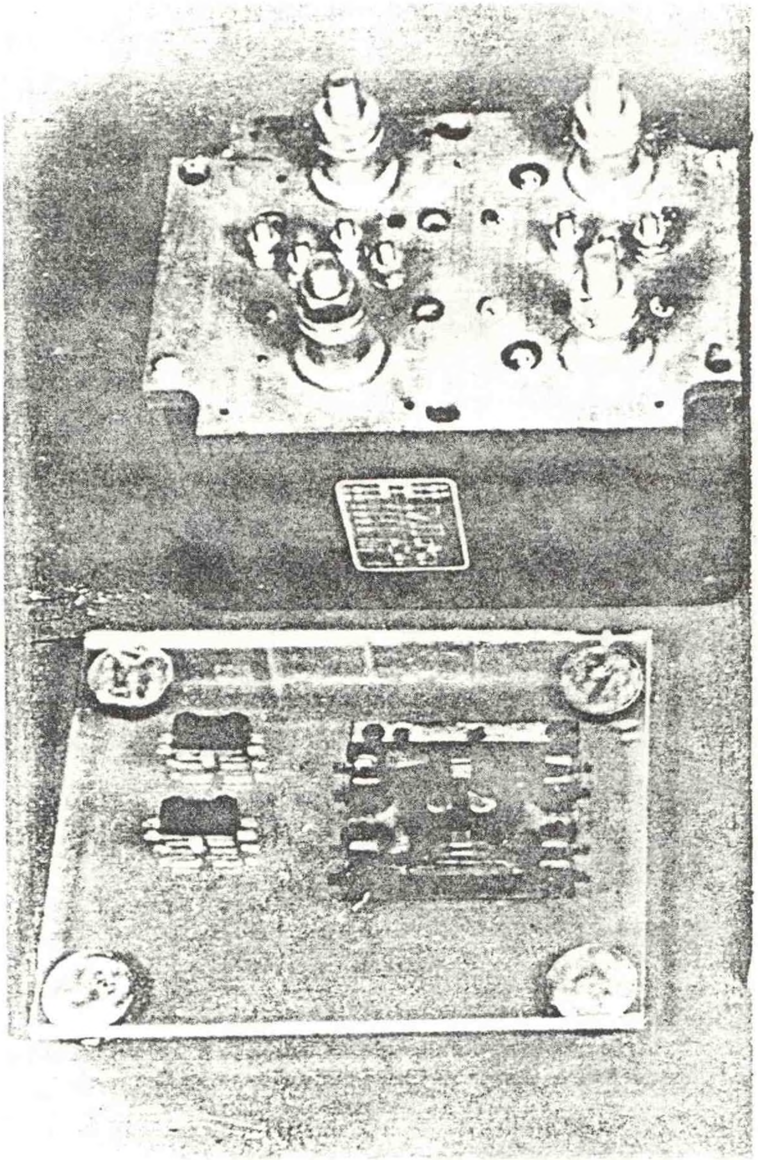
REQUIREMENTS IN PRODUCING LOW DENSITY HIGH STRENGTH SYNTACTIC FOAM



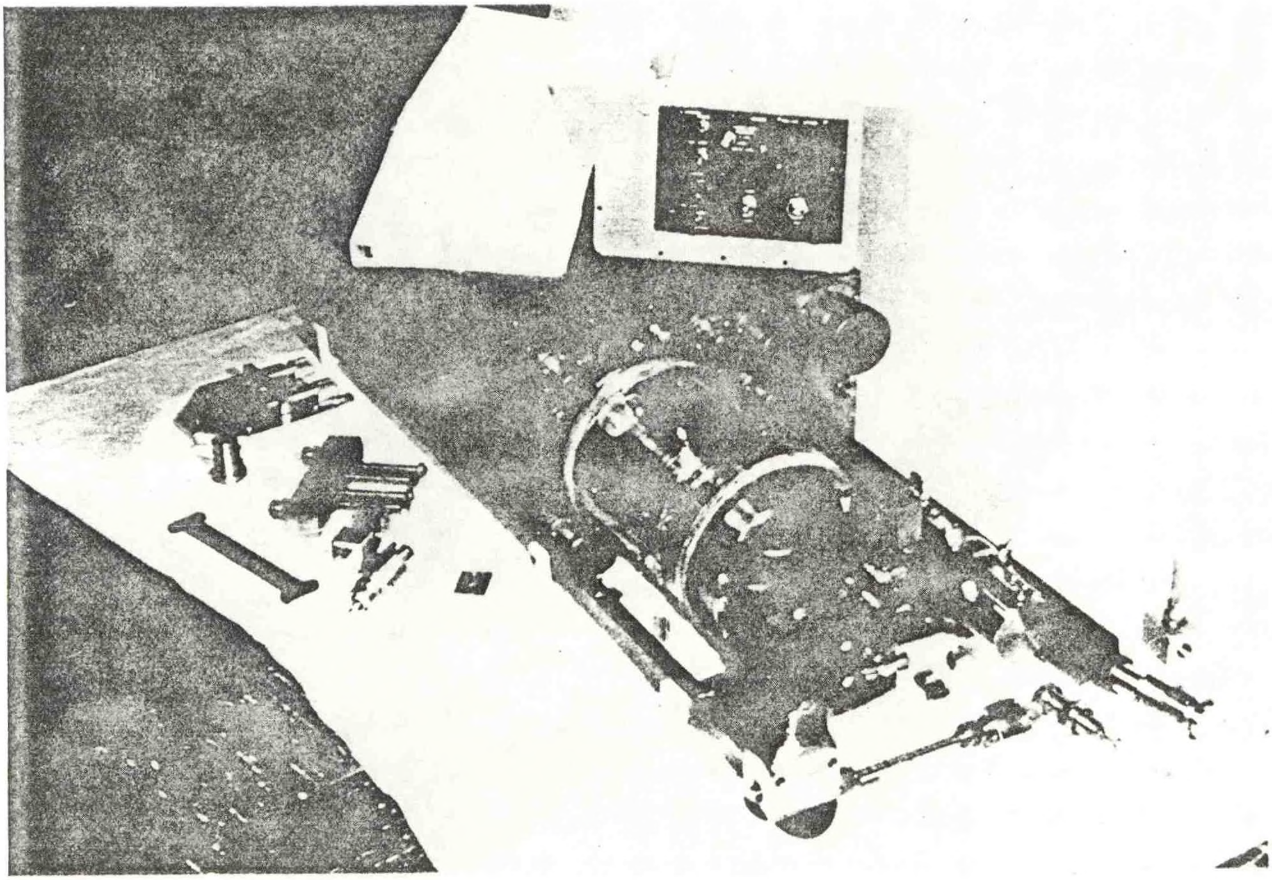
Block of Syntactic Foam

Basic Components

- Properly formulated binary mixture of high strength, low density, water resistant glass microspheres
- Low viscosity, high water resistant, high strength resins
- Compatible resin hardener processing
- Use of high vacuum methods
- Methods suitable for obtaining optimum backing of microsphere components

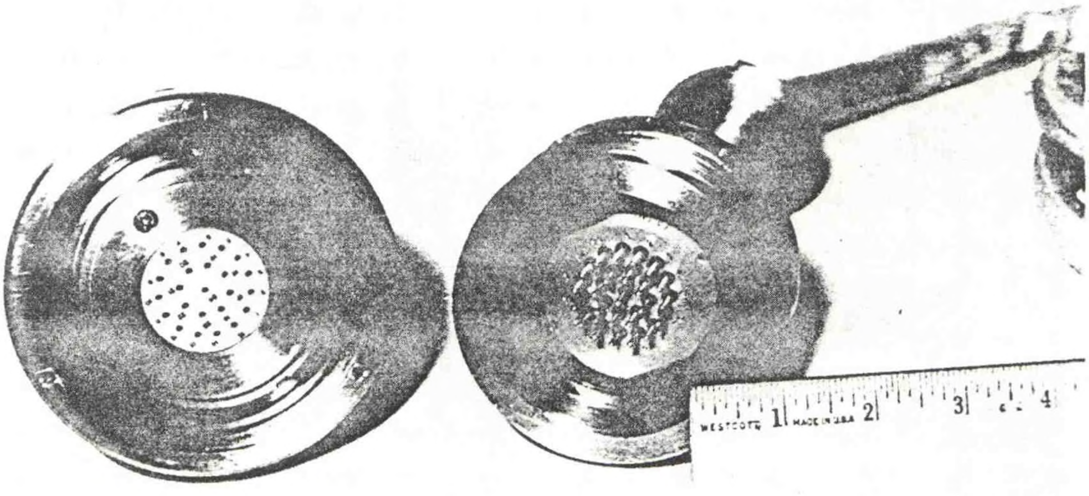


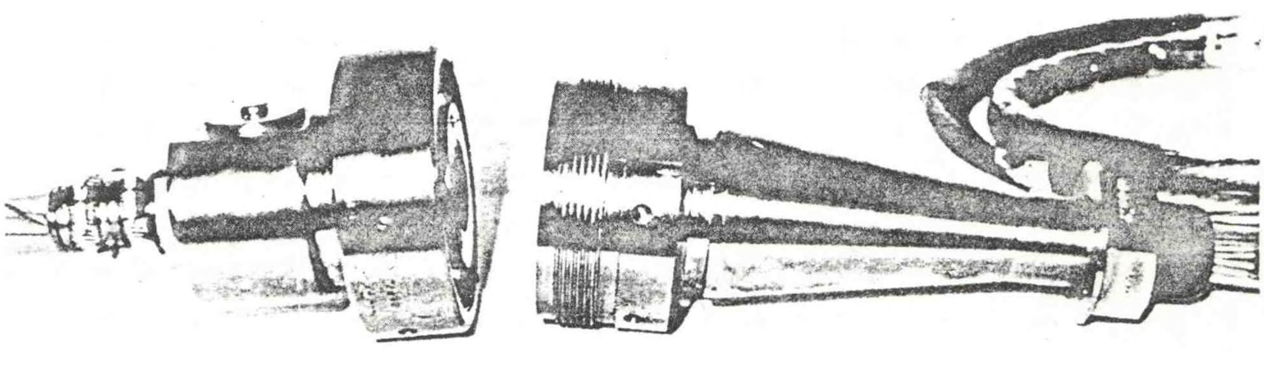
Power distribution system electrical contractor showing modification of internal microswitch contacts. This modification eliminated the formation of a carbon clinker between the contacts when operating at 20,000 foot pressures in a pressure compensated dielectric environment.



Photograph shows Pump/motor package. Oil filled, pressure compensated rectangular titanium box contains the 60 VDC pump drive motor, its controller and hydraulic pilot solenoid valves. The box also acts as a junction box for the various electrical system components. Attached external to the box are the seawater pump and seawater valves along with the hydraulic pilot control system valves and piping. The picture also shows the control panel and various special tools and samples of documentation.

SEA CLIFF Titanium Electrical Hull Penetrator. Note the fluid-filled cable section. This design of cable harnesses considerably improves reliability and maintainability and reduces manufacturing cost.





SALVAGE CAPABILITIES IN THE U.S.

by

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This paper describes a study of the U.S. National Research Council, which was being conducted at the time the paper was written. The author was the Chairman of the study. The views expressed are those of the author and are not necessarily endorsed by the committee or the National Research Council.

INTRODUCTION AND OBJECTIVES

In early 1981, the Assembly of Engineering of the National Research Council convened a committee to assess the present national posture for coping with ship rescue salvage and towing situations and time-critical offshore ship salvage in general. Members of the committee were selected for their competence and experience in salvage and towing operations, ship command and ship management, naval architecture, salvage engineering, admiralty law, risk analysis, marine insurance, and naval and marine systems development. Members also provided experience in public law and environmental matters. The membership was selected on the basis of individual expertise with the accompanying bias being carefully balanced.

The objectives of the study were to analyze historical information on marine casualties, project the occurrence of casualties within 200 miles of the U.S. coast and islands through the year 2000, and to determine if the U.S. has the equipment, personnel, and organization to effectively salve the vessels. Although all merchant shipping is of concern, emphasis was placed on casualties which are likely to involve large-scale release of pollutants or high value ships and cargoes. The capability of ships to be salvaged, such factors as design and outfit, and the preparation, training, and experience of the officers and crew were also considered.

THE STUDY

The study was conducted by holding four meetings of the full committee, employing three regional evaluation groups who visited many sites and met with a great many involved persons, and through the extensive use of the professional staff of the Marine Board. At the outset, the staff compiled information on marine casualties over the past decade from several sources, analyzed these data and projected the likelihood of casualties, and hence the need for salvage, through the year 2000. An enumeration of salvage assets, including equipment and people, was followed by on-site inspection and evaluation of some of these assets.

A parallel effort was conducted by committee members to determine who is actually "in charge" of salvage activities, considering past salvage efforts and statutory and case law. Another group of senior committee members studied alternate salvage postures ranging from full "Government Salvage" to "hands off" or "do nothing," thereby making available for consideration a wide range of alternate postures and their nuances.

The staff studies, regional evaluation team reports, and the records of the committee deliberations provide an impressive amount of timely data. The analysis of these data and their evaluation was a challenging task leading to a comprehensive report which will be available to the public in mid-1982.

FINDINGS

There are approximately 60 to 70 time-critical marine salvage or rescue towing operations in U.S. offshore waters annually with little change expected in the next two decades. This low level of salvage activity precludes a profitable salvage industry involving fully manned and equipped salvage ships held "on station." On the other hand, the consequences of unsalved marine casualties include damage to or loss of crews, cargoes, and ships, and the public consequences of catastrophic marine pollution with attendant liabilities. It must be recognized that even superb salvage efforts will not always succeed thereby raising public doubts on the worth of a subsidized salvage industry. The small number of forecast casualties, the high cost of salvage capability, and the availability of improved communications, air-lifted specialized equipment and personnel, and the large number of special-purpose craft (tugs, supply boats, barges, etc.) suggest that the traditional salvage industry is finished in U.S. waters.

If salvage in U.S. waters is to be performed by salvors of opportunity, there are areas where planned improvement can increase the chances for successful salvage. Ships are seldom designed to permit their expeditious salvage lacking towing attachments, redundant emergency power, methods and equipment for getting equipment and personnel on-board during a casualty, and an almost universal lack of preparation of salvage plans/manuals and ship personnel training. Education and training of salvage personnel can also be improved with concomitant reduction of risk. Lighter and more efficient salvage and fire fighting equipment will enhance rapid helicopter deployment, again reducing risk. Tugs and supply boats can be designed and built to increase their effectiveness when used in salvage situations.

The business climate in which salvors function is another area where improvements are possible. The high financial liability for oil-spill damage frequently serves as a disincentive for undertaking salvage. This is especially true if the salvage is undertaken under the no cure-no pay formula of Lloyd's Open Form Contract. Due to the time-critical nature of true salvage, there is seldom an opportunity to accurately determine values and risks and negotiate a "fair" contract. Most salvage awards are determined after the fact by arbitration and are deemed to be far too low to provide keen incentives or even support the industry. All too often the time value of money is ignored in the arbitration process. An additional concern of the salvor is finding a "safe haven," a port to which he can tow the salved vessel without spending his future award in the towing process. A combination of these factors has decimated the U.S. salvage industry and frequently dissuades the salvor of opportunity from even attempting salvage.

The last area of significant findings concerns the government's role in salvage. The U.S. Navy is, by law, the nation's salvor. Their role is, however, permissive and the Navy has always shown restraint in commercial salvage matters. THe Navy is responsible for the salvage needs of U.S. public vessels and maintains salvage equipment and ships which can be used in civilian salvage, if available, upon request. The Navy is also the main source of salvage-master training and supplies the U.S. civilian salvage industry through normal service attrition. Naturally, the salvage function of the Navy competes with all other Navy functions for limited funding resulting in periodic shortfalls of personnel and equipment. The U.S. Coast Guard, on the other hand, is responsible for saving life and property in our coastal waters. Under U.S. law a Coast Guard officer is frequently the man in-charge at a marine casualty. If there is oil pollution, he is always in charge. In their role of saving lives and property, the Coast Guard is frequently the first party to reach the scene of an accident and immediately joins in fire fighting and other activities which comprise salvage. Towing disabled vessels (yachts, boats, etc.) to port is a normal part of the rescue function providing a potential area of disagreement with commercial salvors since the U.S. Coast does not charge for its services.

The laws of the United States are frequently single-purpose laws which inadvertently overlap or contradict earlier laws. The emphasis on environmental protection during the past decade has resulted in several public laws which strongly influence the salvage industry. It is a truism that our laws can be improved, a fact not ignored in the committee's deliberations.

CONCLUSIONS AND RECOMMENDATIONS

The findings of the study resulted in an impressive list of conclusions and recommendations to provide the U.S. Government and salvage industry with specific guidance, always a goal of a Marine Board study. This report is now under review by the National Research Council. The following conclusions and recommendations do not represent the work of the Committee but are the author's judgements only.

1. The U.S. Navy, as the nation's salvor, should lead a cooperative effort supported by the U.S. Coast Guard, the U.S. Maritime Administration, and the salvage industry to:

   - Maintain a running inventory of the nation's salvage assets, human and material.

   - Train and educate the next generation of salvage masters, divers, and workers.

   - Develop, test, and stock-pile improved salvage systems, equipment, and components taking full advantage of new deployment means and the services of "salvors of opportunity."

2. The U.S. shipping and salvage industry should cooperate to:

   - Design and specify ship features and equipment to make vessels more salvageable.

   - Prepare contingency plans and casualty manuals which, when used by trained personnel, reduce risks and improve the chances of successful salvage.

   - Negotiate provisional contracts to assure fair treatment of both parties and assure the timely application of available salvage assets.

   - Reach agreement with the insurance industry on a rational basis for adequate salvage awards.

3. The United States Government should:

- Hold vessel masters and salvors harmless from liability in pollution incidents if the pollution is the result of prudent professional action to save the vessel.

- Direct the U.S. Navy and Coast Guard to charge for services rendered in providing salvage assistance at a rate sufficiently above commercial rates to encourage use of commercial salvors, when available.

- Require, through the regulatory process, congested marine facilities (offshore ports, harbors, etc.) to provide adequate fire fighting and salvage equipment and personnel to protect the facility, its users, and the public interest.

- Provide a criteria, and in the absence of prompt appropriate responses, designate "safe havens" where damaged ships can be towed for emergency repairs.

- Direct the U.S. Navy to maintain adequate salvage vessels, equipment and personnel to capably handle salvage incidents where the salvage industry cannot/does not respond and the public consequences may be severe.

- Enforce U.S. Navy and Coast Guard cooperation to take advantage of the early presence of the Coast Guard at marine casualty sites and the Navy salvage material and personnel assets.

- Establish an advisory board to the Navy on salvage matters with government, shipping, salvage, insurance, legal, and public members to communicate, educate, and promote a strong national salvage posture.

The full range of approaches to salvage include full government salvage, government subsidized commercial salvage, government supported commercial salvage (with varying degrees of support, but not direct subsidy), government encouraged commercial salvage, "pure" commercial salvage ("hands-off" by the government), government inhibited (or over-controlled) commercial salvage or, no salvage industry at all in the United States. It is my personal conviction that a strong national salvage industry in the United States, encouraged by our government through accomplishment of the foregoing recommendations but not subsidized, operating in a cooperative and supportive atmosphere, can best meet the commercial and public needs of our nation.

Deep Water Mooring and Anchoring of OTEC

by

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Conceptual designs for Ocean Thermal Energy Conversion (OTEC) power plants include unmoored floating plants, moored floating plants, shelf-mounted plants, and land-based plants. Within each of these classifications there are several variations. For example, the platform of a moored plant may be a barge, spar, or semi-submersible. Also, the cold water pipe may be detachable so that the platform can be moved from a region of extreme environmental conditions such as a hurricane. This paper concerns anchoring and mooring considerations for moored floating OTEC plants in general at two possible sites recognizing that the actual forces to be restrained depends upon many factors including design features as well as environmental factors.

Floating plants will have a long suspended cold-water pipe to bring water from a depth of about a kilometer or more to the platform. Movement of the pipe may be limited by connecting it to a foundation on the sea floor, by tension-leg design features, by anchors and catenary mooring lines, or the cold-water pipe may be allowed to move freely and the platform restrained by anchors and mooring lines. It is anticipated that the first large-scale floating moored OTEC plants will employ multiple catenary legs in the mooring and anchoring system. Mooring lines may consist of combinations of wire ropes, chains, synthetic fiber ropes, and hollow chain links.

Catenary Mooring Systems

If a cold-water pipe is to be 1000 meters long, the anchoring depth will probably be as much as 1500 to 2000 meters. The deepest high-capacity mooring system installed for offshore crude oil production is Shell Oil Company's Cognac platform in the Gulf of Mexico. This system consists of 12 legs anchored with 30-inch diameter piles in about 400 meters of water.

The largest temporary mooring system is used to moor the "Ocean Ranger" class of semi-submersible drilling rigs designed by ODECO. These mooring systems also employ 12 anchor legs scoping 8,000 feet and using 45,000 pound anchors. The depth limitation is considered to be 500 meters. Thus the anchoring of a floating OTEC plant at 1500 to 2000 meters represents a significant advance in present technology. Furthermore, the anticipated life for such a facility of 30 years is well beyond experience to date.

Anchors

The types of anchors anticipated for consideration in the OTEC application are: drag embedment, deadweight or gravity, and pile. The characteristics of each are described by Foss, Kvalstad, and Ridley (1) and were summarized at our last meeting in Rockville, Maryland (2). For purposes of this presentation suffice it to say that drag-embedment anchors are of limited use where sediments depths are shollow and sediment slopes exceed about 10^{o}. Deadweight anchors can be built of any needed size, but are not commonly used on sloping terrain. Piles can be made very large, but require considerable ship time for installation.

Catenary Lines

Catenaries used with deep moors will doubtless be made up of combinations of materials. Chains will be used on the sea floor with a transition to wire or synthetic rope above the sea floor. At this time there is little information to guide predictions of service life. Initial plans should call for limited service life with provisions for replacements as needed.

Deployment

Although the offshore industry has substantial experience in deploying catenary systems, the difficulty and expense of doing so at OTEC depths will be considerably greater. A single mooring leg could weigh in excess of a thousand tons.

Valent (3) points out that a new linear winch system will be required to initially install and then refurnish and replace mooring lines regardless of which type of anchor is used.

The installation of a drag embedment anchor will be difficult because of anchor orientation requirements at touchdown and the necessity of setting it properly. Pile anchors will require the precise placement of a template and installation of piles at great depths.

Effect of Slope Angle

The holding power of an anchor is highly dependent upon the slope of the sediment as well as the properties of the sediment itself. Nacci (3) reports that field data agrees with theory at zero slope. Theory predicts a 40% decrease in holding capacity in sands at 10^{o} slope and 60% decrease at 20^{o} slope, but there is no field data for verification. The situation is more complex for clays, but a reduction of holding capacity of 70% is predicted for a slope at shallow depths. Because the overall safety of the OTEC facility depends upon the holding power of anchors, there is a need for thorough investigation of the nature of sediments to be anticipated at sites and the holding power of anchors in that type of sediment.

Tension-Leg System

The tension-leg system is an attractive alternative to catenary designs, but no system of this kind has been built or even modeled for depths required to anchor a floating OTEC platform. Mercier, Goldsmith, and Curtis (4) liken the dynamic behavior of a TLP to that of a multifilar pendulum with the excess buoyancy playing the normal role of gravity. Because the amount of excess buoyancy of the platform can be designed to adjust automatically with deviation from vertical, the swing of the pendulum can be dampened. In this design, vertical motions of the platform are restrained, but it is subject to surge, sway, and yaw. The tension legs serve as parallel-motion linkages.

The tension leg design has the following advantages for the floating OTEC platform:

1. The tension legs, cold and hot water pipes, and the power delivery system may be designed as a unit.

2. The complete system can be fabricated on shore and installed in a logical sequence.

3. Key components may be replaced as frequently as needed.

Site Selection

It is assumed that one of the first OTEC facilities to be built will be a moored floating platform located in the tropics close to mainland with an electrical power cable to shore. Two locations for such a site are Hawaii and Puerto Rico. Based on available bathymetric and sediment data at these sites, Dr. Vito Nacci at the University of Rhode Island and Dr. Philip Valent at Brian Watts Associates were asked to recommend the type of anchors suitable for deployment at these two locations.

Oahu, Hawaii Site

For illustration purposes Nacci and Valent (3) chose an arbitrary location between Barber's Point and Maili Point off Oahu, Hawaii as shown in Figure 1. Figure 2 shows a profile of the island slope through the site. The average slope derived from contours is 14^o, but slopes at specific locations may be 30^o or more with some near-vertical scarps anticipated. Examination by 3.5 khz acoustic profilers indicates that little sediment exists except at shallow elevations and below 8,000 ft. After an examination of all available data, Valent assumed that for engineering purposes the sediment consists of lime mud with sand over pillow basalt. Exposed rock was assumed to occur randomly over 30% of the area. Valent concluded that both gravity and pile-type anchors are technically feasible for mooring the OTEC plant at this site. See Table I. Installation of either type is believed to be within present state-of-the-art, but installation of mooring lines weighing 1,000 kps each, will require specialized linear cable/chain winches. The final decision between the two anchor types will depend largely on: (1) the availability of near flat areas for gravity anchor installation and (2) on a comparision of material, equipment, and labor costs projected at the time of construction/installation bidding.

Punta Tuna, Puerto Rico

For illustration purposes, Valent chose a plant site along the northern edge of whiting Basin, as shown in Figure 3. Figure 4 shows probable anchor locations ranging from 3,000 to 6,000 foot water depth with slope averages of 6^{0} to 18^{0}. A consideration of available topographic and sediment data indicated sediment thicknesses of 300 to 1000 feet at the anchor points. Valent concluded that all of the main anchor types that can be made to function will under these conditions as shown in Table II. The anchor type to be selected will depend on the equipment systems available for installation and their costs.

Conclusions

It is concluded that it is possible to anchor a floating OTEC plant of 40 Mw(e) size by extension of present techniques at the selected study sites in Hawaii and Puerto Rico although the cost of doing so is highly dependant upon the geotechnical properties of the materials on the seafloor.

The tension-leg system of mooring an OTEC plant has many attractive features and warrants continued consideration.

References

(1) Foss, I., Kvalstad, T. and Ridley, T., "Sea Bed Anchorages for Floating Offshore Structures," FIP Commission of Sea Structures Working Group on Foundations, February 1980.

(2) Smutz, M., "OTEC Anchoring," Proceedings of 10th Meeting of U. S.-Japan Marine Facilities Panel, UJNR, Rockville, Maryland October 1980

(3) Nacci, V. A. and Valent, P. J., "Anchors for OTEC Pilot Plant," Interim Report to NOAA/OTES, August 1981.

(4) Mercier, J. A., Goldsmith, R. G. and Curtis, L. B., "The Hutton TLP: A Preliminary Design," J. of Petroleum Technology, p. 208-16, January 1982.

TABLE I ANCHOR TYPES SUITABLE FOR USE AT OAHU SITE

ANCHOR TYPES	SUITABLE?	ASSUMPTIONS	REQUIREMENTS
Gravity	Yes	(1) near-level anchor sites available	(1) drilling vessel for lowering anchor, or dedicated lowering system (2) system for placing of ballast
Drag	No	(1) sediment depth less than required	
Pile-loaded at mudline	Yes		(1) drilling vessel for installation or dedicated remote system (2) group of six pile per anchor
Pile-loaded at midlength	No	(1) near-surface rock will kink or abrade pendant	

TABLE II ANCHOR TYPES SUITABLE FOR USE AT PUERTO RICO SITE

ANCHOR TYPES	SUITABLE?	ASSUMPTIONS	REQUIREMENTS
Gravity	Yes	(1) near-level anchor sites available	(1) drilling vessel for lowering anchor, or dedicated lowering system (2) system for placing of ballast
Drag	Yes	(1) adequate sediment thickness at all anchor sites	(1) development of deep-water setting procedures, or development of reliably tripping anchor
Pile-loaded at mudline	Yes		(1) drilling vessel for installation, or dedicated remote system (2) group of two or three piles per anchor
Pile-loaded at midlength	Yes	(1) no rock in contact with pendant	(1) drilling vessel for installation, or dedicated remote system (2) single pile

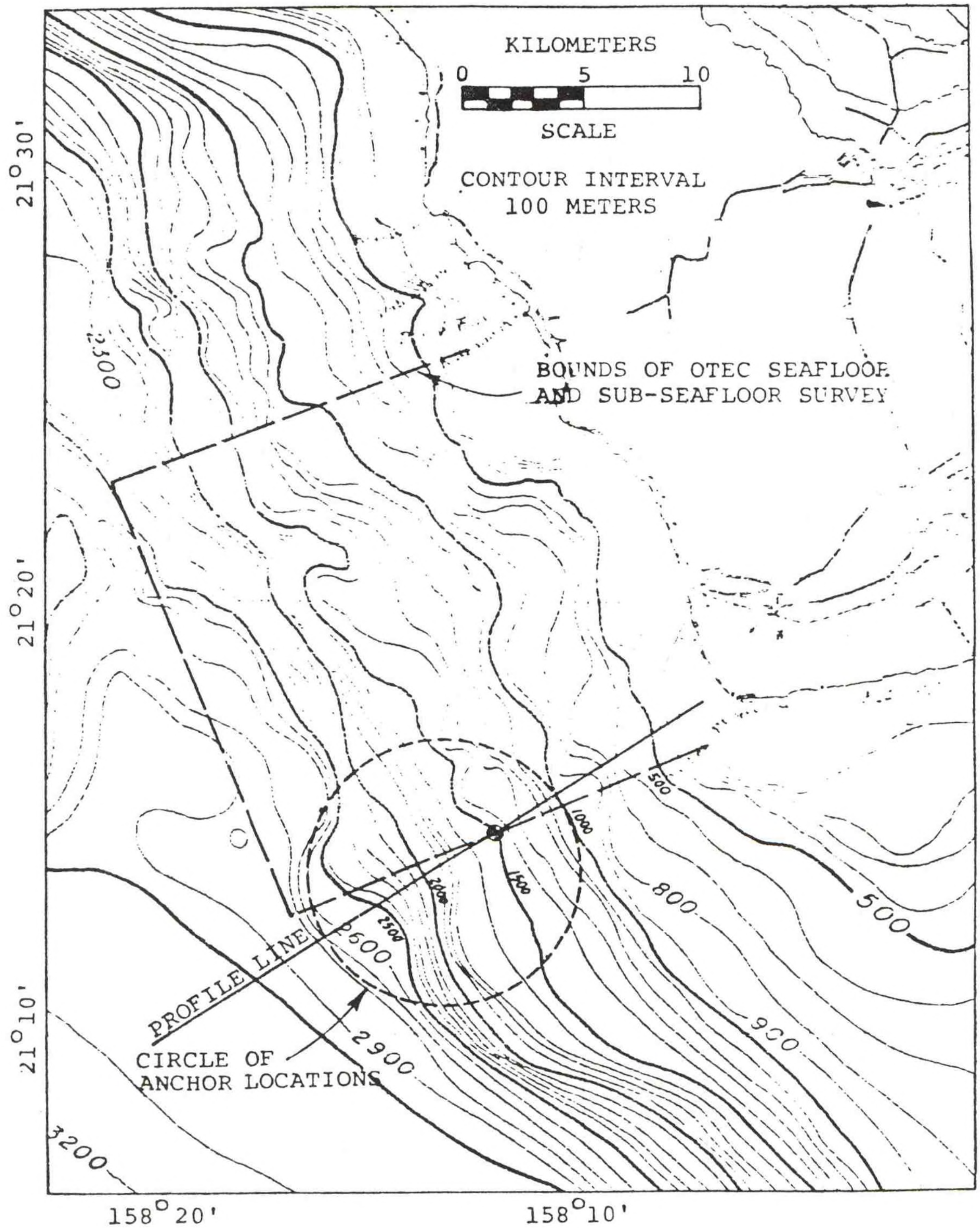


FIGURE 1 **PROPOSED LOCATION AREA FOR OTEC PILOT PLANT, OAHU, HAWAII**

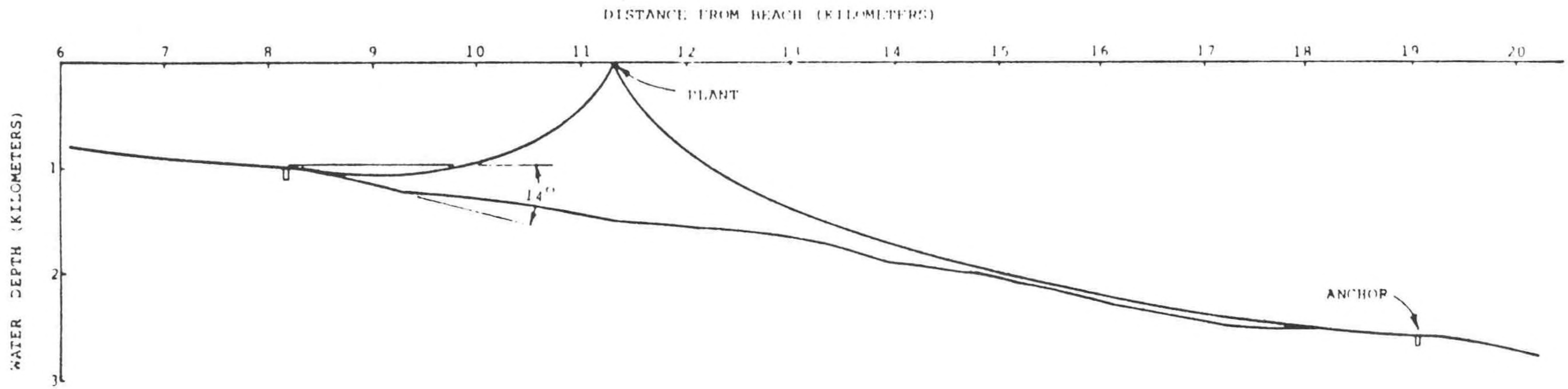
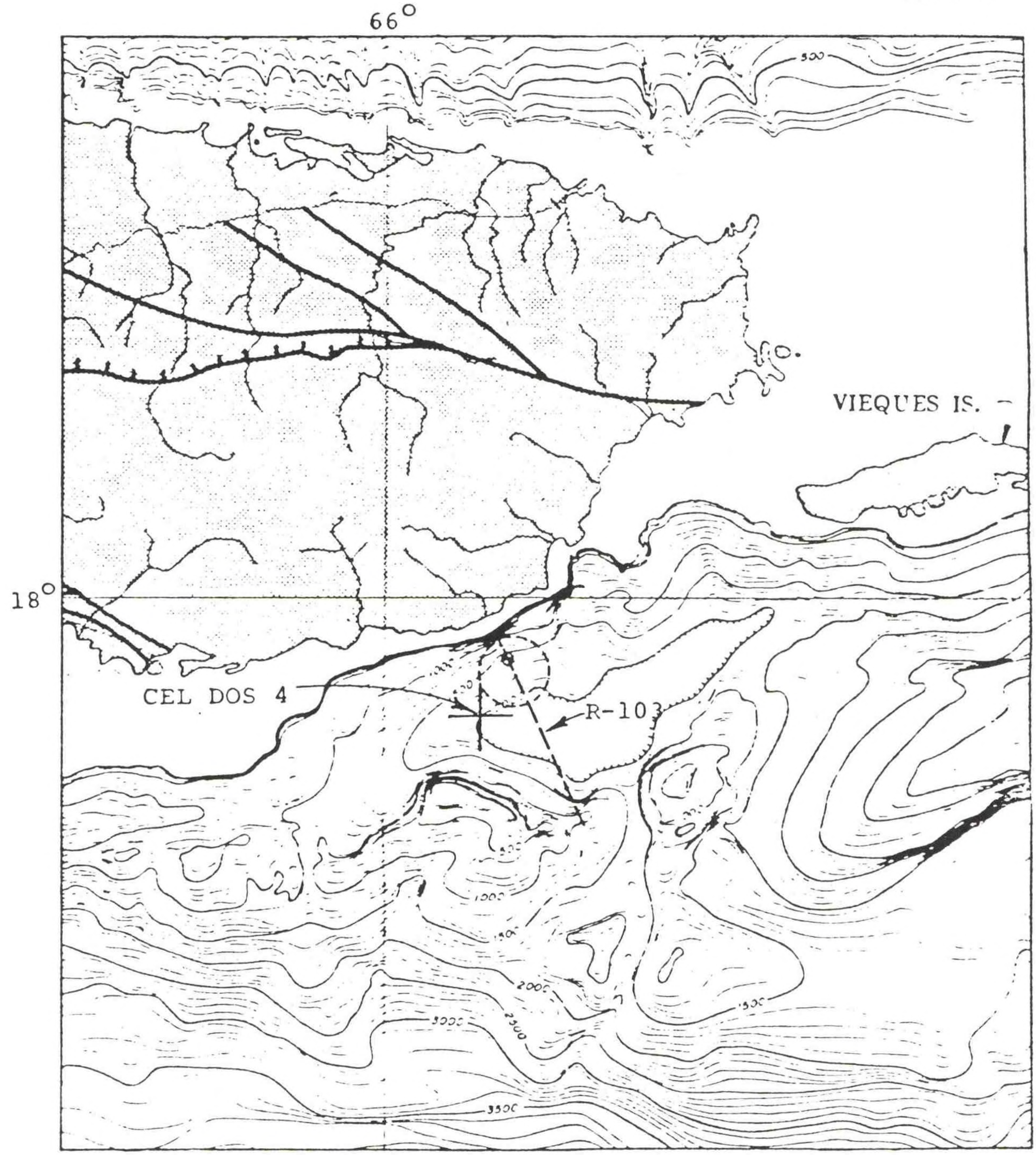


FIGURE 2 SEAFLOOR PROFILE OFF BARBERS POINT, OAHU, SHOWING ASSUMED PLANT AND ANCHOR LOCATIONS ON THAT PROFILE LINE



CONTOUR INTERVAL = 100 METERS
SCALE = 1 INCH = 10.7 NAUT. MILES

FIGURE 3 PROPOSED LOCATION AREA FOR OTEC PILOT PLANT, PUNTA TUNA, PUERTO RICO

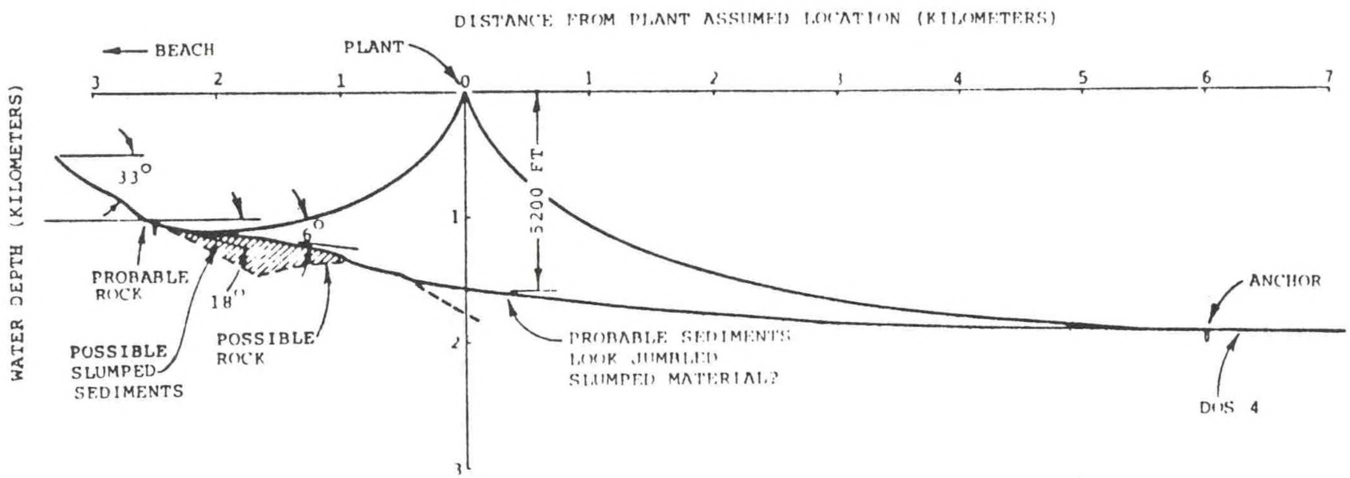


FIGURE 4 SEAFLOOR PROFILE OFF PUNTA TUNA, PUERTO RICO, SHOWING ASSUMED PLANT AND ANCHOR LOCATIONS ON THAT PROFILE LINE

UNDERWATER INSPECTION FOR DEEP OCEAN PLATFORMS

by

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1.0 Introduction

The purpose of this paper is to provide a brief overview of underwater inspection covering: needs and requirements, regulations and Classification Society guidelines; present methods and limitations; and then identify future needs and concepts. Underwater inspection is an integral requirement following installation and operation of offshore platforms. Means for platform inspection are used to: periodically check on structural integrity; provide damage assessment information; and assist in underwater maintenance and repair. Inspection helps to assure safety to personnel manning the platforms as well as the protection of property.

Since the first offshore platform was installed in the U. S. in 6 meters depth in 1947, there are now over 3,000 production platforms operating off U. S. shores to depths up to 310 meters. Figure 1 shows the trend in the U. S. over the last 30 years.

A platform in 100 meters of water in the Gulf of Mexico can cost on the order of $15 million, depending on the number of wells drilled and facilities required. On the other hand, a platform like COGNAC in 300 meters of water in the Gulf of Mexico costs about $265 million to construct and deploy. By the time it was fully equipped and ready to operate with safety devices, blowouts, etc., COGNAC costs were on the order of $800 million before oil production started in 1979 1/.

In parallel with this development, the need for underwater inspection became steadily more important -- to the extent that such inspection guidelines were developed by the Classification Societies, and requirements were imposed in the form of U. S. Regulations by the U. S. Geological Survey and the U. S. Coast Guard.

Present inspection means and methods used reflect the need in fulfilling Classification Society guidelines and Government regulations. Most of the early platforms operating in relatively shallow water gave relatively less attention in design to inspection, maintenance, and repair requirements.

As different types of platforms were introduced and greater depths were involved, the requirements for inspection, maintenance, and repair

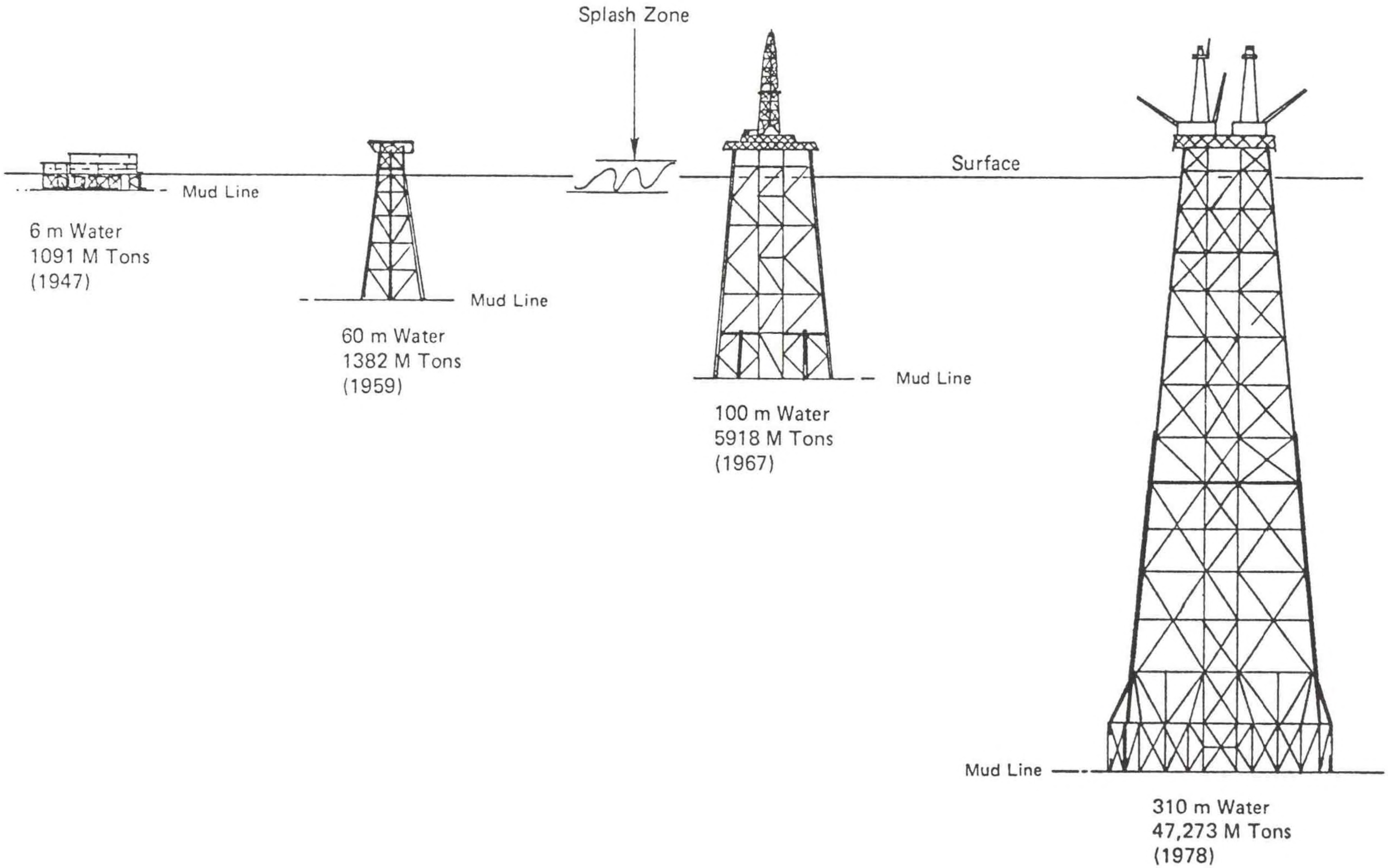

Figure 1: Examples of Offshore Steel Platforms 1/

(IMR) became more imposing and their costs became significant. Preliminary design studies concerned with Ocean Thermal Energy Conversion (OTEC) systems, which involve large platforms and water depths on the order of 1,000 meters, have indicated that over a 30-year life it is possible for IMR to represent as much as half of the life cycle costs. As offshore oil and gas systems operate in deeper waters IMR will become more and more significant and costly.

There are a number of design studies underway for deeper water platforms of various configurations. One of the largest platforms which will be operated in deep waters, on the order of 1000 meters, is Ocean Thermal Energy Conversion (OTEC). Some preliminary findings derived from investigative studies on OTEC Inspection, Maintenance and Repair are included herein.

2. Requirements

Inspection requirements exist for fixed offshore structures, mobile drilling rigs, and pipelines. In the U. S., the U. S. Geological Survey (USGS) has imposed outer continental shelf (OCS) rules applying to fixed offshore structures and allows the American Bureau of Shipping to perform the service and issue certificates. Operating procedures for the OCS platforms have been developed in the USGS Verification Program 2/. The U. S. Coast Guard (USCG) performs inspection of mobile vessels and issues certificates, and the U. S. Department of Transportation oversees inspection requirements for pipelines. In the North Sea area of operations, the United Kingdom and Norway have established legal requirements for periodic inspection and obtaining a Certificate of Fitness. Other North Sea countries are in various stages of development toward the issuance of inspection requirements. Under U. S. regulations, 6 professional classification societies are authorized to issue a Certificate of Fitness: American Bureau of Shipping (U. S.); Bureau Veritas (France); Det norske Veritas (Norway); Germanischer Lloyd (West Germany); Lloyds Register of Shipping (U. K.) and Halcrow Ewbank and Associates (U. K.). Bureau Veritas, Det norske Veritas, and the American Bureau of Shipping have published guidelines for underwater inspection.

In October 1981, the USCG has published Proposed Rules for OTEC Facilities and Plantships. In order to encourage and not constrain development of OTEC systems, new regulations for OTEC are not proposed. Instead, general performance standards are proposed where established regulations are not applicable, and existing regulations are made applicable with only slight modifications where needed to minimize any regulatory burden. Though inspection of smaller OTEC facilities and plantships is desired via drydocking, the rules recognize that provisions for special submerged examinations will be required for the platform, cold water pipe, and deep ocean mooring system. The owner/operator must submit a plan which includes: methods of visual and other inspection; diving facilities used; cleaning methods; identification of high stress areas and methods used to examine intake and discharge pipes and joints. The list of required plans is general in character but includes all plans which normally show construction and safety features coming under the cognizance of the USCG. The USCG proposes to use ABS guidelines when reviewing facility designs. The rules provide for examing innovative or unique designs on an individual basis. Each facility should be examined every 24 months. 3/

3.0 Present Technology

In offshore oil and gas development, fixed steel structures are most commonly used as production platforms. The production equipment is situated on the superstructure,and the main function of the steel jacket structure is to safely support this equipment and other items such as risers and electrical cables. The steel structure must be designed to take the compressive platform loads in addition to bending and shear loads due to environmental forces.

In order to provide the assurance that the structure can withstand this loading, periodic underwater inspection is required. Typically steel structure inspection includes general visual survey for examination of: alignment and indentations; complete or incipient failure of welds and metal loss due to corrosion or abrasion. Inspection includes assessment of the cathodic protection system including measurement of anode wastage and deterioration of protective coating.

Five underwater inspection and non-destructive testing techniques have been in use in the U. S. and North Sea waters: 1) visual inspection; 2) magnetic particle inspection; 3) ultrasonic inspection (thickness and flaw detection); 4) radiography, and 5) corrosion-potential (c-p) measurements. Variations on these techniques include a magnetographic method of crack measurement and an acoustic holographic technique for internal flaw detection. Table I summarizes these methods and presents the advantages and limitations. All testing techniques require that the structures be cleaned of marine organisms. Brushing, chipping, scraping and high pressure water jet is used. Cleaning represents a major effort and cost expenditure in underwater inspection.

Locating the site and positioning the equipment to conduct the inspection test can be quite difficult, particularly on complex nodes or in the interior of a steel structure. If there are no markings on the platform or if visibility is poor, location is much more difficult.

A further complication to inspection and testing is in the splash zone where the periodical rise and fall of the sea surface can prevent the surveyor and equipment from maintaining position at the work site. Above certain sea states, depending on the underwater inspecting techniques used, it is impossible to deploy any instruments near structures in the splash zone.

TABLE I

Present Underwater NDT Techniques: Advantages and Limitations 4/

Method	Material	Defects	Advantages	Limitations
Visual	All materials	Surface cracks/pitting, Impact Damage, Surface Corrosion, Marine Fouling, Debris, Scouring, Concrete spalling/crumbling	Results easy to interpret. Can be conducted with a variety of techniques.	Limited to surface defects. Surface must be cleaned for detailed observation.
Magnetic Particle	Magnetic materials only	Surface cracks, laps, seams pits and some near-surface flaws.	Easy to interpret	Thorough cleaning required. Weather dependent in splash zone. Limited to surface and near surface defects. Does not measure depth of defect. Interpretation done only in situ. No permanent record. Cumbersome to perform underwater. Now limited to diver use.
Magneto-graphic Method	Magnetic materials only	Surface cracks, laps, seams, pits and some near-surface flaws.	Simple to perform. Permanent record. Defect depth can be obtained. Interpretation conducted on surface.	Thorough cleaning required. Limited to surface and near-surface defects. Geometry of structure can be prohibitve. Now limited to diver use.
Fe Depth Meter	Reinforced Concrete	Depth of steel reinforcement in concrete	Easy to perform. Results immediate. Can be performed by mechanical manipulation.	Thorough cleaning required. Bar size must be known for greatest accuracy. No data recording feature.
Ultra-sonics	Metals, Concrete, Plastics, Ceramics, Glass, Rubber Graphite	Cracks, Inclusions, Porosity, Laminations, Bursts, Grain size, Lack of bond, Lack of weld penetration and fusion, Thickness variations.	High sensitivity. Penetrates up to 10m of steel. Accurate flaw location. Access to only one side needed. Fast.	Thorough cleaning required. Operator skill is required. Comparative standards only. Surface roughness can affect test. Difficulty with complex shapes. Present equipment limited to diver use.

Table 1 continued

Method	Material	Defects	Advantages	Limitations
Acoustic Holography	Same as above	Same as above.	Provides three-dimensional view of internal defects which can be precisely measured and located.	Thorough cleaning required. Present equipment limited to diver use.
Radio-graphy	All materials	Internal defects such as inclusions, porosity, shrinks, corrosion, lack of penetration and fusion in welds. Thickness measurements.	Provides permanent record. Standards established. Accepted by codes and industry. Portable.	Thorough cleaning required. Potential health hazard. Defect must be at least 2% of total section thickness. Difficulty with complex geometry. Water must be displaced between source and subject. Requires access to both sides. Present equipment limited to diver use.
Corrosion Potential	Metals	Tests cathodic protection system by measuring interface potential between structure and seawater.	Simple to perform. Rapid measurements. Easy to interpret. Can be performed by mechanical manipulation.	Thorough cleaning required. Measures external potential only.
Acoustic Emission	All	Cracks, breaks	No diver required to conduct tests. Can detect a crack. Can ascertain relative rate of crack growth. Can determine crack location.	Long-term reliability not yet verified. Cannot determine crack size. Cannot determine nature or significance of the crack. No standards of calibration from system-to-system.
Vibration Analysis	All	Breaks, large cracks	No diver required to conduct tests. Quick set-up time. Can detect broken load-carrying members.	Limited operational experience. Cannot assess significance of break. Detects cracks of large magnitufe. Difficult to locate cracks or break and monitor crack growth. No standards of calibration from system-to-system.

Unlike surface NDT, where a surveyor is used to conduct all testing, underwater NDT instruments are carried and deployed at the work site by one of four techniques: divers; manned submersibles; remotely operated vehicles; and one-atmosphere diving suits. The diver (either free-swimming, tethered, or deployed from a bell or lockout submersible) is most generally used at present for inspection and testing.

Each one of the above deployment capabilities has strengths and weaknesses in performing nondestructive testing. The greatest limitation at present is that nearly all underwater NDT devices are designed to be used by a diver. Consequently, the mechanical manipulators of the submersibles and remote controlled vehicles, and the grasping terminations of atmospheric diving suits are at a distinct disadvantage. Other limitations include positioning, stability, maneuverability and entaglement potential. At present there is no vehicle or deployment capability that is a complete substitute for the diver, and each has its own peculiar advantages and disadvantages. One of the more promising capabilities for inspection and certain forms of testing is the remotely operated vehicle, but certain of its obvious deficiencies must be corrected before it can realize its full potential.

In view of the accelerated offshore drilling and production activities in ever-deepening waters, it is expected that the diver's capability to routinely conduct inspections and testing at the depths required will soon be surpassed.

As present, for depths up to 200 meters, most of the methods and equipment noted in table 1 are used by divers. Though other means, such as remotely operated vehicles, one atmosphere diving suits and diving bells, and one-man submersibles have potential for applying NDT, there are many technical limitations that must be overcome by further development.

Various manned submersibles and remotely operated vehicles are being developed for use in underwater inspection as alternatives to the diver. These systems are capable of providing high quality visual and photographic inspections and can be equipped to provide cleaning facilities to the inspection site. However, since application of most NDT devices are designed for diver handling, they must be adapted to other means for deep water deployment. Major North Sea submersible operators are utilizing some instrumentation which can be deployed by a locked-out diver or by the submersible itself. These include a diver-held ultrasonic flaw detection device which is based on holographic techniques, a submersible-held c-p meter, a diver-held Wells-Krautkramer UT thickness-measuring device, and a closed circuit TV capable of providing base relief on the monitor in which slight details appear as ridges or valleys. A variety of other NDT devices and capabilities are being developed for application from lockout or one atmosphere submersibles.4/

Two areas currently under development for structural monitoring are: acoustic emission analysis and vibration analysis. These methods seek to determine a change in the structural dynamic response of a platform which may be deduced as a cracked or broken structural member or some other change in configuration which affects dynamics.

An acoustic emission monitoring and analysis system is capable of detecting minute, crack-induced acoustic signals via sensitive piezoelectric transducers attached to the structure at strategic locations. The crack-induced signals are processed via advanced signal processing and computer techniques to determine the location and significance of the physical discontinuity that propagated these signals.

Vibration monitoring and analysis system is based on the fact that a fixed strucutre, which is continually excited by the motion of the sea and wind, has a natural resonance frequency. The natural resonance frequency can shift significantly if a structural member is cracked, broken, deformed, or loosened significantly. This technique enables detecting, measuring, and processing the signals received from sensors such as accelerometers placed strategically at critical locations throughout the structure.

Except for the transducers, both of these techniques can be operated on the platform itself and do not require divers or undersea vehicles. Research and development of these techniques are continuing with tests being conducted on offshore platforms. Present indications show that changes in structural integrity can be measured and traced to a general location: easier on a single, shallow-water platform; and more difficult on a complex deep-water platform. More research is needed for better resolution location, especially for more complex structures in deep water.4/

4.0 Future Needs

Improvements in inspection devices needed for present day offshore platforms in water depths less than 300 meters are also applicable to the new deep-water platforms under development for oil and gas recovery and ocean thermal energy conversion (OTEC). New deep-water platforms ranging in depths from 300 to 1,000 meters are under various stages of development from conceptual design to test and evaluation of prototypes. Systems being considered for deeper water operations include tension leg platforms (TLP), guyed towers, single anchor leg moor (SALM), gravity structures, floating OTEC systems, shelf-mounted OTEC systems and hybrid OTEC systems.

The enormous size and complexity of such systems, deep-water operation, proportionately greater investment risk, and expectations for long-term survivability with a high confidence factor place substantial requirements on the design, deployment, operation, and maintenance of such structures. Preliminary studies of deep-water OTEC platforms indicate that the inspection, maintenance, and repair over a 30-year life could cost as much as half of the total life cycle costs. Of course, life cycle IMR costs for the deep-water platforms noted above would vary considerably depending on the depth, operating site, capacity of platform and complexity of design. However, it is logical to assume that IMR costs will be greater for most deep-water platforms. Therefore, it seems also logical that deep-water platform designs include consideration for IMR at the outset. In order to minimize the costs associated with IMR and to minimize catastrophic risk, it also seems logical to improve structural designs, provide sufficient structural redundancy, and integrate IMR requirements in the design process. As noted before, there are many tradeoff considerations versus cost that must be made.

Assuming that present-day devices in use and under development are suitable for deep-water operation, the main design consideration will be focused on the overall system approach; the strategic location of built-in sensory devices; and intergration of systems and techniques which can be remotely operated to perform basic IMR functions.

Floating and shelf-mounted OTEC systems can be developed in various kinds of configurations and involve deep-water operations. Preliminary IMR studies 5/ have been performed and have produced the following significant findings which must be taken into account for future OTEC designs:

- The majority of inspection will be visual, relying on divers to some extent, but due to depth limitations, primarily on remotely operated vehicles (ROV). Existing NDT techniques such as ultrasonics, mag particle, piano wire measurements will be the primary non-visual inspection methods employed.

- Almost all OTEC inspection tasks requiring only observation and photographic/video recording can use available equipment and techniques.

- The majority of OTEC inspection tasks requiring the use of NDT to determine the condition of OTEC components and structures can be performed on a routine basis by divers to a depth of up to 300 meters and on a special basis to a depth of 460 meters, employing currently available techniques and equipment.

- If a multi-anchor-leg mooring system is used, permanent anchoring may be more effectively achieved with the use of piles or piled templates instead of fluke anchors. Otherwise the desired 30-year life requires periodic inspection of the entire mooring system with periodic replacements, including the anchor.

- Both the divers and undersea vehicle operational ability is severely restricted either where there are significant oscillations caused by vortex shedding of the CWP, or where current velocity exceeds approximately 2 knots.

- Underwater repair of a suspended CWP must be accomplished by either raising the CWP to the surface for major repair of severe damage; or if the damage is minor, it may be possible to attach a patch or sleeve section.

Based on these several recommendations which appear significant for use in future OTEC work, those items which may impact design, cost, or technological risk are as follows:

- Continuous monitoring of the CWP for bending strain; torsional rotation, tensile strain and deflection, will enable continuous assessment of the CWP forces and facilitate operational control of a floating platform.

- Below 500 meters water depth, the CWP design should either be sufficient to require no maintenance or should be designed for remote maintenance mainly relying on ROV capabilities. This conclusion is based on current limitations of divers to depths less than 500 meters and the limited capability of manned submersibles (excluding JIM and WASP-type systems). IMR of the platform/ CWP interface is of prime interest. Therefore, a platform-CWP disconnection capability would provide access to the interior of the CWP and facilitate IMR operations

- Any cold water intake screen at the bottom of the CWP should be a coarse mesh in order to limit maintenance and cleaning requirements. Fine screens, if required (e.g., traveling screens, self-cleaning) should be located near the top of the CWP.

In addition to inspection and NDT equipment and methods, present and future needs require that special emphasis be placed on training of inspectors/surveyors and development of a comprehensive data acquisition and assessment program.

Assuming that inspection and NDT equipment is capable of performing the necessary tasks, one of the prime areas of concern is the capabilities of the inspectors using the equipment and interpreting the results. Past experience has indicated that divers often do not have the qualifications, experience, and training required to assume the full responsibility for inspection of present and future planned complex structures.

The inspection process must be supported by a comprehensive plan and program to: collect the necessary inspection data; facilitate analyses and assessment of the data; provide data storage for future comparison in determining long-term trends; and to develop a data base that will help to improve not only the platform design process, but the entire inspection and data handling process, itself.

5.0 Future Concepts

Based on future needs for complex deep-water platforms the following ideas are suggested for consideration in future concepts for IMR:

- Deeper and more complex platforms imply less accessible areas for IMR and, therefore, should be given special consideration in the design process, including redundancy.

- Because of the high life cycle cost of IMR, it is essential that IMR be included at the outset of the design process and integrated into the system design.

- Structural monitoring techniques such as acoustic emission or vibration analyses should be incorporated to the best extent possible so that preliminary data can be obtained directly on the platform without requiring diving systems or undersea vehicles. The acoustic and vibration sensors must be strategically placed and capable of being easily replaced.

- In order to facilitate inspection, replaceable stress-strain gages should be placed at strategic high-stress locations.

- Equipped divers and diving support systems can be used to provide the IMR capability to depths down to about 200 meters. Remotely operated vehicles can be used to assist divers in performing the IMR role. For greater than 200 meters depth, remotely operated systems equipped with visual, photographic, and NDT equipment can be effectively used.

- The entire structure should be appropriately marked to enable divers and remotely operated vehicles to perform more efficiently. A guided system can be developed which allows a remotely operated vehicle to follow a prescribed path. The vehicle would be equipped with low-light level, color stereoscopic TV cameras to permit remote observation by trained technicians topside. The vehicle can be stopped at any selected point and special measurements can be made for crack detection, wastage, or abrasion.

- The ROV can be guided up and down tubular structures, risers or OTEC cold water pipe. The ROV can traverse the exterior as well as the interior of the cold water pipe and make the necessary inspections and measurements.

- For the multi-leg mooring system, the ROV can be designed to climb up and down a mooring cable and examine the entire cable and fittings at each end. A concept suggested by April Engineering, Mystic, Connecticut, proposes continuous monitoring of synthetic mooring lines by incorporating twisted pairs of electrical conductors which can be monitored by electrical measurements based on capacitance changes.

- A preventive maintenance schedule should provide for a capability which allows periodic replacement of components damaged by fatigue such as mooring lines and fittings.

- A comprehensive IMR data acquisition, processing, recording, and analysis system must be incorporated in the integrated design and used to predict maintenance intervals, replacement components, and to develop a data base for future design improvements.

6.0 Conclusions

Continued development of offshore resources of oil, gas, and minerals, and ocean energy conversion is headed for operations in deeper waters. Based on present trends, future deeper water platforms will be larger, more complex and of different configurations. Structures and components that are relatively inaccessible will require special design considerations. IMR must be integrated into the overall design process after careful tradeoff considerations are made. Future IMR will continue to require divers and diving systems at the shallower depths, with remotely operated vehicles and compact manned systems handling deeper depths either tethered from topside decks or platforms, or built into the platform. Remotely operated vehicles or systems equipped with high quality visual aids and NDT may be built into the system on tracks or guideways. Also, techniques such as acoustic emission and vibration analysis could provide continuous monitoring for overall assessment before other means are deployed. Future deep-water IMR will require further research and development and application of the integrated systems engineering approach.

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NAVIGATION

NEW SCIENCES IN AN ANCIENT ART

INTRODUCTION

Thousands of years ago navigation was respected as one of the highest forms of human endeavor and Navigators were the pride of nations. Over the past fifty years new sensor sytems rapidly modernized the exploration of the ocean resources while navigation became a relatively undynamic nuisance required to locate and return to areas with advantageous resource content. (Regardless of relative emphasis over the years it has remained forever true that the surveyor, whether on land or sea, is the key to all financial institutions - in order to develop wealth a resource must be located in an area proven to belong to developers.)

Today navigation instrumentation has re-established a leading through the innovative use of micro-computer technology.

SYSTEM CONCEPT

Even from the earliest days of navigation beyond sight of land man has employed the system concept to maximize the safety and profitability of his voyages. The shadow of the mast across the deck during the day or the bowsprint against a star field at night gave a measure of his heading. The song of the mast stays could be related to speed. Multiple independent sensors - a system. Later the magnetic compass provided more accurate heading in all weather and the speed log, almost certainly a piece of fire wood tossed into the sea at the bow and timed as it drifted by the known length of the ship, proved a measure of speed with respect to a medium more stable than wind. Even today for the vast majority of vessels the system has changed little over thousands of years. The magnetic compass is still aboard though often supplemented with a gyrocompass and the fire wood has been replaced by pitot, electromagnetic, or doppler speed logs which still measure speed relative to the water. The end product, a plot of periodic positions on a navigation chart, is sufficient for the decisions required.

Even the survey teams through the first half of this century which made the charts, a part of the system just described, relied only on compass and log beyond land fall because they had no other sensors and the shallow draft of most vessels insured their safety until they were within sight of land. Major offshore hazards were marked with lights, buoys, bells, or horns.

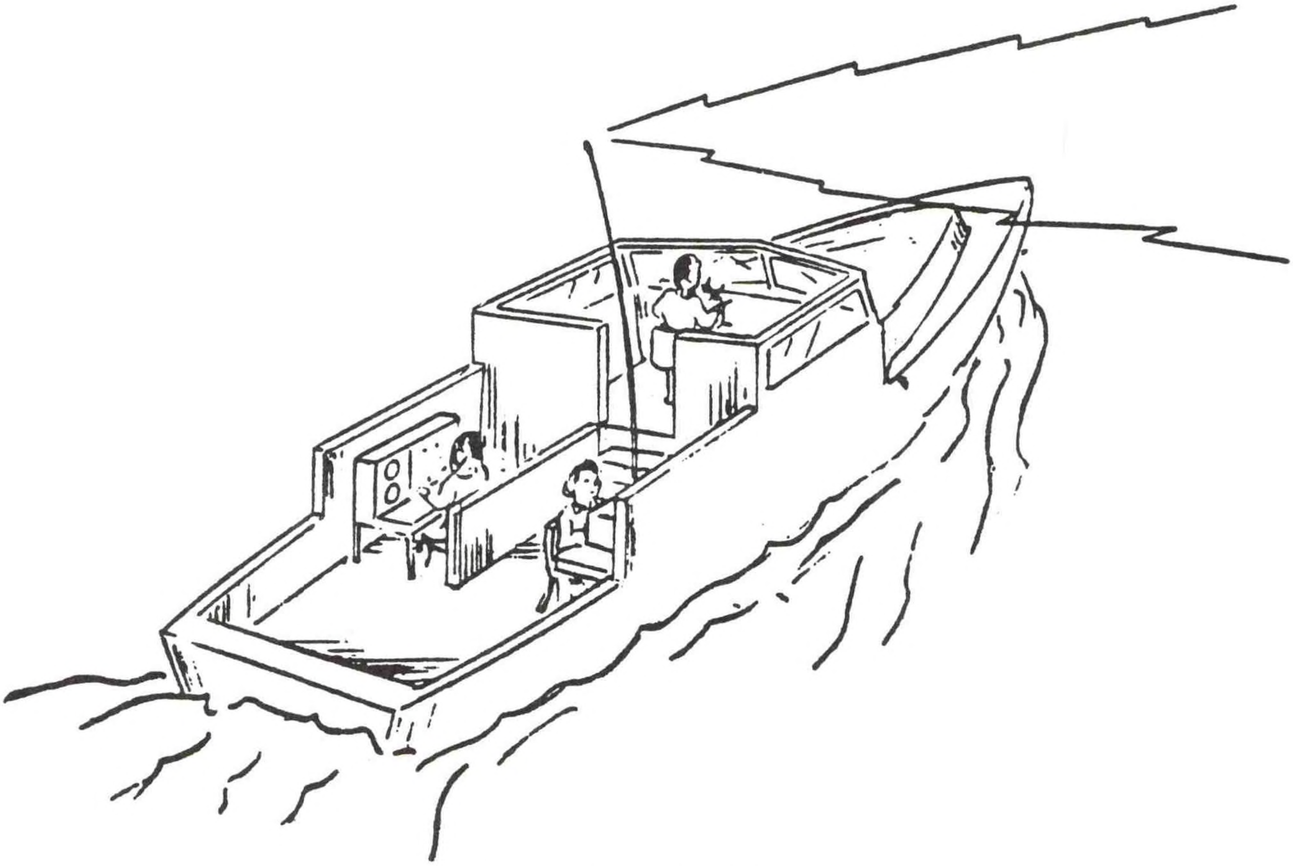
Precision near-shore surveying was accomplished with optical instruments on clear days and it was common to have dozens of vessels queued outside a major port in bad weather because visual land reference was required for safe entry. Commodities were cheap and spoiled cargos were common.

World War II and the years immediately thereafter produced the first major new navigation sensors since the chronometer. Radio technology expanded in many directions. High energy VHF pulses were found to reflect off solid objects and RADAR was born. SHORAN, a high precision navigation system was developed by transponding received radar pulses back to the sender at high power so he could determine a position fix by measuring ranges from a pair of transponders. Continuous LF and MF radio transmissions were stabilized and stations arranged in "chains" so that position fixes could be obtained from phase relationships between pairs of transmitters. DECCA, LORAC, LORAN A, and many other similar navigation systems soon appeared. Acoustic anti-submarine developments spawned precision depth sounders and doppler sonar navigation systems.

The tools were now available, in a confusing array, for all weather surveying beyond line-of-sight of the shore. Of equal importance, commodity prices had risen sharply and a world economy stimulated by wartime spending generated fierce competition for the remaining merchant tonnage and the necessary energy to run these vessels and the numerous new industries awaiting their cargos. Merchant ships now equipped with radar and depth sounders, in addition to compasses and logs, demanded all weather entry to congested harbors. Newer, larger, more efficient vessels required better charts, more precise navigation aids, and accurate approach and harbor dredging to gain the necessary access to world markets.

Pressed by these rising needs for a better end product the integrated navigation system evolved in both the hydrographic and geophysical industries. Necessity, not design, characterized these early systems and the results were at best haphazard.

As indicated in Figure 1, early attempts at marine survey systems left a great deal to be improved upon. On the vessel three independent operators "did their own thing." The bridge crew used whatever sensors they had at their disposal to try to steer the ship along a grid of survey lines handed to them by the project manager. Meanwhile, in separate rooms, the geophysical or hydrographic crew recorded their data and the



"SYSTEM" BLOCK DIAGRAM

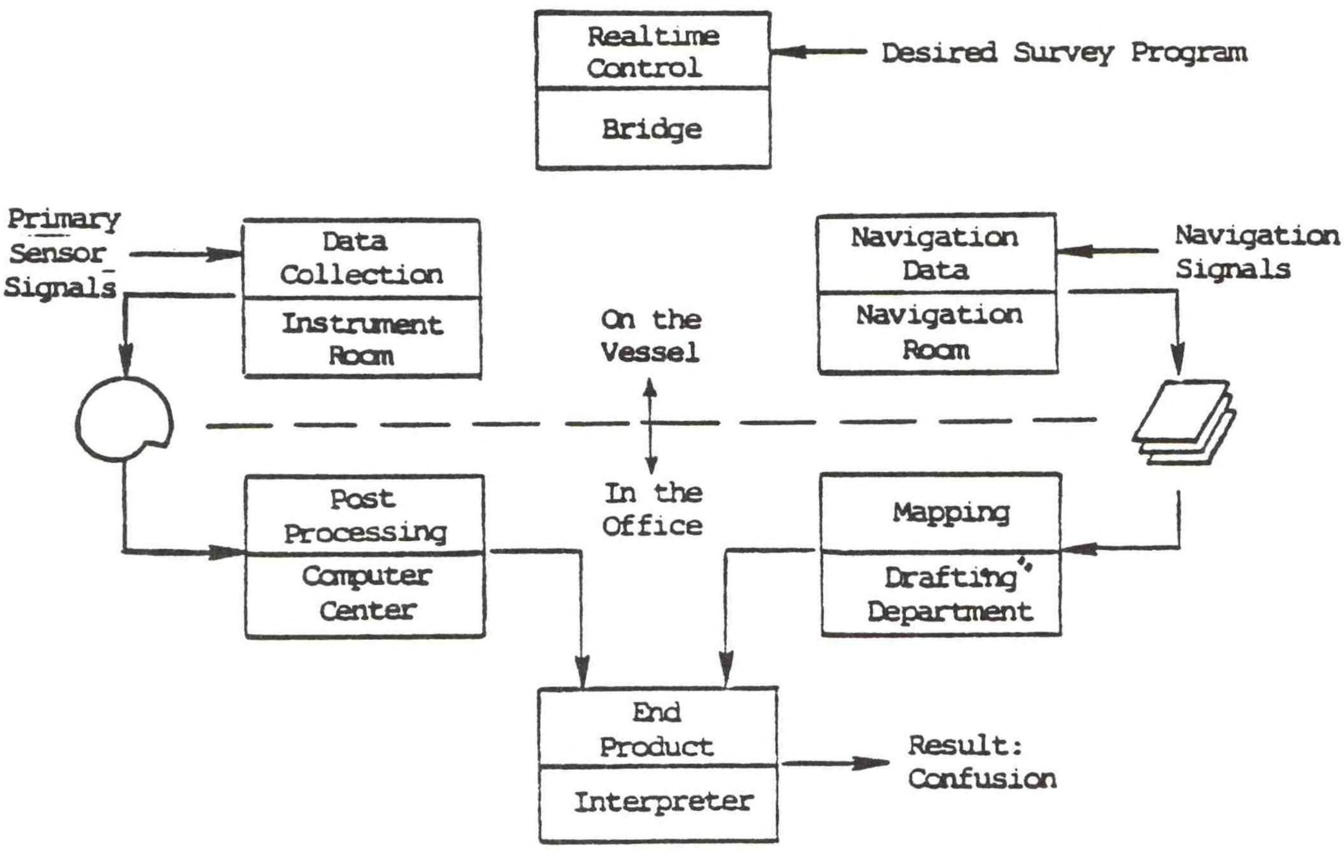


FIGURE 1

Navigation crew recorded its data. Often the bridge crew was far from the desired program line, the instrument crew recorded their data sequentially by event or "shot point" number with little regard for time, and the navigator recorded his readings by time with no regard for shotpoint number. After separate processing the two results were handed to an interpreter who often found it impossible to correlate the map with the primary sensor sections or found that the navigation was "down" in areas of the most interesting primary data, but was strong and reliable in areas of little consequence. The only feedback in this system occurred at meetings hastily called by the interpreter to try to resolve what really went on. It was generally negative in character.

The first attempt at integrating the marine survey crew improved the end product enormously. The added elements, as shown in Figure 2, were a common event clock which simultaneously recorded both primary and navigation data, and a intercom system to relay steering commands to the bridge. Now the navigator was in command of the survey unless safety considerations took precedence. Instead of handing the captain a chart with the desired survey lines on it, these lines were reduced by a shore based computer to pages of navigation instruments readings that should occur at the desired position for each shot point. The navigator was reqired to give left, right steering commands to the bridge "wheelman" to cause his instrument reading to correspond to the pre-plot listings at the proper actuation of the event clock. This type of survey navigation system required an operator with a unique capability to visualize his position and formulate steering commands by comparing noisy instrument readings with column upon column of computer printout. This talent was so varied between operators that the survey quality would change from shift to shift on a single boat. Boat-to-boat differences were significant and even company-to-company performance differences were measureable. Numerous problems plagued these early attempts at beyond sight of land marine survey systems, but even with these shortcomings they filled a real need.

A new and unique navigation sensor was made available to the marine surveyor, when in 1967, the U.S. government released the details of the signals transmitted by the Navy Navigation Satellite System (NNSS), or TRANSIT satellites. The NNSS receivers coupled to a minicomputer could provide all-weather, worldwide position fixes of about 500 feet RMS accuracy every two to four hours. By 1969, two companies had capitalized on the new satellite technology and had produced nearly identical systems based on an NNSS satellite receiver, gyrocompass, doppler sonar sensor, and large scale mini-computer. This truly <u>integrated</u> system is shown in Figure 3.

These integrated satellite gyrocompass doppler sonar systems freed the marine surveyor from restrictions of coverage by his shore-based radio stations and gave him access to all the world's continental shelves out to water depths exceeding 600 feet. Perhaps of equal importance, the consistency of the survey was notably improved by taking the operator out of the real-time system interface loop. These systems were fully automatic after initialization. Similarly equipped boats produced similar results.

While sensor reliability improved dramatically in the 1979's due to competitive pressures, minicomputers simply grew more complex, and therefore, more failure prone by way of increased number of components operating in an environment for which they were not designed. Vibration, salt air, and often widely varying power are not conducive to long life of mini-computers normally pampered by separate filtered computer room air supplies and supported by AC line conditioners even against the vagaries of industrial power distribution. Once again, these systems did not develop from a sound system concept, they simply evolved due to market pressure.

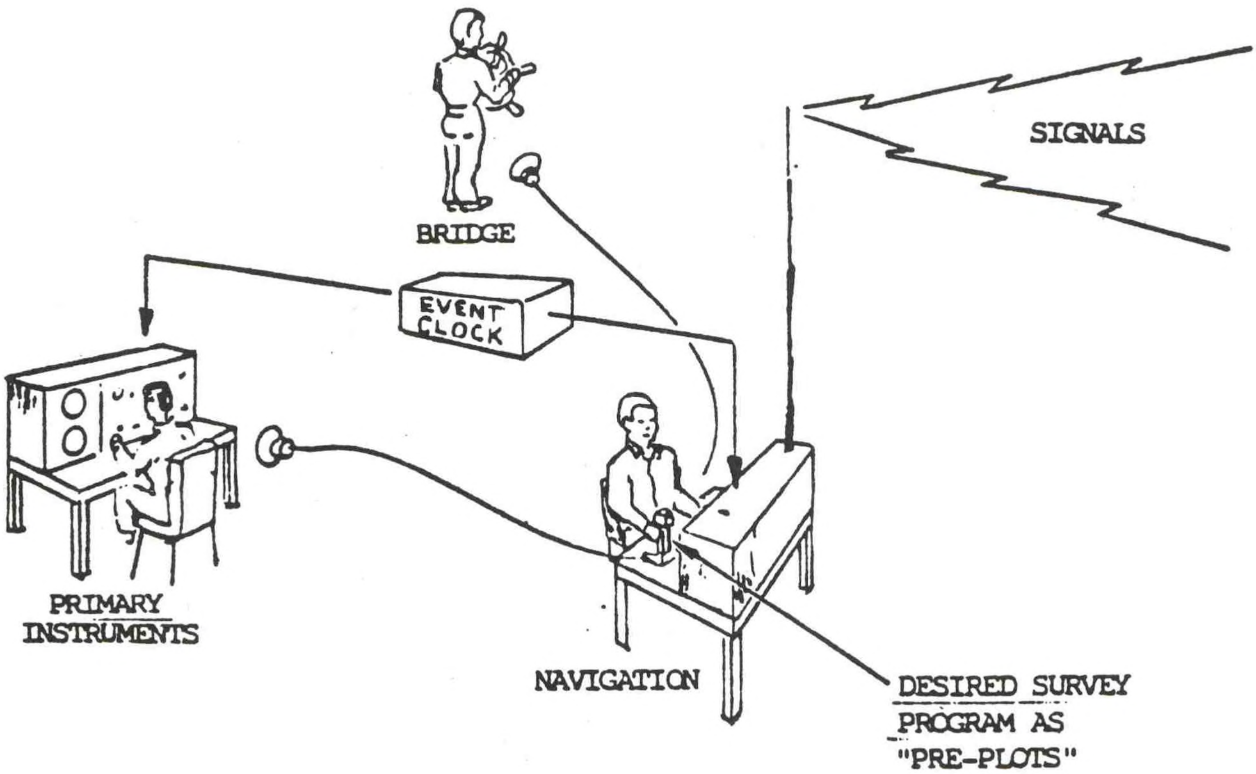


FIGURE 2

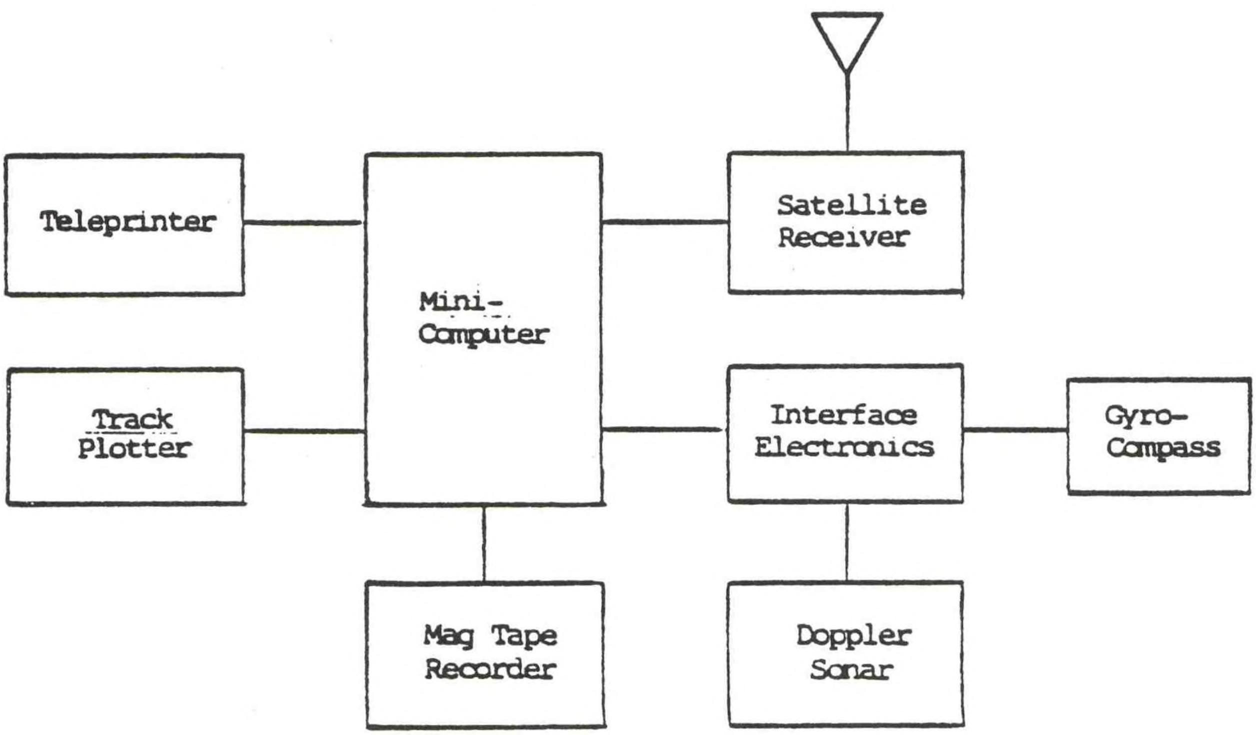


FIGURE 3

STATE-OF-THE-ART SYSTEM DESIGN

In the late 1970's, as the classical integrated navigation systems were being stretched well beyond their realistic boundaries other system designers were beginning to seriously question this trend toward the all-the-eggs-in-one-basket design. It was improving the end product, but the sharply rising initial investment required, along with high maintenance costs and marginal system reliability, caused a number of designers to step back and evaluate the total system concept.

In this same time frame, the microprocessor had matured to respectability as a scientific data processor after years as only a simple process controller. A complete computer-processor, memory, and I/O channels - could now be placed on a single printed circuit board (PCB). Compiler level languages became available for the microprocessors. A totally new tool was available for the system designer.

The biggest problem with the "classical" mini-computer based integrated system was that it was autocratic. The working sensors all scurried about gathering bits and pieces of data to hand to the dictatorial central processor. The central processor was forced to do all the analyses and then make and communicate its decisions. In the human experience, this form of organization has been demonstrated to be highly inefficient and prone to serious disruption if the leader becomes ill. Also, as more and more data is delivered to the leader, the quality of each decision declines.*

Since human beings design system to solve human needs, perhaps the above analogy could be taken another step along. In a free society and in a well intentioned, well organized group there is a leader who makes decisions at the highest level based upon the best condensed information presented to him by the managers who report directly to him. These second level managers are given the freedom and responsibility to make many decisions regarding the gathering of the data and the analysis thereof

* This analogy of integrated system design with respect to human behavior may appear humorous or even frivolous. However, a discussion along these lines actually influenced the direction of at least one active system design group.

so that only the most useful, complete, and thoughtfully weighted information is presented to the highest management level for the organization sustaining decisions. With confidence in his next level managers' inputs, the leader is free to spend a reasonable amount of time to render the best possible decision before he is again presented with new data. Once a decision is made, the leader notifies his communications manager and is, therefore, free to take on the next important task while the previous decision is faithfully distributed to those next level managers who need it to properly guide the activities for which they have accepted responsibility. If a second level manager becomes temporarily ill, the organization does not collapse in a heap. The leader can continue to make decisions based on the remaining information available to him while the missing manager recovers. If one manager's job is proven to be overwhelming, another second level manager is added to share the workload equitably. If a manager is shown to be incapable of taking the "heat," he is replaced by one who can.

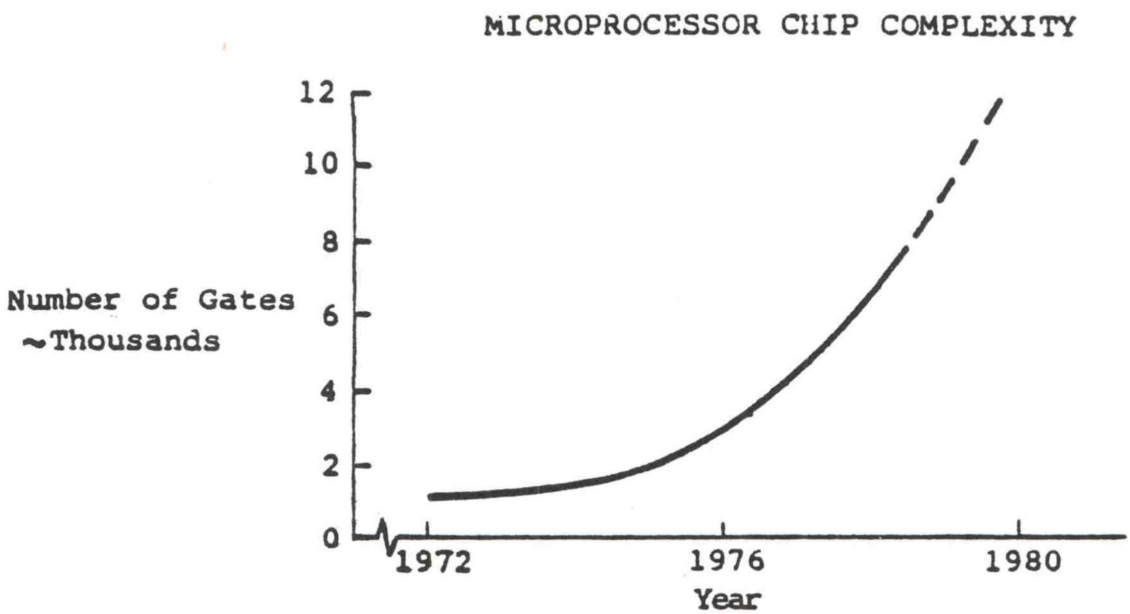
In computer terms, this analogy has described:

(1) Distributed Processing
(2) Fail "soft" system design
(3) Design to the operating environment

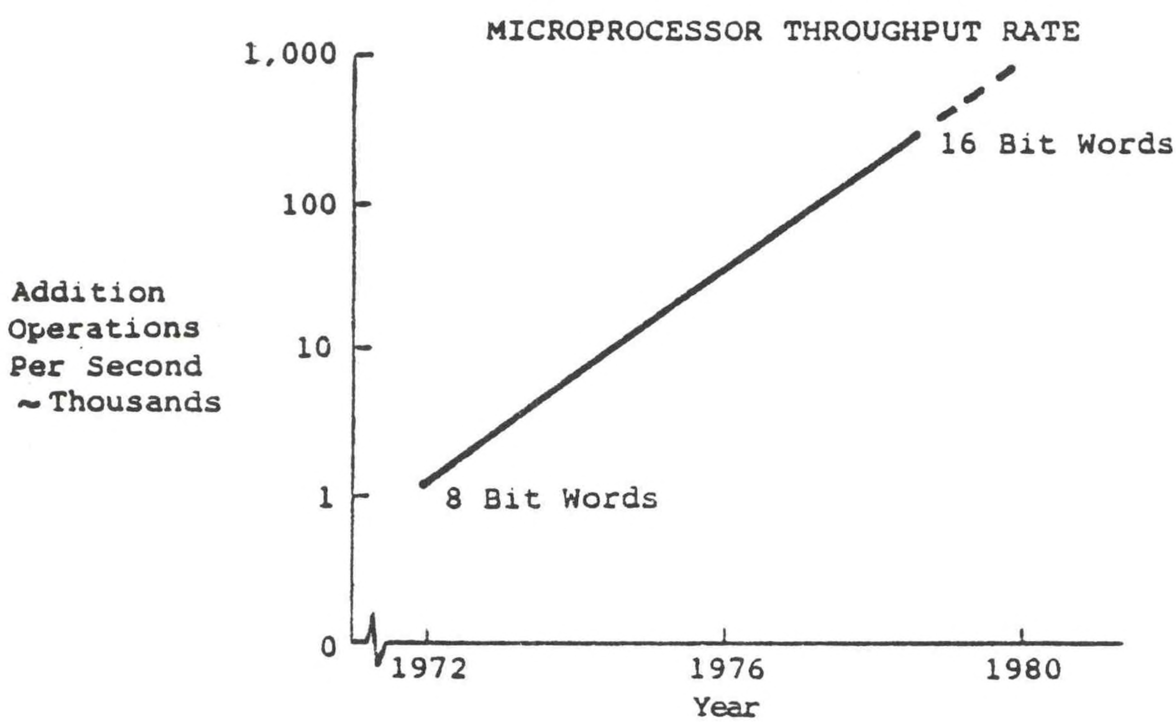
THE MICROPROCESSOR BASED SYSTEM

In order to appreciate the current trend toward microcomputer based navigation systems, whether they are used as simple process controllers in individual sensors or form the basis for a distributed processing central navigation system computer in a multi-sensor system, some background in the progress of microcomputer components is desireable. The figure presented in this section must be considered qualitative in nature even though it is given in quantitative parameters. In order to show trends, step function jumps in component capabilities due to changes in ship organization or manufacturing techniques have been smoothed out to avoid confusion. Orders of magnitude are correct. Memory chips also jumped dramatically in the amount of information which could be stored in a unit volume.

The microprocessor had matured to respectability as a scientific data processor. A complete computer - a processor, memory, and I/O channels - could now be placed on a single printed circuit board. Compiler level language became available for the microprocessors. A totally new tool was available for the system designer.



MICROPROCESSOR CHIP COMPLEXITY
Number of Gates ~Thousands
12
10
8
6
4
2
0
1972
1976
1980
Year



MICROPROCESSOR THROUGHPUT RATE
Addition Operations Per Second ~Thousands
1,000
100
10
1
0
16 Bit Words
8 Bit Words
1972
1976
1980
Year

FIGURE 4

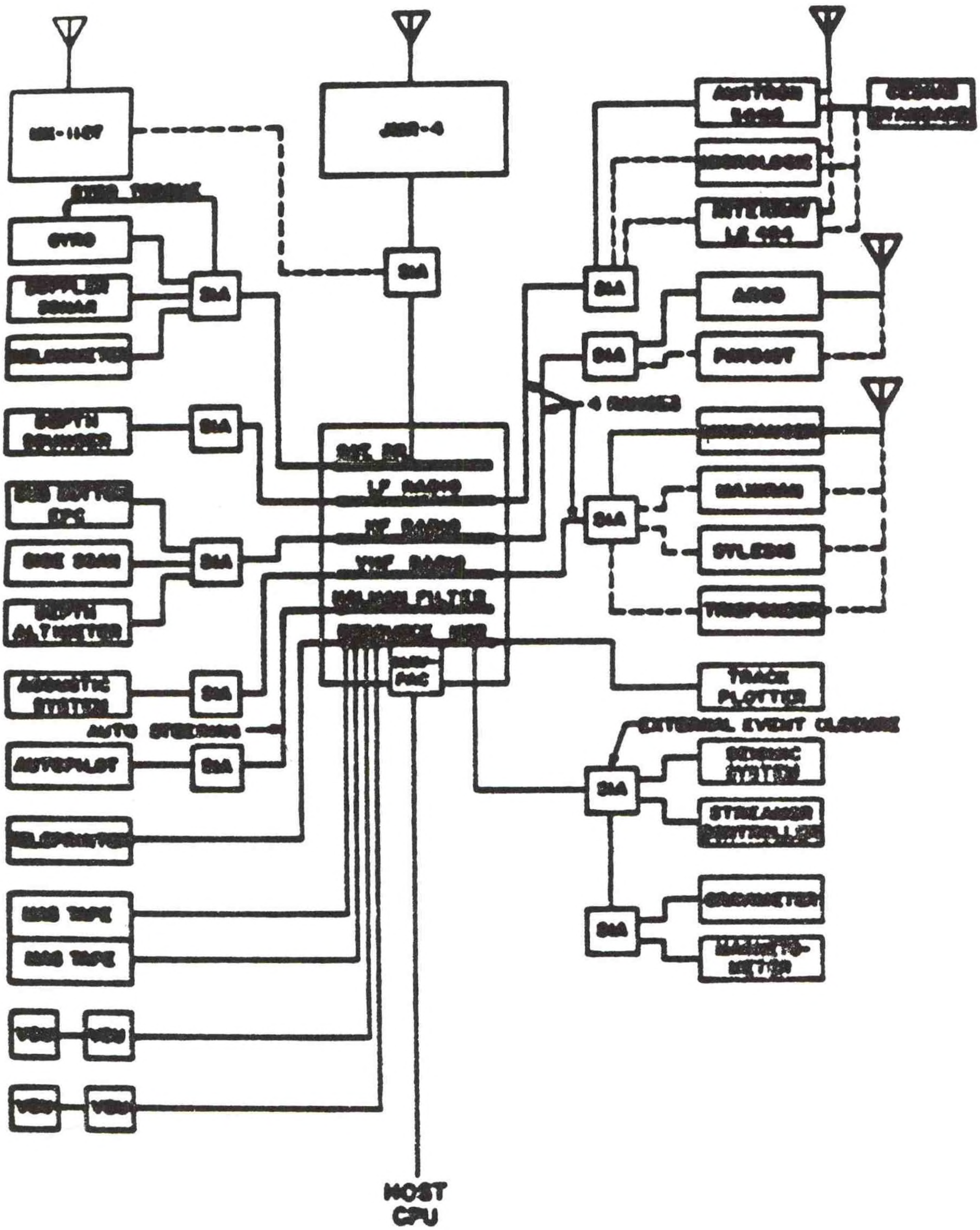
If the processing workload (thruput) becomes too heavy for a system, an additional processor could be added to distribute the workload. Since these processors needed to communicate with one another, a protocol for efficient real-time data transfer was developed. The distributed micro-processor system design is not limited by thruput or memory. A modern JMR Integrated Navigation system is shown in Figure 5. In just the central Integration Module and the Sensor Interface Adapters (SIA's) this system employs almost 40 independent, but intercommunicating micro-computers. The inherent characteristic of "fail-safe" operation, growth flexibility, and reliability suggest the significance of this major breakthrough in Navigation system design.

SUMMARY

The first integrated satellite navigation systems were conceived to free the marine surveyor from the restricted coverage of shorebased radio navigation aids. In addition, they provided the first offshore survey tool for 24-hour all-weather operation. The creditability of the survey end product was enhanced by the absolute nature of the satellite fixes, and survey mileage production increased markedly even though these systems suffered from poor reliability. Once accepted by the survey industry, these integrated navigation systems tended to become central mission systems controllers as well. An enormous burden was soon placed on the central mini-computer processor and on the system programmers.

The decade of the 70's saw the micro-processor chip and its VLSI support chips mature to the point that a different, more flexible and reliable approach to system development was feasible. Many designers successfully implemented single purpose navigation systems and navigation sensors based on the micro-computer concept. Dramatic improvements in navigation central processor reliability were realized because the micro's could only be superficially protected against the survey environment. In the mid-70's complete high performance micro-processor systems were constructed that could, powered only by an automobile battery, give multi-pass satellite 3-D positioning solutions in real-time in any environment in which the surveyor himself could survive.

MODERN INTEGRATED SYSTEM



- DYNAMIC POSITIONING SYSTEM
- DREDGING SYSTEM

FIGURE 5

In 1978, two system design groups, one just entering the field and the other one of the largest integrated navigation system producers, realized that while others continued to try to ingest more and more data into the navigation center mini-computer, the time had arrived for a new approach based on the micro-processor. Specialized functions, such as sensor specific processing mission coordination functions, multi-sensor optimal filtering, could best be spread among intercommunicating micro-computers. These two design groups chose different processor chip sets for different, but locally valid reasons. However, the most remarkable result was two independent, but almost identical design philosophies - one approached from more what <u>can</u> be done and the other from what <u>needs</u> to be done.

This paper has traced the basic history of integrated satellite navigation systems and has described the more fundamental reasoning leading to their early system design philosophy. The intent of the presentation was to show that new tools are now available and new priorities can realistically be set for system performance, reliability, and flexibility if good design practices are used to take advantage of the newest and most versatile computational element - the micro-processor.

TOTALLY INTEGRATED SYSTEM FOR HYDROGRAPHIC SURVEYING

by Peter J. Clifford and Richard M. Shamp
EG&G Environmental Equipment Division

ABSTRACT

Microprocessor technology has been applied to both inwater sensors and shipboard electronics to improve hydrographic surveying capabilities. EG&G has developed a single cost effective system for the collection of precise bathymetric data along with accurate plan view maps of the seafloor. The system is described with emphases on the collection, processing and display of the data.

INTRODUCTION

Accurate high resolution bathymetric data and plan view maps of the seafloor are now possible from a single cost effective hydrographic survey system.

Side scan has become a widely used, often indispensable tool for hydrographic surveying. However, the conventional systems have not reached full potential because of their qualitative nature. Skilled operators and interpreters are required and even then, the results are inconsistent. EG&G combined microprocessor technology with its extensive application experience to develop a new system, the Model 960 Seafloor Mapping System (SMS), which was introduced in 1978. For the first time, data are collected and presented in a repeatable manner to give a true plan view of the seafloor. True relative positions and scattering strengths are presented on a graphic record. Multiple records may be pieced together to form a mosaic. The mosaic allows for direct correlation (even overlays) of bathymetric and seafloor mapping data. Figures 1 and 2 are a seafloor map and the corresponding hydrographic chart of the same area.

The original SMS system utilized a conventional analog towfish. Now with the introduction of the EG&G Model 990 microprocessor based towfish, the system achieves total integration of precision high resolution seafloor mapping, bathymetry, navigation and even sub-bottom profiling data.

The system is particularly well suited for hydrographic applications:

* All data are collected by a single tow sensor whose position may be accurately determined using an integrated acoustic responder.

* High resolution bathymetry is obtained from a stabilized narrow beam (1°) transducer towed close to the seafloor.

* Map data may be used to optimize bathymetric survey line spacing, thereby reducing required sea time.

* Ship wrecks, downed aircraft and underwater obstacles are displayed on the map with high resolution (¼ meter), in proper perspective, and at their exact location.

* Classification and extent of seafloor materials is possible based on the darkness and texture of the map image. Sediment transport may be determined by subsequent surveys.

* Subbottom profiling data may be collected using an integrated hydrophone in conjunction with an integrated pinger or a surface towed source.

* Integrated temperature sensor may be used for sound velocity analysis.

SEAFLOOR MAPPING

A seafloor map is a plan view, acoustic (side scan sonar) image of the seafloor, analogous to an aerial photograph of a land area. The side scan sensor, commonly called a "tow fish", is normally towed behind and below the recording survey vessel, positioned in the water column at a height from the bottom of 10 to 20% of the selected scanning range to each side. See figure 3. The tow fish has two identical transducers which collect data at ranges up to 500 meters to each side. Each transducer has a narrow beam (approximately 1°) in the horizontal plane and a wide beam (approximately 50°) in the vertical plane. The narrow, horizontal beamwidth concentrates the energy in a swath perpendicular to the axis of travel. The wide, vertical beamwidth gives continuous data from directly beneath the transducer out to the maximum system range. The instantaneous echo level is a measure of the backscattering strength or roughness of the seafloor material. As the transducers are moved forward subsequent sonic transmissions generate parallel swaths of data giving a continuous seafloor image.

As with any image, a seafloor map is a two-dimensional array of pixels (smallest resolvable picture elements), each having an associated density (amplitude). In a side scan sonar image there are distortions in all three dimensions, each requiring correction to give a true image. The EG&G Model SMS 960 Seafloor Mapping System (SMS 960) implements each of the corrections and maintains a high quality, high resolution image. The acoustics, signal processing, data recording and graphic recording are consistent with a pixel size of 1/800 of the range to each side and an amplitude dynamic range of 64 db (of backscattering strength variation).

All system capabilities are available in real time and/or on playback of the recorded data. The following sections describe the implementation of the seafloor mapping corrections.

AMPLITUDE CORRECTIONS

The pixel amplitude should be a function of the seafloor material, not of the equipment or the operator, as in the case of a manually operated time varied gain (TVG). Input data from the tow fish varies in amplitude due to four basic factors - range, transducer beam pattern, grazing angle of sonar with seafloor, and seafloor backscattering strength. The pixel magnitude, gray scale density, should be a measure of backscattering strength (roughness) of the seafloor.

In the SMS 960, signal strength variations due to range are automatically compensated by a FIXED analog TVG circuit based on the sonar equation. Since the tow fish height is required for slant range correction, it is also used to automatically adjust the input data for grazing angle and beam pattern corrections, which are implemented digitally for a nominal beam pattern and seafloor model.

The resulting pixel data on tape has 6 bits of amplitude, 1 db per bit for a 64 db dynamic range. Using the gain and contrast controls these data are transformed into the 16 gray scales of the graphic printer.

SLANT RANGE CORRECTION

Slant range correction is not merely water column removal, but a geometric correction of every pixel. The side scan sonar signal received by the transducer is a measure of backscattering strength versus time (or slant range). The slant range is the straight line range from the transducer to the point of interest. For the initial return, from the seafloor directly beneath the transducer, the slant range is vertical. For returns at long range, the slant range is nearly horizontal. Thus, each data point has a different lateral distortion. See figure 4.

In the SMS 960, a new height determination is made for each sonar transmission and is used to locate each pixel at its true horizontal range with an accuracy of $\pm$ 1 pixel. There are 800 slant range corrections per scan per channel in the SMS 960. The transformation assumes that the seafloor is horizontal. In general, bottom slopes are gentle and little error results from this assumption (3% for 15° slope). The correction is completely automatic, with no external entry required.

SPEED CORRECTION

To maximize the sonar data rate, the transmit rate is determined by the round trip travel time for sound to return from the maximum desired range. Thus, for a given range the transmit rate is fixed. Subsequent swaths of data will be separated by the distance traveled between transmissions. This distance is speed-dependent. See figure 5.

Speed correction is not simply adjusting the paper speed to correspond to the tow fish speed. This is acceptable for only a very narrow range of speeds (typically 2.6 knots or less), because the line spacing changes with speed. As speed increases, the image density becomes less, and the image may be unreadable because of the wide gap between lines. For example, a 19-inch display speed corrected at 10 knots results in a spacing of 14 lines or scans per inch.

The SMS 960 maintains a constant line spacing (200 lines per inch) over the full range of speed correction (0 to 12.9 knots). Every pixel is automatically displayed at its true position (±1% of distance traveled) along the tow fish track using the instantaneous speed from a variety of sources.

GRAPHIC RECORDING

Conventional graphic recorders do not have the precision, speed, or reliability necessary for seafloor mapping. The SMS 960 has a unique multi-stylus digital gray tone graphic printer with a map display width of 20 cm (7.9 inches). Since it controls the printing precisely (1/8 mm pixel size) and repeatedly, the resolution is greater than that of a 19-inch display (1600 pixels across the map, 800 each side).

The SMS 960 printer precisely prints the 50 lines per second necessary for high quality, 100 meter data. Conventional recorders can print only a maximum of 10 lines per second, and at that speed the precision and reliablility of the printer are poor.

Since the SMS 960 printer head travels only 2 mm, accuracy and life are very high. Many systems have been operating in the field for several years and are still utilizing the original styli.

TAPE RECORDING

Tape recording of data should be consistent with the desired pixel data; anything less will eliminate useful (often necessary) information. The digital data are recorded on tape with a dynamic range from 0 to 63 db in 1 db step

On the SMS 960, only the RANGE control affects the data being put on tape; all other controls affect only the sonar data processing done after the point at which it is recorded. (The RANGE control changes the system transmit repetition rate). Therefore, the real time graphic record is not critical; it is only one of many possible presentations that can be achieved by tape playback.

IMAGE PROCESSING

Since the seafloor mapping data is another form of remotely sensed imaged data, it makes sense to format the SMS data to be compatible with existing image processing system.

As an experiment, EG&G modified the SMS software to output data in a format compatible with the Comtal Vision One/Twenty Image Processing System. Pseudocolor images and a variety of other sophisticated post processing were done. There are libraries of software developed for landsat and space image processing which have direct application to seafloor mapping data.

BATHYMETRY

A vessel mounted narrow beam echo sounder (depicted in figure 3) in many cases is not very accurate and has many operational problems, particularly in rough seas. The Model 990 towfish incorporates an accurate linear pressure transducer to measure the depth of the tow fish. When used with the SMS 960, this tow fish depth is added to the tow fish height as determined by the SMS 960 to give a continous automatic bathymetric reading along the tow fish track.

These high resolution data are very accurate because:

a) The sonar is close to the seafloor, isonifying only a small area,

b) the repetition rate is very high,

c) the tow fish is hydrodynamically stable, and

d) sound speed variations (which can be several percent) affect only the tow fish height measurement.

The bathymetry is continuously displayed, printed beside the map, and is available as a digital output from the SMS. This capability is available in real time or on playback if the tape deck is used.

SEISMIC PROFILING

The tow fish incorporates a broadband hydrophone for use as a seismic receiver. A sub surface receiver used with a surface towed source has the following advantages over the conventional surface-towed receiver and source:

1) The source/receiver geometry gives higher lateral resolution; there are coherent echoes from a much smaller lateral area due to the time dispersion of the echo from a given layer.

2) Lower noise level because the receiver is farther away from the vessel and the surface waves.

3) Higher signal level because there is only a one-way transmission loss through the water column instead of a two-way loss.

4) If the receiver is towed well behind the source, refraction studies are possible.

Since the receiver is broadband, it may be used with most high resolution sound sources at the surface. In an alternate mode, an integral pinger and narrowband receiver may be used when a deep-towed source and receiver are desired.

Analog and digital outputs are available for tape recording or graphic recording (after filtering). The seismic data are not recorded on the tape deck or displayed on the SMS 960 but are processed separately.

TOW FISH LOCATION

The tow fish incorporates an acoustic responder for tow fish location. On electrical command from the surface, the tow fish emits an acoustic tone burst. This tone may be used to interrogate a transponder network on the seafloor or may be received by a vessel mounted short base line, range and bearing system. Three standard frequencies and pulse lengths are provided to interface with several different acoustic navigation systems. Other optional frequencies and pulse lengths are available.

Navigation data (from an acoustic and/or radio navigation system) may be recorded on tape and displayed on the map along with the bathymetric data.

SYSTEM DESCRIPTION

The basic system components are the Model 990 Tow Fish, the Model 996 Modem, the Model SMS 960 Master Unit, and the Model 9000 Tape Deck. See figure 6.

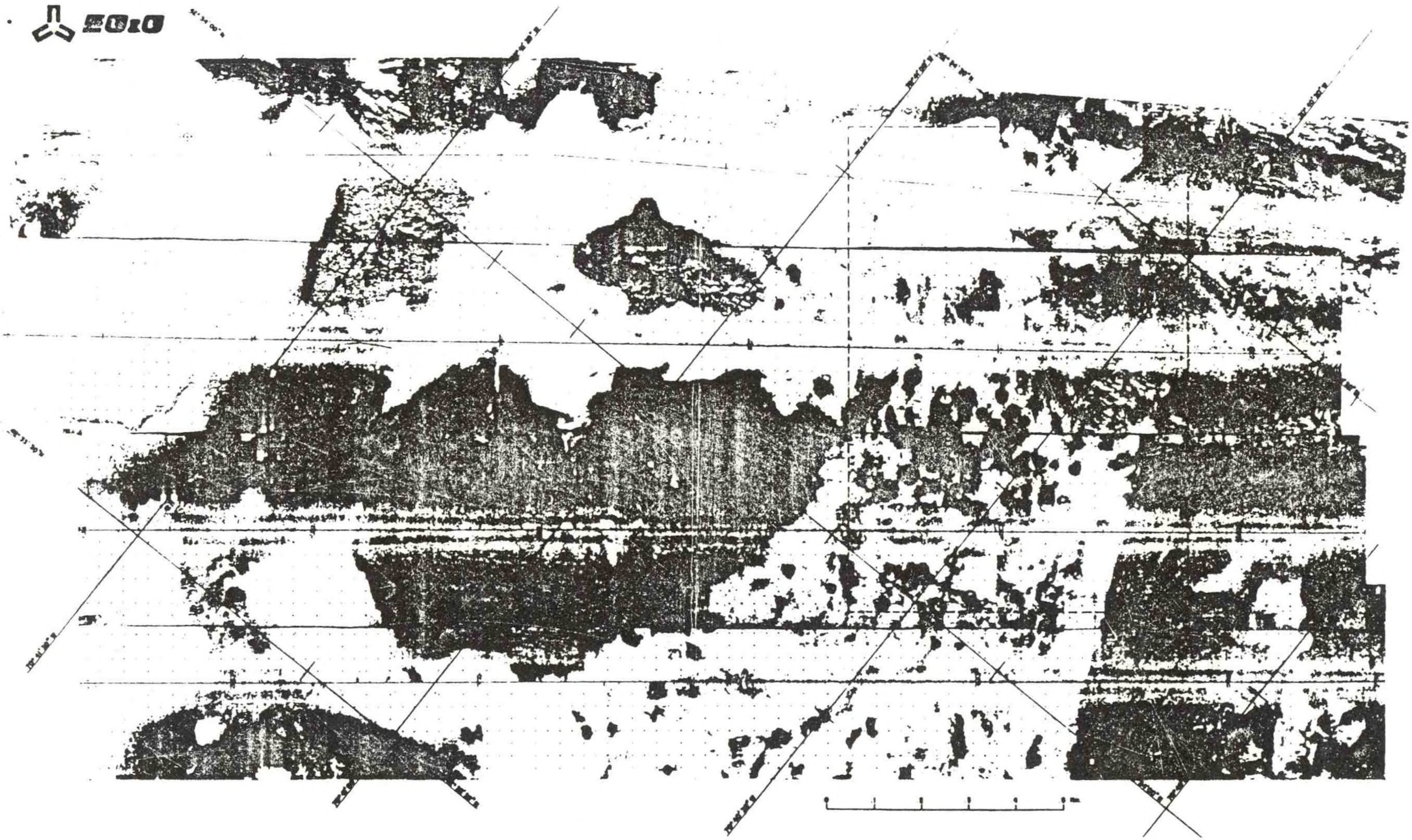
The tow fish must be used with the Modem; several standard lengths of double armored single coaxial tow cable connect the tow fish to the Modem. Tow fish power and control signals are generated in the Modem and transmitted digitally down the cable to the tow fish. All sonar and sensor data are digitized in the tow fish and transmitted digitally up the cable to the Modem.

The Master Unit processes and displays data directly from the Modem or from the digital tape deck. It applies all the necessary corrections to generate true plan view seafloor maps.

Other system configurations with various combinations of capabilities are available.

CONCLUSION

Microprocessor technology has provided the tools for more precise, more complete hydrographic data collection. Application of these tools by the hydrographic community should result in a better knowledge of the worlds coastal regions.



LOCATION:	MASSACHUSETTS COAST, OFF GLOUCESTER
TOTAL AREA:	3.75 SQ. KM.
NUMBER OF SURVEY LINES:	4
SYSTEM RANGE:	200 METERS EACH SIDE
SURVEY TIME:	2 HOURS AT 5 KNOTS

FIGURE 1

TYPICAL SEAFLOOR MAPPING SYSTEM MOSAIC

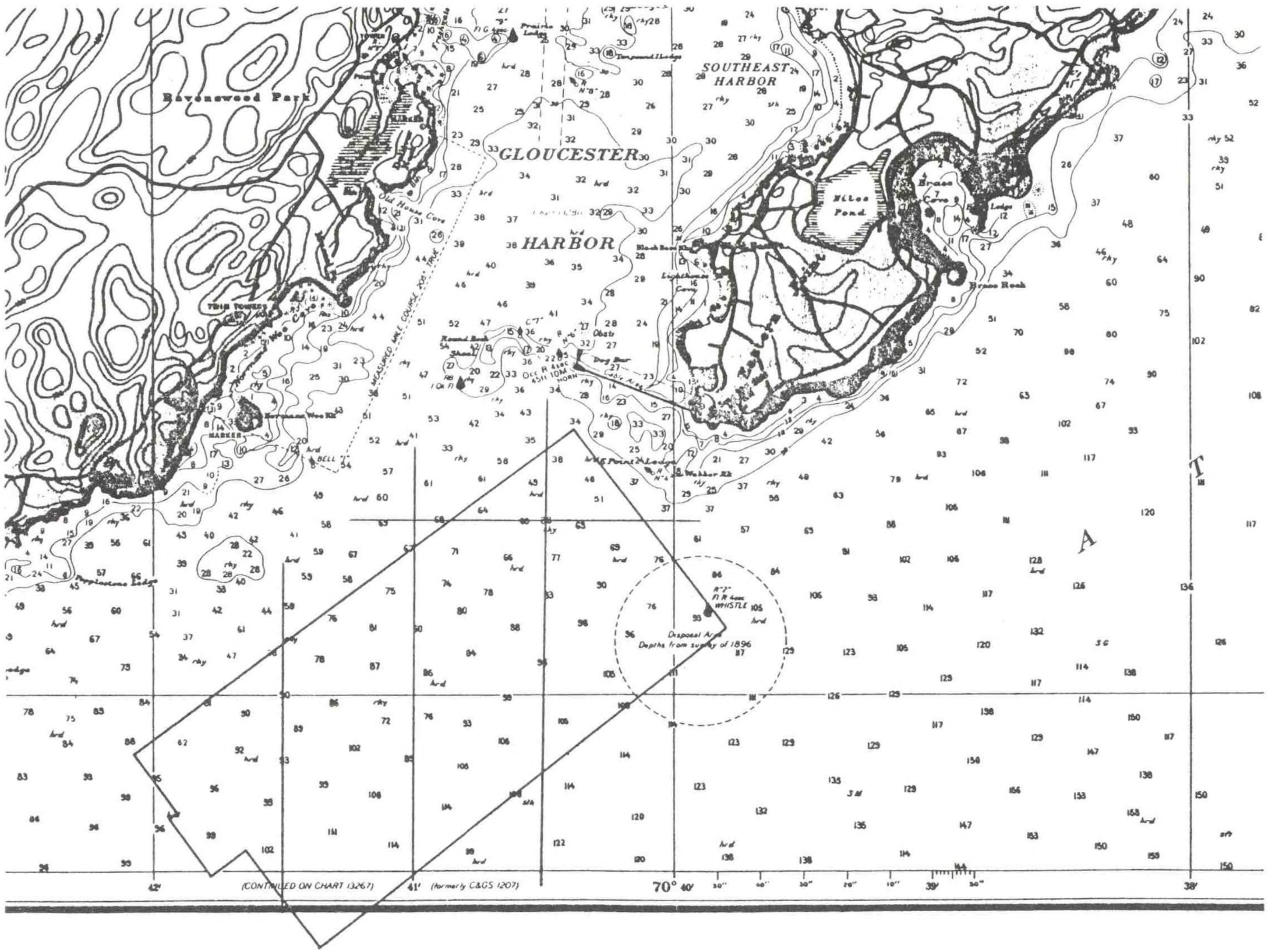


FIGURE 2

CHART OUTLINING AREA OF MOSAIC SHOWN IN FIGURE 1

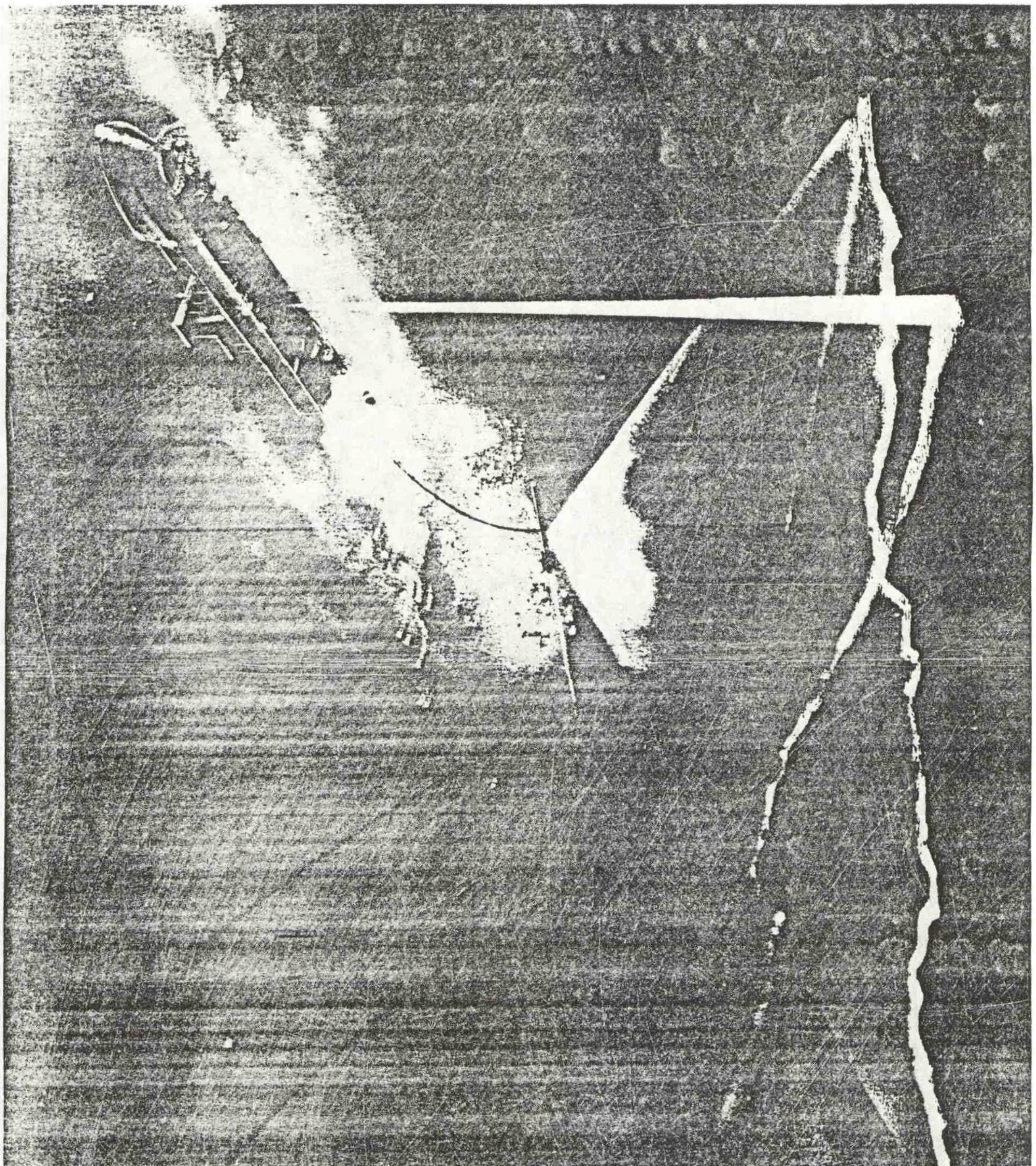
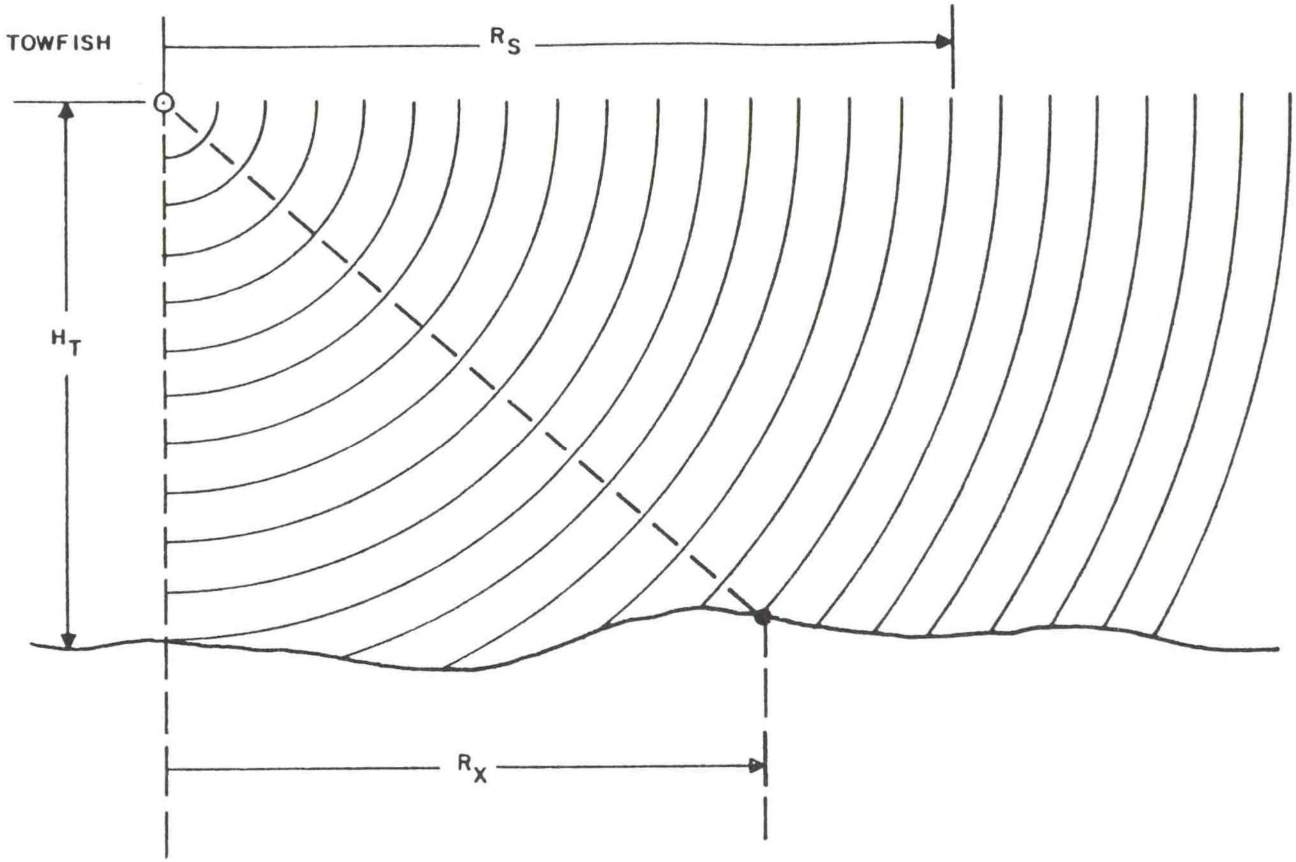


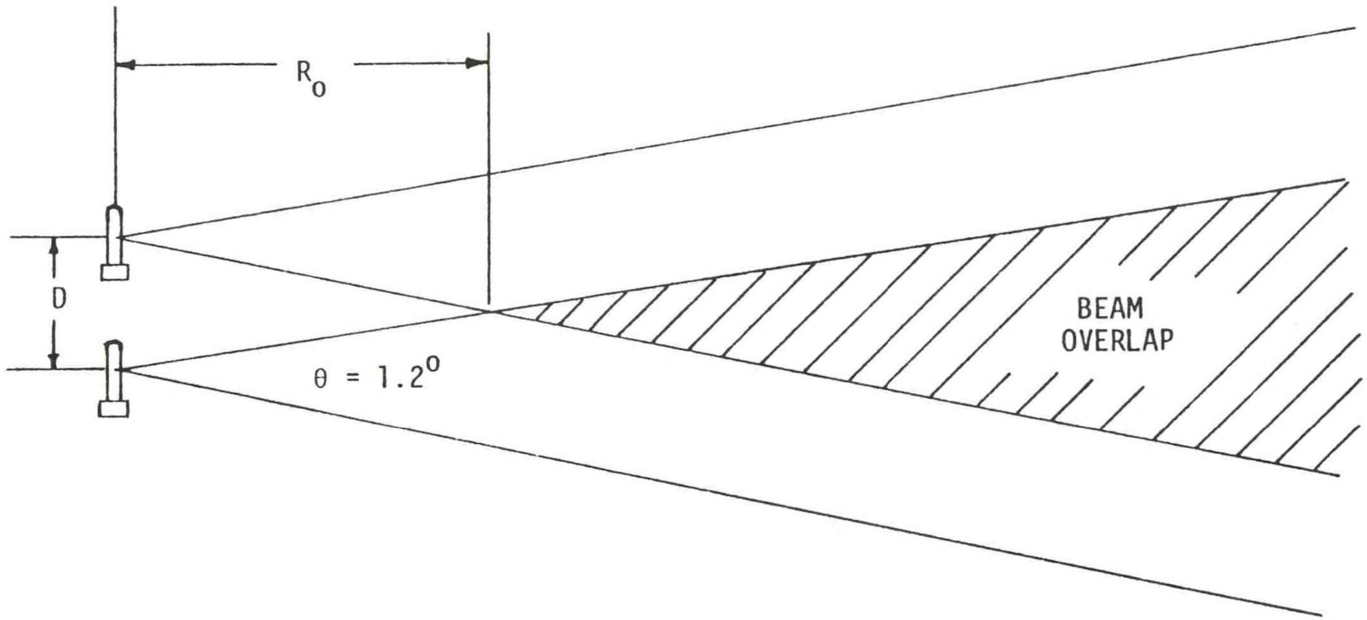
FIGURE 3
SIDE SCAN SONAR DATA COLLECTION



$$R_X = \sqrt{R_S^2 - H_T^2}$$

FIGURE 4

SLANT RANGE CORRECTION



Pulse Period, P (sec) = $0.0015\ R_m$

Travel per Pulse, $D = 0.5144\ V_k P = 0.00077\ V_k R_m$

Beam Spreading = $R\theta = 0.021\ R$

Range for No Overlap, $R_o = \frac{D}{0.021} = 0.037\ V_k R_m$

where

R_m = Selected system range in meters

V_k = Towfish speed in knots.

FIGURE 5
SPEED CORRECTION

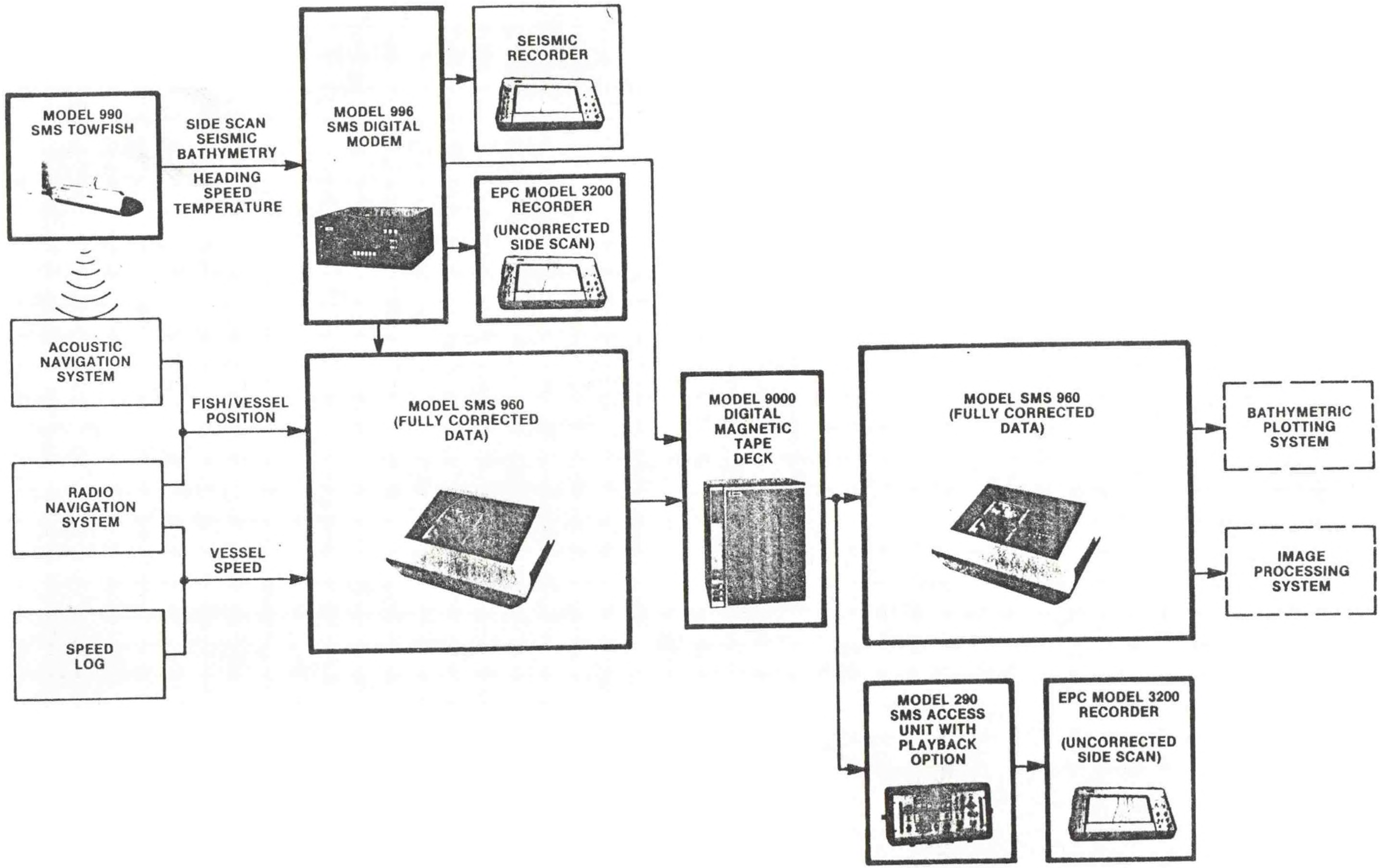


FIGURE 6

SMS SYSTEM COMPONENTS & CAPABILITIES

REAL-TIME ENVIRONMENTAL SURVEY TECHNIQUES

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ABSTRACT

Renewed interest in the effect of environmental pollution on rapidly occurring biological events in the marine environment has led to the development of continuous near-real-time analytical survey techniques. The techniques discussed have been used recently to study the close relationship that exists between the water "chemistry" and primary biological productivity. This paper describes electrochemical and spectrophotometric techniques which couple rapidly responding sensors to automated instrumentation in an attempt to correlate and understand the complete dynamic processes occurring in the marine milieu.

REAL-TIME MARINE ENVIRONMENTAL SURVEY TECHNIQUES

INTRODUCTION

Navy-used estuarine environments are monitored for water quality in compliance with environmental regulations and to ensure that marine facilities are maintained as viable resources for future generations. Such monitoring usually concludes in an environmental quality assessment, i.e., a value judgment on the relative health of a body of water and to recommendations which may lead to changes in Naval activities. These recommendations may be of considerable importance since changes in Naval activities and procedures often involve sizeable expenditures and may affect fleet mobility and operations.

Several difficulties often prevent the accurate determination of water quality. These include an overabundance of chemical, physical and biological variables, a lack of analytical sensitivity for possible crucial parameters, and the fact that the concentrations of the variables may change rapidly with both space and time, thereby introducing ambiguities. Present monitoring technology does not deal well with these problems because monitoring is conducted by spot sampling. Trace toxic constituents are generally analyzed, after pre-concentration, in laboratories far from the field. This procedure risks contaminating the sample, as well as changing the chemical form of the constituents. Over-all, sampling is too sparse to reflect the dynamics of the environment accurately. Similarly, laboratory analyses reported long after collection seldom represent the current state of the environment. Moreover, the belated availability of environmental information generally hampers the settlement of disputes involving the Navy and its operations.

In 1978, so as to improve and expedite the Navy's capability for marine water quality monitoring and environmental assessment, the Naval Ocean Systems Center, San Diego, initiated the Marine Environmental Survey Capability, or MESC program. The objectives of this program are to provide the Navy, through the various Engineering Field Divisions (EFD's) of the Naval Facilities Command, with a real-time or near-real-time environmental monitoring capability. Ideally, the MESC program ultimately will provide trained personnel and advanced instrumentation for the taking of environmental measurements at any U.S. Naval installation in the world on a "rapid response" basis. Accordingly, analytical results and data reports of surveys are to be made available to the agency requesting the MESC service with all expediency.

DESCRIPTION

Approach

Environmental measurements may be classified as being either "inorganic", i.e., the purely physical or physicochemical, such as those of temperature or copper concentration, or "biological", such as the measurement of chlorophyll fluorescence or of enzyme activity. Biological measurements generally provide a measure of the concentration of living organisms, as well as giving some information about their physiological state. The scope of the MESC program requires that biological measurements be made along with the inorganic since environmental judgments are always best made with respect to living organisms. Environmental considerations may range from the purely aesthetic to complex questions of physiology, population dynamics and economic impact.

The desirability of conducting surveys which produce sound data in real-time or near-real-time severely narrows the choice of methodology that can be used for this purpose (Zirino et al, 1978a). Additionally, the implicit requirement that environmental assessments be made before damages occur implies that measurements must be sensitive enough to detect toxic yet non-lethal concentrations of physiologically active constituents. The approach of the MESC program has been to package suitable, commercially available techniques so that they may be delivered to any world-wide Navy site and be made ready in short order. Furthermore, through the MESC's companion research effort, the Marine Environmental Quality Assessment (MEQA) program, specialized analytical systems have been developed and added to the suite of those which are commercially available. This effort has been directed towards the construction of highly sensitive, automated, electrochemical systems. What follows is a brief presentation of the packaging approach and of some of the analytical systems developed or currently under development.

The Marine Environmental Survey Craft

A suite of instruments may be arranged in several small packages or as a single large package, depending on the complexity of the task. Since an environmental assessment generally requires the measurement of many variables, all of the program's available instrumentation may be installed aboard the program's survey craft, also known as the MESC (Figure 1).

The MESC is a small (13m x 3.4m), self powered, transportable (by truck) houseboat of shallow draft, designed for use in well protected areas. The cabin, which measures 10m by 3.4m, is almost entirely dedicated to laboratory use. Within it are laboratory racks for electronic instrumentation, as well as 12m of "bench" space for wet chemistry and specialized equipment.

Figure 1
The Marine Environment Survey Craft (MESC) in San Diego Bay

The cabin can house six scientists plus the vessel's operator, who stands at a forward console. Power is provided by a Chrysler 318-cu. in. engine. Electrical power comes from a 6.3-kW Kohler generator and is regulated by a frequency converter. The MESC contains a metal-free seawater pumping system which directs fresh seawater to a permanently mounted all-Teflon sampling manifold. From this point, running seawater is available to different instruments on the vessel. Usually, the intake of the pumping system is connected to an Interocean Conductivity-Temperature-Depth (CTD) environmental probe which can be towed at any depth to 100m. A specially designed plane on the probe prevents "porpoising" and maintains depth.

On-board data recording and instrument control are provided in an in-house constructed data recording system based on the Motorola 6800 microprocessor. This Marine Environmental Data Acquisition System (MEDAS) features 16 channels of electrically isolated I/O, averaging and time delay options and autoranging.

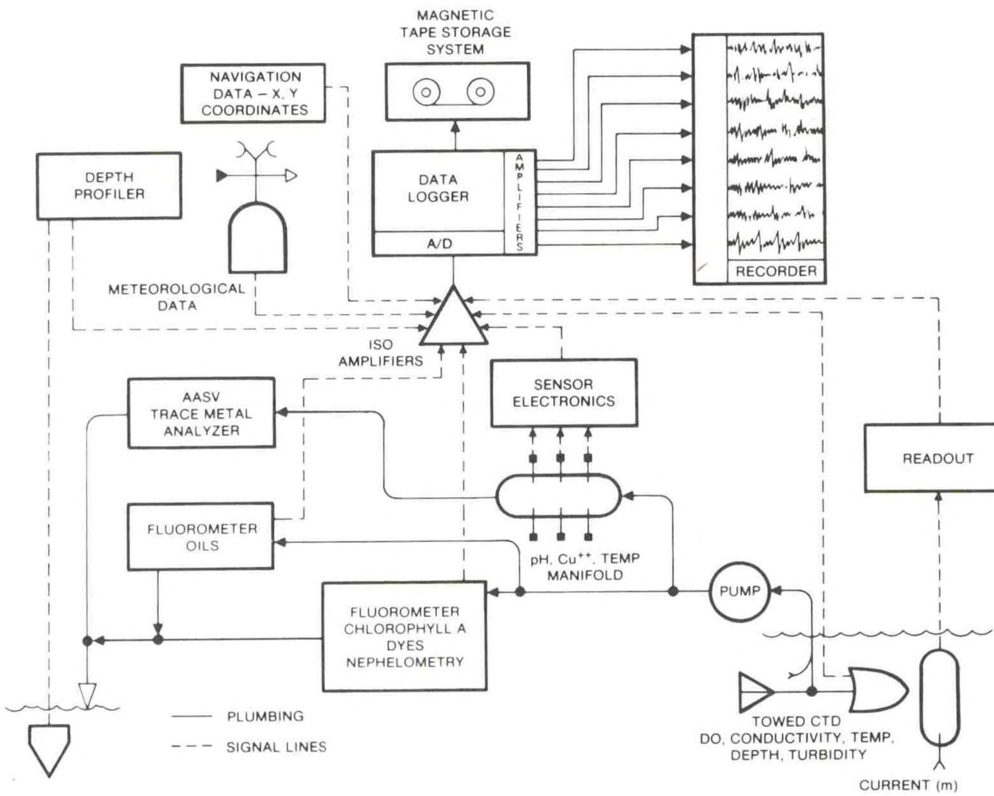


Figure 2
Schematic of MESC instrumentation package

Forty-word comments may be inserted at any point in the record. Data storage is on cassettes and final output is obtained on a laboratory-based minicomputer which provides listings, plots and data analysis capabilities. A Watanabe 8-pen recorder provides an immediate data record on the MESC. Table 1 shows a partial list of equipment either installed or available on the MESC. A more detailed description of the MESC and of it's capabilities is available in NOSC Technical Document 383. A schematic representation of the instrumentation package aboard the craft is shown in Figure 2.

Figure 3 shows 24 hours of data taken by the MESC while on station in the channel which connects San Diego Bay to the ocean. The figure shows plots of the continuous output of six of the sensors on board, including fathometer readings (the depth of the water from the hull to the bottom of the channel), in-vivo chlorophyll-a fluorescence (a measure of the phytoplankton concentration), Cu(II) ion selective electrode potential (a measure of the concentration of copper ion), conductivity (a measure of salinity), temperature and transmissivity (a measure of the number of particles in the water). Notable is the semi-diurnal periodicity visible in all of the records. The

Table 1. MESC instrumentation package

EQUIPMENT/ INSTRUMENTS	CAPABILITIES	FUNCTION
	Interocean CTD Environmental Probe	
	Temperature: -5° to 45° C (±0.02° C)	Continuous horizontal mapping and vertical profiles.
	Oxygen: 0 to 20 ppm (±0.2 ppm)	
	Depth: 0 to 100 m (±3%)	
	Salinity: 0 to 40 ppt (±0.02 ppt)	
	Turbidity: 0 to 100% T (±1%)	
	Pumped Flowthrough Seawater System	
A. Specific Ion Electrodes	pH: 0 to 14 (±0.01 pH units)	Continuous horizontal mapping and vertical profiles.
	Cu^{++}: 0 to 100 ppb (±5 ppb)	
	$S^{=}$ and other electrodes are under investigation	
B. Automated Trace Metal Analyzer	Cu: 0.5 to 100 ppb (±0.2 ppb)	Semicontinuous horizontal mapping and vertical profiles.
	Pb: 0.5 to 100 ppb (±0.2 ppb)	
	Cd: 0.5 to 100 ppb (±0.2 ppb)	
	Zn: 0.5 to 100 ppb (±0.2 ppb)	
C. Turner-Designs Fluorometer	Chlorophyll A: 0 to 1000 ppb (±0.005 ppb)	Continuous and vertical mapping of biomass.
	Rhodamine B: 0 to 1000 ppb (±0.01 ppb), circulation patterns	Dye studies to determine currents.
	Light scattering by particles	Nepheloid layers, turbidity.
	UV fluorescence: to 5 ppb oil in water	Oil detector.
	Discrete Instrumentation	
A. Cold Vapor Atomic Absorption Spectrophotometer	Mercury in seawater: 0 to 100 ppb (±0.002 ppb)	Detect mercury contamination.
B. Savonius Rotor Current Meter	Currents: 0 to 300 cm/s (±0.5 cm/s)	Mixing rates, currents.
C. Irradiance Meter	Relative irradiance (downwelling light relative to surface)	Estimate turbidity, light intensity.
D. Biological Sampling Gear, Scuba Equipment	Nets (fish, plankton)	Biological collectors.
	Corers	Biological collectors.
	Dredge	Biological collectors.
	Refrigeration/freezers	Storage of samples.
E. Data Logger	Hewlett-Packard HP21MX system with HP 2645 terminal	Data acquisition.

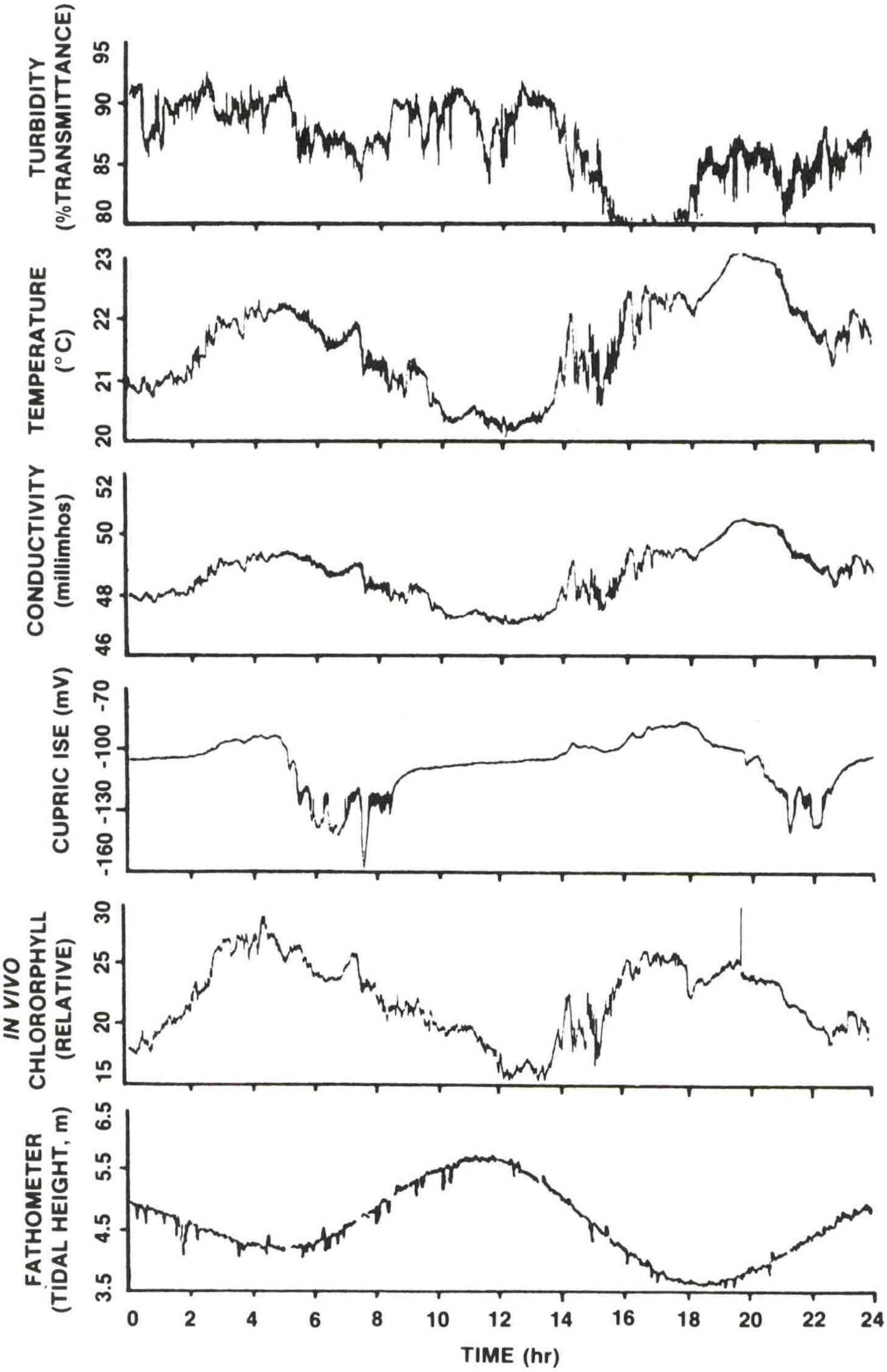


Figure 3
24 Hours of continuous data recorded at a station in San Diego Bay

fathometer plot shows that the changes in the other parameters are in fact related to the action of the tides. At low tide, chlorophyll-a, temperature, conductivity and Cu(II) concentration increase (for the copper probe, more positive values indicate a higher Cu(II) concentration). On the other hand, at high tide the sensors show lower values, indicating that the bay water which moves past the MESC during ebb is warmer, more saline and richer in both phytoplankton and copper than the oceanic water. These observations are consistent with the view that San Diego Bay is a Mediterranean-type basin which supports a considerable amount of commercial and Naval traffic. Presumably, the high copper content of the bay water is attributable to the leaching of copper from the ships' anti-fouling paints, which may contain 50% or more copper.

Contrary to conventional wisdom, the higher copper content of the bay water does not lead to a suppression of algal growth, manifested here by the high fluorescence. However, a careful study of this area by Krett-Lane (1980) has shown that the predominant plankters present in the high copper water belong to copper resistant genera. Also, the diversity of phytoplanktonic species which populate the polluted water is less than that of the incoming ocean water. This observation is a good example of the subtle environmental effects which can occur in a burdened, but sublethal, environment. While a cursory or purely chemical environmental assessment would have concluded that the higher copper content has no effect on the biota, a more detailed microscopic examination reveals that environmental changes have occurred. These findings are in agreement with the results obtained by Thomas et al (1977), who studied the effects of sublethal copper toxicity in large, deliberately polluted seawater enclosures. The observations made above indicate the desirability of using a multidisciplinary, multiprobe approach for accurate environmental assessments.

FINDINGS

The Cu(II) Ion Selective Electrode and Anodic Stripping Voltammetry

The Cu(II) ISE has found considerable application in MESC programs, both in the making of surveys and for monitoring the release of copper from ship hulls which occurs during <u>in-situ</u> hull cleaning. This electrode is an extremely sensitive device whose electrochemical potential changes when exposed to Cu(II). Although it is available commercially, its use generally is limited to monitoring copper in fresh waters, a medium in which this electrode behaves ideally. Its routine use in salt water is a NOSC application. It was possible because NOSC personnel had already developed an automated voltammetric method for the

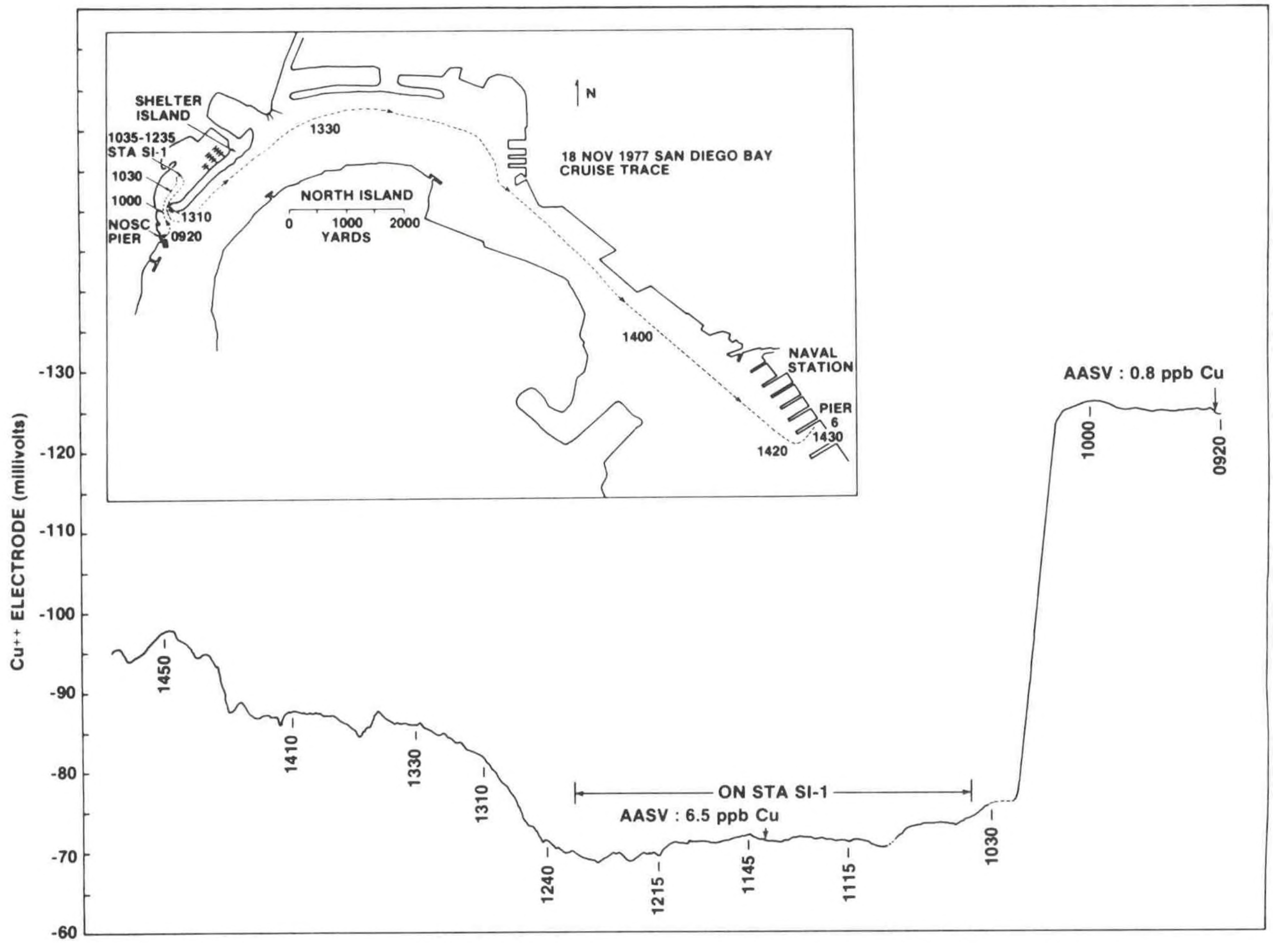


Figure 4
Trace of Cu(II) ion selective electrode in San Diego Bay

measurement of copper in marine waters (Zirino et al 1978b; Zirino and Lieberman, 1975; Lieberman and Zirino, 1974). The simultaneous use of both the ISE and the voltammetric sensor clearly showed that the potentials generated by the ISE corresponded to copper concentrations as measured by voltammetry (Zirino and Seligman, 1981). Figure 4 shows a trace of ISE potential vs. time (or distance) obtained as the MESC transited in San Diego Bay from the shipping channel into a narrow inlet tightly occupied with commercial and pleasure craft. Prior to entering the inlet, the electrode potential read approximately -130 mv vs. a reference electrode. This corresponded to approximately 0.8 ppb (parts/billion) as measured by the voltammetric technique. As the MESC entered the inlet, the potential increased over a short distance, finally reaching a plateau at -75 mv, which corresponded to 6.5 ppb copper. When the MESC left the inlet and re-entered the bay, the potential again decreased, corresponding to copper concentrations of about 2 to 3 ppb, in agreement with other observations previously made

(Kenis et al, 1978). Here, the advantages of making measurements by more than one technique are illustrated. The discrete method offers good calibration but poor spatial resolution. The continuous technique, the Cu(II) ISE, offers resolution but no calibration. Using both together optimizes performance.

The field voltammetric technique mentioned above also illustrates some of the principles employed in the MESC approach and perhaps merits some additional comment. The measurement is based on the method of anodic stripping voltammetry (ASV) now used in most analytical laboratories. In the NOSC system, as with all ASV techniques, seawater flows past a mercury surface upon which a potential has been impressed. Trace metals in the seawater, under the applied potential, amalgamate with the mercury and accumulate therein. Reversing the potential releases (ionizes) the metals accumulated in the mercury. The current that flows during ionization is proportional to the concentration of the metal in the seawater. Typically, a plot of current vs. ionization potential will produce several sharp peaks against a neutral background. The voltammetric analysis of trace metals in natural seawater has been discussed in detail by Zirino (1981).

In the early 1970's it was realized that if electrodes were shaped into tubes the entire analysis could be developed around a stream of seawater flowing in a tube. This had the advantage of providing a "closed" system, even in a field environment. A system closed to airborne contamination is essential to trace analysis. Also, it was appreciated that any analysis of seawater could be packaged and automated simply by using tubing, pumps, valves and sensors in an appropriate configuration. Automation and readout could be provided by microprocessor controlled circuitry. A schematic illustration of the automated ASV cell is shown in Figure 5. It functions as follows: a pump taps into a flowing stream and fills a reservoir. A second pump then guides the stream through the electrodes. The same pump also coats the tubular graphite electrodes with mercury, following a re-setting of two valves. Finally, a separate pump makes additions of a standard solution of metals to the reservoir and the cycle is repeated. The system is very sensitive and is able to measure Cu, Zn, Pb and Cd in seawater to better than 0.1 ppb. The latest version of this device is microprocessor controlled, carries out analyses unattended and prints out the concentrations of the metals analyzed (Clavell, 1980). Zirino et al (1978b), were able to demonstrate the effectiveness of the system during several surveys of San Diego Bay. Copper and zinc were not detectable at eleven locations outside of the bay. Similarly, Cd and Pb in the surface waters outside of Pt. Loma were at the limit of detection of the instrument. However, all four metal concentrations increased as measurements were made in the channel and in the bay proper. Overall, it was observed that the four trace metals increased with distance from the center of the channel and were

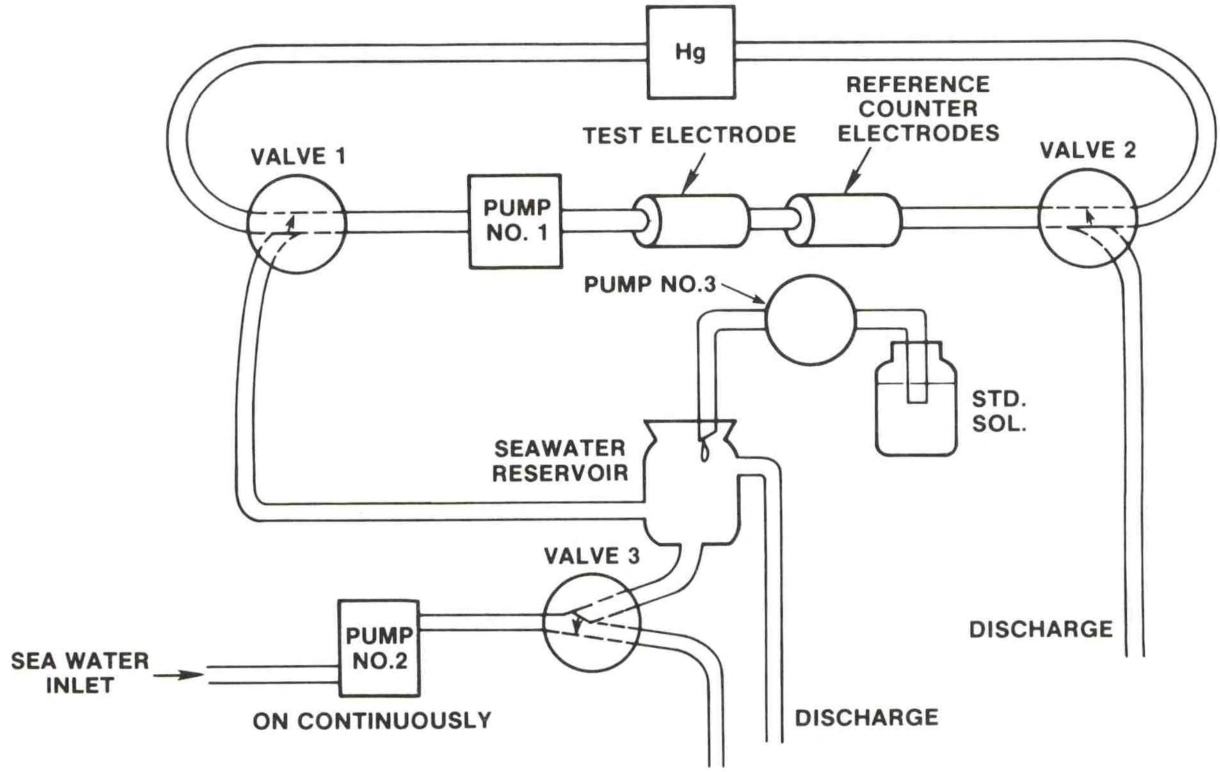


Figure 5
Flow-through cell for anodic stripping voltammetry (ASV)

highest in concentration along the shore, in baylets with the poorest circulation, and high density moorings.

CONCLUSIONS

Future Work

At NOSC, work is underway on an instrument which may characterize organic compounds found in seawater and simultaneously provide a real-time identification of the plankton. The underlying principle of the technique is that many natural organic compounds, as well as microscopic plants, fluoresce when excited with an ultraviolet light. Figure 6 shows emission peak wavelengths for some environmentally significant compounds. It can be seen that natural organic compounds and petroleum products fluoresce in the blue portion of the visible spectrum while the photosynthetic pigments fluoresce in the red. However, there is considerable spectral overlap among similar substances. Nevertheless, fluorescence already is used widely to measure oils (and oil spills) in seawater and to measure planktonic abundance. Recently, Yentsch and Yentsch (1979) have indicated that individual phytoplankton populations may be

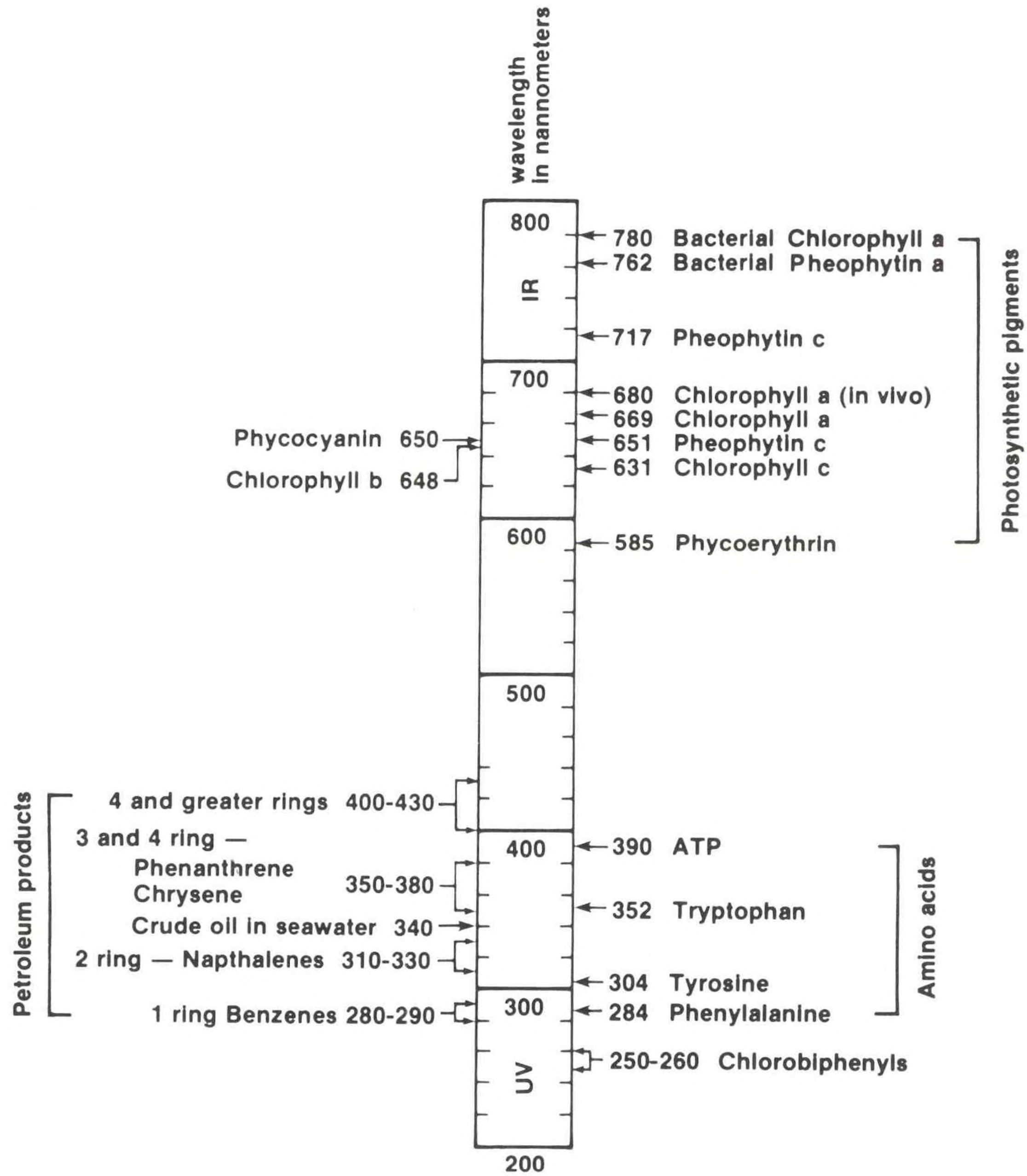
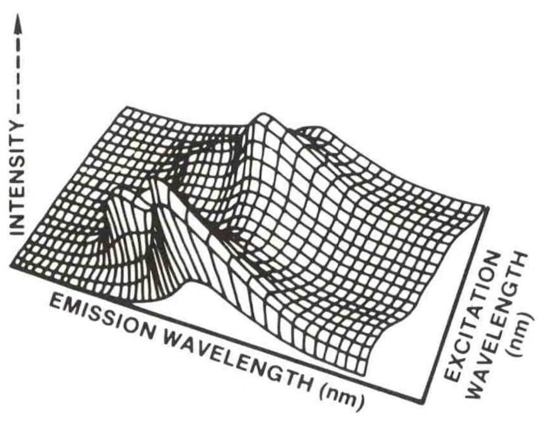


Figure 6
Fluorescence emission peak wavelengths for
some environmentally significant organic compounds

characterized by the use of excitation and emission spectra. During the same period, Warner et al (1979) have developed a three-dimensional, rapid scanning fluorimeter which promises greater resolution in the characterization of planktonic organisms and dissolved organic materials. For this system, a plot of the intensity of fluorescence as a function of the excitation and emission energies results in a three-dimensional plot. When the intensities are contoured, patterns are obtained which resemble fingerprints. The work at NOSC aims to study the fluorescence "fingerprints" of the surface waters of the coastal and open ocean by building a flow-through shipboard instrument of sufficient sensitivity to detect groups of organic substances in real time.

The instrument of Warner et al (1979) has been set up at NOSC. It features a 150-watt xenon arc source, two J-Y Optics Model UFS 200 polychromators and a Princeton Applied Research Optical Multichannel Analyzer (OMA) system with a PAR model 1254 silicon intensified target (SIT) multichannel detector. The system is controlled by a Hewlett-Parkard 21 MX minicomputer and spectra are displayed for analysis on an AED 512 graphics terminal. Alternatively, plots are drawn with a Cal-Comp Model 565 plotter. Figure 7a shows a three-dimensional display of the fluorescence of a mixture of chlorophyll a and b obtained with the NOSC system. Figure 7b shows a contour map, or "fingerprint", of this mixture. The system as presently configured is not sufficiently sensitive for the direct analysis of seawater. However it is hoped that improvements in excitation source and detector ultimately will provide the required sensitivity.

Because the interactions between toxic trace metals and the organic constituents of seawater are very complex, correct environmental assessments require that inorganic and biological constituents be measured together, in real-time, if possible. The NOSC program represents the first few steps in pursuit of that goal.



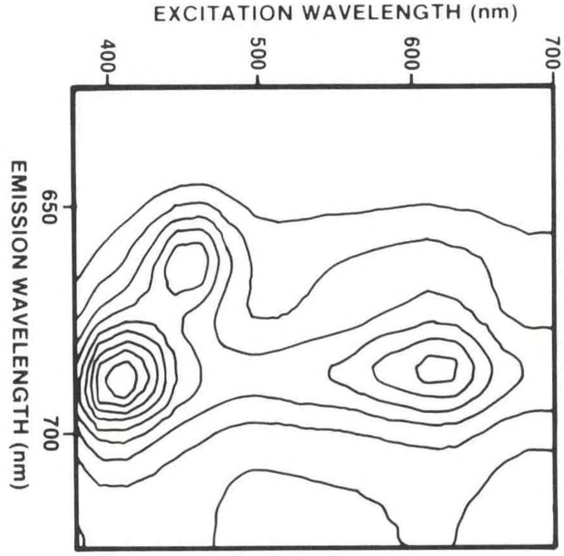


Figure 7
Figure 7a (left) is a three-dimensional display of the fluorescence of a mixture of chlorophyll a and b. Figure b (right) is a topographic display of the same components

ACKNOWLEDGEMENT

The work described herein is the composite effort of several scientists, among whom C. Clavell and P. F. Seligman have made outstanding contributions. S. Yamamoto and S. Hurley have provided guidance and encouragement over the life of the MESC program. This work was sponsored by Naval Facilities Command.

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SELECTED EXTRACTS FROM RECENT ACTIVITIES OF THE MARINE BOARD

by

Jack W. Boller
Executive Director, Marine Board

Summary

The purpose of this paper is to provide extracts from four reports that cover subjects of interest to the Marine Facilities Panel of the U.S./Japan Cooperative Program in Natural Resources. These are: Problems and Opportunities in the Design of Entrances to Ports and Harbors, Research in Sea Ice Mechanics, Safety and Offshore Oil, and Use of the Oceans for Man's Wastes. In addition, a short description is also provided of selected current projects in arctic seafloor engineering, design criteria for dredged depths of channels, OTEC, and the collision of ships with bridges.

This paper describes a study of the U.S. National Research Council, which was being conducted at the time the paper was written. The author was the Chairman of the study. The views expressed are those of the author and are not necessarily endorsed by the committee or the National Research Council.

Background

The Marine Board

The Marine Board is a unit of the Commission on Engineering & Technical Systems in the National Research Council. First organized in 1965 as the Committee on Ocean Engineering of the National Academy of Engineering, it was expanded and renamed the Marine Board in 1970. The Board's work is sponsored by various government agencies, including the Departments of the Army, Navy, Commerce, Interior, State, Transportation and Energy, and the National Science Foundation.

The Board initiates and provides on request assessments of the nation's technological capability to accomplish its objectives for the oceans; evaluates the safety of coastal and offshore operations; projects developing technological needs and how they might be met; and fosters exchange of information and collaboration in the international community of ocean science engineers. The board serves as the U.S. National Committee of the Engineering Committee on Oceanic Resources, an international non-governmental engineering organization on ocean matters.

The Board's ocean engineering activities are conducted in four broad program areas:

Resource Development--the technical support, information, engineering resources, manpower, and training needed to assure responsible development and use of ocean-based resources and to support the implementation of the government's regulation responsiblities.

Coastal Use--the engineering support, technical knowledge, manpower and capabilities needed to permit balanced and continued use of ports, marine systems, and other ocean uses such as recreation and waste disposal.

Support of Science--engineering aspects of equipment and systems, such as data-gathering buoys and geophysical coring units, and engineering information acquisition that supports scientific investigation of the ocean.

National and international exchange of information and technology on ocean engineering.

Problems and Opportunities in the Design of Entrances to Ports and Harbors[1]

The Marine Board has been concerned for some time that the rapid changes in naval technologies and social patterns, and the intensification of discernible trends affecting the design of ports and harbors have not been met with corresponding alacrity and intensification of efforts to gather crucial data, formulate needed analytical techniques, or develop the processes for synthesis of all significant factors in a rational set of procedures for design. This situation can be seen in sharp focus at the entrance to a port or harbor, a critical area for navigation and traffic control that most clearly manifests the complex interactions of physical forces, vessel traffic, and other factors with the results of the designer's work. This area also seems a convenient locus for investigating the engineering implications of designing ports and harbors to meet several objectives; among them, safety of the public, of navigation, and of the marine environment, increased economic activity and accommodation of the vessels of today and tomorrow.

Among the responsibilities of the Marine Board under its charter is to undertake, on its own initiative, investigation of issues that lie outside the compass of any single agency of government. Accordingly, the National Research Council appointed a panel at the request of the Marine Board to investigate problems and opportunities in the design of entrances to ports and harbors under the board's direction. The panel planned and convened an interdisciplinary meeting of about 50 experts to exchange information on these problems and opportunities, and to identify the problems most requiring solution.

The participants represented a great many views and interests in ports and harbors--those of research and design engineers, marine scientists and environmentalists, naval architects, port directors, dredgers, ship operators and captains, harbor pilots, salvors, authorities on modeling and simulation, representatives of the U.S. Coast Guard, U.S. Army Corps of Engineers, National Oceanic and Atmospheric Administration, and the U.S. Navy. An interesting result of bringing together such distinctly different views and interests was the enthusiastic exchange of information and experience and the questions and answers of the participants that gave ample evidence of the need most often expressed in the meeting: the need for methods of analysis and decision making that encompass necessary engineering and functional information, that allow full consideration of fundamentally different concerns and that instantiate man's long experience with ports and harbors.

In iterative and collaborative workshop sessions, participants in the meeting agreed that the most important problems requiring resolution in the design of entrances to ports and harbors are the following, in order of urgency and consequence:

- Improved and validated models for the prediction of horizontal and vertical ship movements in the particular conditions of harbor entrances
- Use of systems analysis in the design of harbor entrances
- Reliable and economical measurement, reduction, presentation, and storage of environmental data
- Cost-effective models of the physical environment for prediction of natural conditions and forces, and changes caused by human activity
- Improved procedures for prediction of shoaling rates and patterns, including development and verification of appropriate field methodologies
- Improved entrance-channel design and operating criteria
- Development of accepted standards and uniform methods for measuring and assessing navigability of harbor entrances
- Quantitative definition of the needs of mariners
- Review and reform of decision-making processes for port and harbor projects

- Evaluation of the importance of natural resources for balanced decisions about harbor siting and related matters, and increased attention to the restoration of natural habitats.

Research in Sea Ice Mechanics[2]

An understanding of sea ice mechanics is essential to the design and integrity of cost-effective structures and fundamental to operating in the polar oceans. In recognition of this, the board appointed the Panel on Sea Ice Mechanics to investigate the available information and research needs in this area. The committee defined the scope of its interest to include the whole state of knowledge of sea ice mechanics, but to stop short of in-depth analysis of physical and environmental forces, such as wind and waves, that directly affect the mechanics of sea ice.

The panel chose to limit consideration of research needs to the mechanics of ice masses on the scale of the engineered structures that could be introduced into the natural icescape. These may range in size from a few meters to several hundred meters or longer in the case of causeways. The panel did not consider mechanics on such a large scale as tens of kilometers. The geophysical motions of sea ice, as driven by winds and ocean currents, that would figure in such large-scale studies are important in determining the loads ultimately imposed on engineered structures in a sea-ice environment. Nevertheless, an examination of the mechanics of sea ice and its oceanic and atmospheric driving forces would involve an investigation considerably different in character and would emphasize other disciplines. Likewise, the other extreme of spatial scale, the behavior of single crystals of sea ice, is not addressed in this study, because such an investigation would not be linked directly to engineering activities.

While many of the engineering problems posed by river and lake ice are similar to those of ice mechanics at sea, the panel chose to address basic relationships not made more complex by the variations attending fresh and salt water or the addition of other constituents to the sea and ice environment. In regard to the snow-ice (or soil-ice) problems that can be encountered offshore, the panel chose to treat these as subsets of ice types.

Sea ice mechanics is concerned, in general, with the interaction of environmental forces of oceanographic and meteorologic origin with an ice cover at sea, and the manner in which such forces are transmitted to other ice masses and eventually to man-made structures. Important aspects of the subject include the mechanical origins of deformation features, such as cracks, leads, pressure ridges, and rubble fields, and the mechanical properties of ice sheets and the bulk properties of large ice masses.

The interaction of the ice cover with fixed and moving structures was identified by the panel as an important subject for research. Important ice types include sheet ice, ridges, rubble, fragmented covers, frazil ice and brash ice. Additional field observations, analytical studies, and laboratory model studies are needed to better understand the formation, mechanical behavior, and interaction of ice aggregates with engineering structures.

Sea ice is a complicated material, consisting of crystals of pure ice, solid salts, and liquid-filled brine pockets. The mechanical properties of sea ice have been studied for many years, but our understanding is still largely qualitative. Most small-scale test results are inconsistent and gaps remain in the data. Large-scale properties have proved difficult to measure. Scaling factors for model tests have not been well defined.

The panel recommends that laboratory tests be conducted to obtain mechanical characteristics of sea ice with appropriate internal states. Experiments should be conducted to determine the large-scale mechanical characteristics of natural sea ice cover of known internal state, and theories should be developed to provide satisfactory properties essential for engineering design.

The interaction of sea ice types with fixed and moving structures is fundamental to the basis of the engineering design and operation of offshore structures. The mechanical behavior of sea ice aggregates, as they interact with structures, is not well understood. Therefore, the panel recommends that further knowledge of the mechanical behavior of sea ice aggregates be obtained through field observations. Laboratory studies should be conducted to better understand the formation and interaction of ice aggregates with engineering structures. Analytical studies combining field observations and laboratory experiemtns with the basic laws of mechanics should be conducted to develop theoretical models of the mechanical behavior of various ice types.

Much of our understanding of ice processes and the interactions of ice and structures will be derived from small-scale model tests. The panel recommends that a systematic research program be conducted to investigate the properties of different materials for modeling ice such as synthetics, doped ice, or paraffin. The feasibility of using model ice to determine the large-scale mechanical properties of ice features also should be investigated.

The panel concludes that a systematic approach to sea ice research at the national level will require an integration of government and private planning, long-term research, contractual commitments, and the interpretation of research missions in relation to national needs. The government needs to increase its sea ice research efforts by stating a clear commitment to their pursuit, coordinating the activities of the several interested agencies, promoting the dissemination of research results, and attracting more investigators into the field.

Safety and Offshore Oil[3]

Long a concern of the Marine Board, the safety of offshore oil and gas operations has come forcibly to public attention with the loss of the semisubmersible drilling rig, the Ocean Ranger. The Ocean Ranger--the world's largest semisubmersible drilling rig--capsized and sank in a storm on the North Atlantic on February 15, 1982, taking 84 lives. Although waves and wind were severe at 40 to 50 feet and gusting up to 80 miles an hour, the Ranger had been designed to withstand higher waves and stronger winds. The precipitating cause of the accident seems to have been in the ballasting system--an engineered system. As a U.S. Congressman noted at a special hearing, "This kind of tragedy is intolerable in light of the fact that advanced design, engineering, and construction techniques were used to build this rig." The following section of the Marine Board report, Safety and Offshore Oil, is extracted for information in this regard.

Mobile Offshore Drilling Units. MODUs are used primarily as a base of operations for exploratory drilling and for well workovers. Types of MODUs include submersibles, floaters, semisubmersibles, and jack-ups. While all these may carry similar kinds of drilling equipment, their hull configurations and consequent diverse maritime capabilities suit them for distinct applications.

Submersible drilling units usually consist of a barge hull that is floated to the drilling location and then sunk to the seafloor by ballasting. This technique is limited to water depths that permit the upper structure of the barge to be high enough above water for drilling operations to be conducted. Submersible barges were used extensively in drilling the first shallow water wells in the Gulf of Mexico. Submersibles have only limited application to the OCS, however, because they are confined to shallow water operations. As a result of this lack of versatility, submersibles have been largely replaced by the jack-up type of rig discussed later in this section.

The term "floaters" is used in this report to refer to drilling rigs mounted on ship-shaped hulls and floating barges. Floating drill barges are towed on location and then moored with anchor and chain systems.

Although they can be used at any depth at which they can be efficiently moored, out to 600 feet or more, the barge hull shape has poor motion characteristics. Therefore the preferred location for floating drill barges is in protected waters.

The lines of a drillship are similar to those of traditional merchant ships. Major design differences include the moon-pool, an opening mid-ship through which drilling operations are conducted, and ballasting to accommodate the installation of the drilling rig above the moon-pool. Drillships are self-propelled and therefore capable of moving from one drilling location to another without assistance. Positioning is accomplished by either a mooring system of anchors and chains or a dynamic positioning system. This latter system employs a series of beacons, sensors, and thrusters to detect and compensate for movement. Drillships have already been used in almost 5,000 feet (1,500 meters) of water. Developments are continually under way to increase these limits.

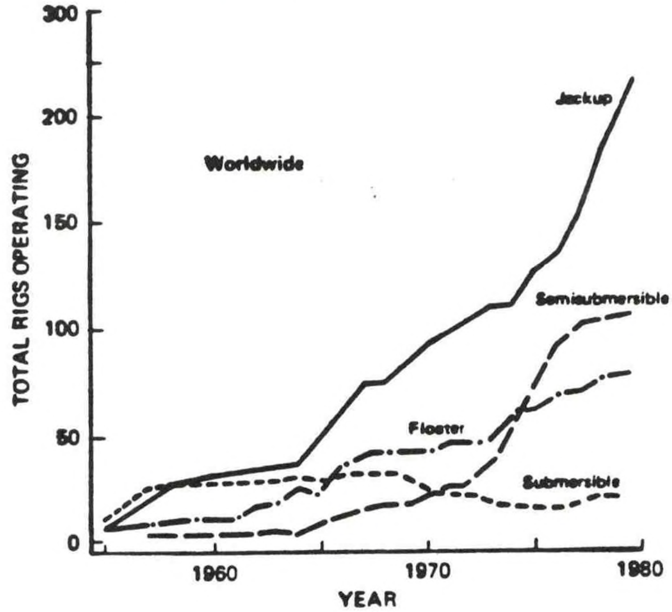
Semisubmersibles consist of a platform deck supported by columns that are connected to large underwater displacement hulls or caissons. Once on station, the lower portions of the rig are flooded so that the major buoyancy members are located beneath the water surface and away from surface wave action. Semisubmersibles may or may not be self-propelled. They provide relatively stable drilling platforms that can function under more severe sea and weather conditions than the others. On location, they are held in place by a mooring system of cables and anchors or by a dynamic positioning system consisting of computer-controlled propulsion units. Semisubmersibles share the station-keeping limitations of floating drillships. Mooring systems tend to become unwieldy at great depths; dynamic positioning systems can theoretically be used at great depths, but tend to be practically limited by current and wave height.

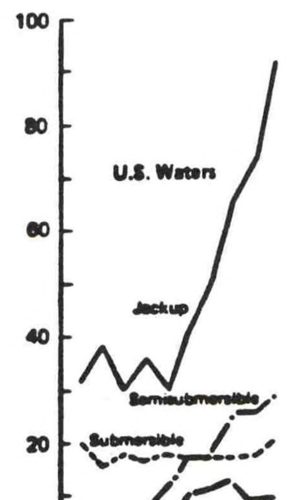
Jack-up rigs are platforms with legs that can be moved up and down. After lowering a structural foundation to the seafloor and extending the legs, the platforms can be elevated above the water to provide a temporary bottom-standing platform. The foundation systems used are of two types: three or more individual footings each supporting one foundation leg or column or a single mat providing combined support to three or more legs. Maximum practicable water depth for jack-ups is about 300 feet, although most units operate in shallower waters.

Exposure to Risks. During the last 25 years, the worldwide fleet of MODUs has grown by an order of magnitude. Most of the growth has occurred in the last 15 years and has been concentrated in the jack-up and semisubmersible types of rigs. Figure III-19 illustrates this growth both worldwide and for the U.S. fleets. In late 1979, there were approximately 450 MODUs worldwide and about 148 in U.S. waters. The U.S. fleet is about one-third of the worldwide total.

Mobile Offshore Drilling Units

Growth of the Worldwide and U.S. MODU Fleet





Source: Worldwide - Modified after Huff, John R., "Study Analyzes Offshore Rig Casualties," Oil and Gas Journal, Vol. 74, November 29, 1976.

U.S. Waters - Committee on Assessment of Safety of OCS Activities; data from Offshore Rig Data Services, Inc.

Figure III-19

Each of the MODU groups has unique characteristics when moving, setting up, or operating on location, which strongly influence the risks commonly experienced by each group. Some of the more significant of these characteristics are described below. A separate section comments on risks of blowouts, fires, and collision damage-risks to which all OCS installations are more or less equally exposed.

- Jack-ups The extreme transformations that jack-ups must go through--between their bottom-resting state, with legs down, and their floating condition, with legs up--constitute a severe design requirement that must be met with compromise. These hazardous transformations are regularly and frequently experienced by jack-ups as they move on or off location, changing from a static to a dynamic condition or vice versa. Irregular development of or release from bottom support, resulting in unequal vertical movements in the foundation system, can lead to both structural and mechanical failures in the support system and, progressively, to overturn or capsize of the unit.

  Jack-up foundation systems are dimensionally fixed, except for depth of penetration below the seafloor, and are not custom fitted to a specific site. Definitive information on the engineering properties of sub-bottom materials is not always available for a proposed jack-up location. With footing-supported jack-ups, preloading of the foundation system by applying and then removing water ballast is relied upon to achieve a margin of safety under operating loads. Preloading is not practiced with mat-type jack-ups. Despite the uncertainty in actual soil conditions at some sites, very few accidents on location have been attributed to soil bearing failure after jacking up and preloading were completed.

  One type of accident that constitutes a unique risk for mat-type jack-ups, but which is not noted in the available summary accident record, is sliding. At least five instances have occurred during hurricanes of lateral movements of 2 to 100 feet, resulting in slight rig damage in only one case. Lateral movements are also experienced at times during storms of less than hurricane intensity. Records of such movements apparently are not available, but the recent (August 1980) loss of the HARVEY WARD near the mouth of the Mississippi, several hundred miles from the center of hurricane "Allen," may be such an occurrence.

  Possibly the major risk with jack-ups occurs during their transit periods while they are afloat and under tow. Their tolerance of heavy seas is low in these conditions.

- Semisubmersibles Semisubmersible rigs enjoy a good safety record. A very high percentage of accidents that do occur to them, whether on location or in transit, involve structural cracking. Units of this type are designed to operate in very rough waters. The major concern under these conditions is the fatigue life of welded joints in a corrosive environment.

  It is of interest that a number of major accidents have involved major cracking or structural damage that was detected and repaired. While the cost of repair exceeded one-half million dollars, there apparently was no consequential loss beyond that of repair. Occurrences of undetected structural cracking leading to collapse or capsizing are few in number but can be disastrous when they do occur; one of the worst was the loss in 1980 of a quarters platform in the North Sea with 123 casualties.

- Floaters Drillships and barges also have excellent overall safety records. There is only a single loss recorded while moving. The major loss category, except for an equal number of blowout accidents, has been storm damage on location.

- Submersibles Since they are primarily intended for use in very shallow waters, submersibles represent a minor part of the MODU fleet, and the accident record is sparse. Unspecified storm damage on location is the most frequently reported accident. As in the case of mat-type jack-ups, submersibles are also subject to sliding under storm loading, with consequent hazard to wells and other installations but with only limited risk of major damage to the drilling unit itself.

The Safety Record From 1955 to 1980, MODUs suffered 86 major accidents, including 42 losses, from environmental or operational overloads (worldwide). Table III-31 classifies these accidents, by activity, weather, and type of rig. Of the 86 major accidents 60 (70 percent) involved jack-up units, about half of which were completely lost. A breakdown of the data by general cause and activity indicated that the U.S. record and the worldwide record were similar. Consequently, in most of the remaining discussion, the worldwide data are utilized to provide a larger statistical base.

From Table III-31 it is clear that the major risks for jack-up rigs occur, as previously noted, in the transit and moving on or off location phases. A major influence of storms can be noted in the transit accidents, but not in moving on or off location. This difference is probably due to the fact that the brief moving on or off period can be more easily scheduled to occur in good weather than the longer transit period.

TABLE III-31

Mobile Offshore Drilling Units
Accidents from Environmental or Operational Overload
(Worldwide)

Activity and Weather	Severity	Type Rig				
		Jack-up	Semisub-mersibles	Floater	Sub-mersibles	Totals
In Transit Storm	Major Acc.[1]	21	2	1	0	24
	Loss	9	1	1	0	11
In Transit No Storm[2]	Major Acc.	8	1	0	0	9
	Loss	6	1	0	0	7
Moving On Or Off Location	Major Acc.	21	2	0	1	24
	Loss	9	1	0	0	10
On Location Storm	Major Acc.	1	0	1	1	3
	Loss	0	0	0	1	1
On Location No Storm	Major Acc.	3	0	2	0	5
	Loss	3	0	0	0	3
Unknown Storm	Major Acc.	4	4	4	4	16
	Loss	3	1	3	2	9
Unknown No Storm	Major Acc.	2	3	0	0	5
	Loss	0	1	0	0	1
Totals	Major Acc.	60	12	8	6	86
	Loss	30	5	4	3	42
Total Rig Years Operation		2,332	921	1,048	662	4,966
Rig Years Per Loss		78	184	262	221	118

*1/ "Major Accidents" are those which involve over $500,000. Losses are included in this category.

*2/ "No Storm" means only that "Storm" was not mentioned in the available records.

Source: Committee on Safety of OCS Activities; data from Offshore Rig Data Service, Inc.

Of 29 jack-up accidents occurring in transit, 15 were losses; 12 of the 15 were noted to have sunk, capsized, or capsized and sunk. Of the 29 incidents, 21 involved storms, 5 lost towlines, 4 damage to the legs, and 7 unspecified damage.

Of the 9 losses while moving on or off location, 2 were due to leg failures, 2 were foundation failures, and 5 were noted as "collapse" or "capsized" without specifying a more detailed reason. However, of the 12 accidents that did not result in losses, 5 were noted as leg failures, 4 as foundation failures; an additional one was recorded as a case of capsizing without further detail. This indicates that leg structures and foundation sediment failures were major causes of accidents while moving on or off location. It appears probable that some of the accidents that were noted as "capsized" or as "collapsed" were also leg or foundation failures.

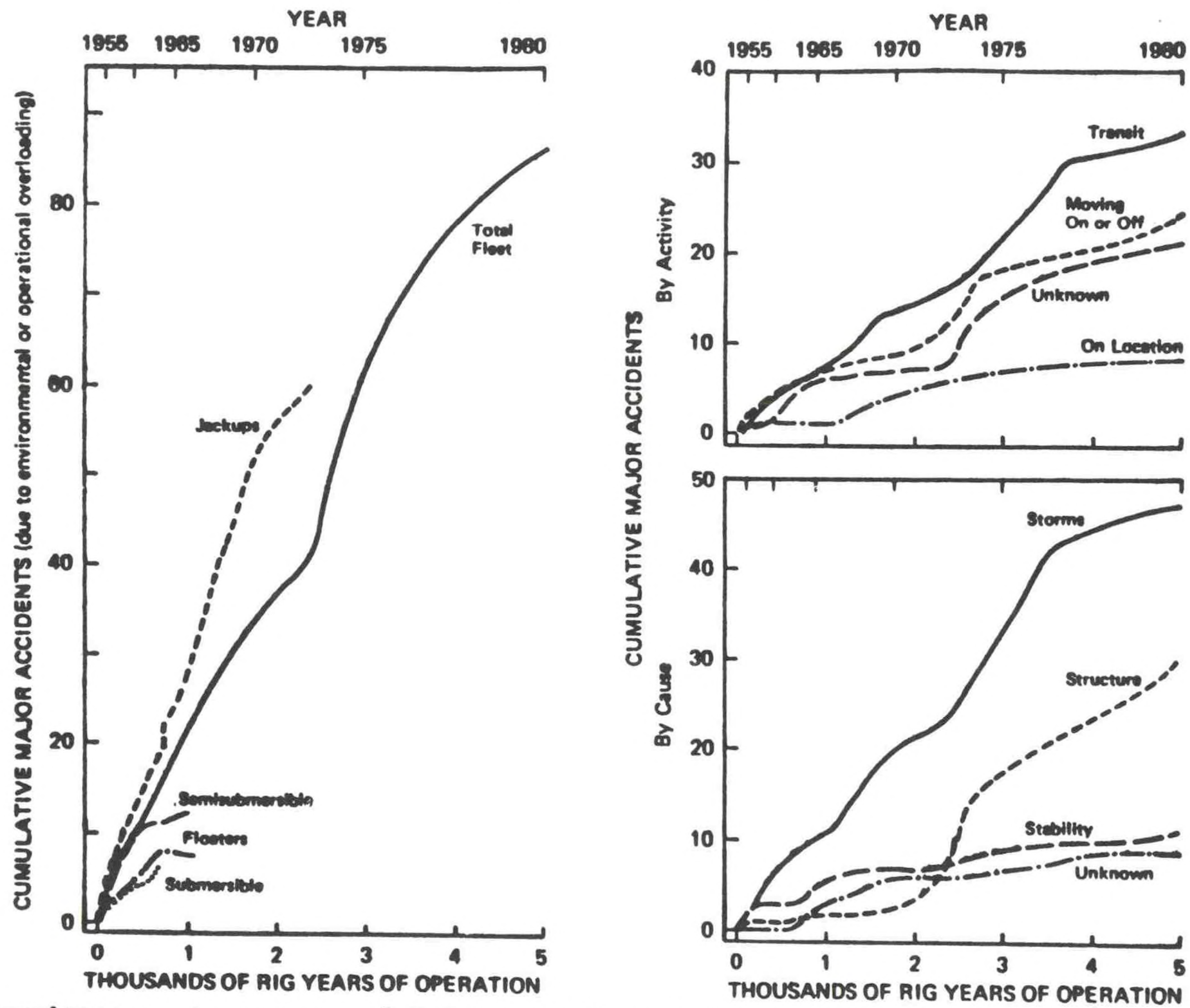
The 12 semisubmersible accidents were largely associated with storms and structural cracking of the legs. Storms were noted in 7 cases, and "structural cracks from a previous storm" in one other. "Structural crack," "damage to legs," or "possible fatigue" were noted in 6 accidents. These results lend credence to the earlier discussion of structural cracking or fatigue as a major risk for semisubmersibles.

Floaters and submersibles have the best safety records of the four types of MODUs. Together they account for only 16 percent of the accidents (14 of 86 accidents and 7 of 42 losses). The data are too sparse to reveal anything about the influence of type of activity since that was "unknown" in 8 of the 14 cases (4 for each type). Storms, however, did appear to have a major influence since 12 of the 14 records noted storms.

Causal data indicate that of the 86 major accidents involving MODUs, 47 were storm-related, 30 were structure-related, 11 were stability-related; the causes of 9 were unknown (including 1 "human error"). The individual numbers do not total 86 since some of the storm-related cases were also structure- or stability-related, and some of the accident records contain no causal information beyond "damage in storm" or "lost in storm."

Figure III-20 plots cumulative accidents against cumulative rig years of operation. Most of the curves exhibit the general decreasing-slope shape characteristic the result of learning and improved technology. However, the curve representing the risk of moving on or off location and the curve for losses due to structural problems show a recent upward trend, in both cases due to the experiences of jack-up rigs. Also, the curves show rises in accident rates for the early 1970s when the rate of exploratory drilling increased and many new or less experienced crew members joined the fleet.

Trends in MODU Accidents



Source: Committee on Assessment of Safety of OCS Activities

Figure III-20

Findings on the Safety of Mobile Installations

The following findings relate to MODU accident history covering the period 1955 through mid-1980 and exclude those accidents and losses related to blowouts, fires, and explosions. In general, the loss rate for MODUs exceeds that of fixed platforms by almost an order of magnitude. Over the record period, the loss rate steadily diminished in all categories of operation except when in transit or moving on or off location.

Since 1955, the worldwide fleet of MODUs of all types experienced approximately 4,870 platform-years and recorded 86 major accidents (0.017/year). Approximately half of these accidents (42) resulted in total loss of the installation (0.008/year).

Among the different MODU types, jack-up units have experienced the highest accident rate (0.026/year). Their two worst hazard exposures, accounting for 77 percent of jack-up unit accidents, occurred (1) while the units were in transit or (2) when they were moving on or off location.

The high incidence of damage to, or loss of, jack-ups while in transit indicates this to be the largest single accident category for MODUs. The causes of in-transit accidents appear to be related to stability under tow, particularly during storms. Only 5 of the 29 reported accidents resulted from broken towlines. Available reports do not identify the extent to which inadequate weather forecasting and human error were contributing causes in this accident category, but expert opinion identifies both of these as important factors.

The record indicates that jack-up mobile units are vulnerable also when moving on or off location, i.e., when undergoing the transformation from a floating vessel to a bottom-supported platform, or vice versa. Accident reports include numerous indications of leg collapse and also of soil failure beneath the legs. While most accident categories exhibit a clearly declining rate, this category does not. OCS Order No. 2, paragraph 2, "Drilling From Fixed Platforms and Mobile Drilling Units," provides the U.S. Geological Survey with the authority to require seabed data at any drilling site. Using this authority to require a foundation installation plan (and contingency planning) offers a possible means of reducing the risk of installation loss of damage when a jack-up unit moves on or off location.

The jack-up operational phases of transiting and moving on and off location are clearly hazardous and therefore demanding of personnel skill and judgment. The quality of personnel skill and judgment could possibly be improved through the establishment of manning provisions for jack-up units requiring (1) certification or licensing of persons, through examination, to establish their competence to serve in MODU command positions during specific operation phases, and (2) the designation by each MODU operator of the person who has command and control of the unit during all operational phases and the identification of when the command responsibility shifts from one phase to the next.

Semisubmersibles experienced the second-highest accident rate (0.014/year) among the MODU groups. The record shows a vulnerability to structural cracking, resulting from the combined influences of structure configuration, severe cyclic loading, and corrosion fatigue. It is significant, however, that many of the major accidents reported for these structures consisted of storm-related structural cracking that was detected and repaired without installation loss. There were only five total losses of semisubmersibles (0.005/year), which is roughly comparable to the loss experience of floaters (0.004/year) and submersibles (0.005/year).

MODU accident frequency is serious enough to warrant continued industry efforts to seek technological and operational improvements.

Use of the Ocean for Man's Wastes Engineering and Scientific Aspects[4]

Use of the oceans for the disposal of waste generated from our increasingly urban and coastal society brings to bear in one issue those forces shaping national ocean policy for over 30 years. These forces include advancements in technology--in the knowledge of the nature of the sea and of systems to operate in it and on it, concern for the preservation of the environment which has emphasized the ecological well-being of our coastal waters, and the growth of government regulation that reflects the often contending pressures of development and preservation.

The improvement of ocean engineering capability that will respond to the balanced use of our coastal ocean resources has long been a priority interest of the Marine Board, beginning with an investigation of waste management concepts for the coastal zone in 1970. For over a decade, there has been an increasing requirement for disposal locations for municipal sewage sludge, industrial waste, and dredged material. At the same time, a series of public laws severely restricted the options available for disposal, first in the oceans, then by incineration, and finally by placement in or on the land.

A steering committee under Marine Board auspices was established to plan and conduct a symposium "to provide an assessment of the state-of-knowledge fundamental to identifying and scoping the engineering problems involved in using the oceans as means of accepting and assimilating waste."

About 70 engineers, scientists, and persons responsible for the conduct of municipal and industrial waste management programs met for the two-day symposium to present, discuss, and review the scientific basis of understanding about waste disposal in the oceans. With the background, the various needs for using the ocean disposal alternative were identified. The engineering response to these needs, based on scientific knowledge and experience, was presented, and the regulatory response was then discussed by a panel of experts in waste management and environmental protection.

The following are extracted excerpts from a paper entitled Alternative Strategies for Ocean Disposal of Municipal Waste Water and Sludge by Norman H. Brooks and James E. Krier.[5]

Predictability of Outfall Effects

Effective management of wastewater and sludge discharges to the ocean depends critically on the ability to measure and predict the effects of treatment and outfall systems. The design of new or revised outfall systems is based on certain water quality objectives to be satisfied by the system under design. Fifty years ago outfalls were designed simply as hydraulic pipelines into the sea with the location and length decided either by guessing or by pure judgment, without any scientific analysis of the resulting water quality in the ocean.

In the intervening years, the state-of-the-art has advanced considerably, especially in the physical aspects of design (Fischer et al., 1979). In the design of outfalls we can now do the following predictive analyses quite well:

(1) Initial dilution for a multiport diffuser, taking account of environmental factors like ambient density stratification and currents

(2) Maximum height of rise of the initial plume in a stratified ocean, i.e., the level at which neutral buoyancy is achieved between the diluted plume and the ambient ocean and further spreading occurs as an internal flow

(3) Frequency of advection toward shore and probable travel times

(4) Coliform die-off and expected coliform counts along the shore

(5) Maximum dissolved oxygen depletion based on dilution

(6) Order of magnitude of regional flushing based on oceanographic variables

(7) Rate of dissolution of particulate forms of metals on sewage particles

(8) Substances likely to be bioaccumulated in the food chain and to require special attention and source control.

We have good empirical observations on, but less ability to predict, the following:

(1) Settling velocity of particles as a result of flocculation in the ocean

(2) Size and extent of resulting enriched patches on the bottom near outfalls

(3) Detailed ecological effects of wastewater, other than by empirical comparison to existing discharges

(4) Biochemical conversion of trace contaminants to more toxic forms by marine organisms

(5) Rate of degradation of potentially toxic persistent organics.

None of the predictions are exact; there is a degree of uncertainty. (The reliability of the various predictive modeling techniques is described in detail in the forthcoming NOAA book [The Impact on Estuaries and Coastal Waters of the Ocean Disposal of Municipal Wastewater and its Constituents].) However, the performance of an outfall is not fixed but follows frequency distributions driven by variations in the ocean environment (the time of the year, storms, tides, etc.). Consequently, when all the factors are considered and conservative assumptions are made, recent design experience has been successful in meeting the prescribed sets of water quality requirements.

In summary, the development of outfall structures to achieve very high dilutions (over 100:1) in locations of good coastal water circulation has been instrumental in achieving good disposal for the conventional pollutants and pathogens. In many locations, secondary treatment is not necessary as part of the system and primary treatment is sufficient.

Monitoring

An important part of the ocean option for disposal of sewage or sludge (when permitted) is an adequate monitoring program to identify any trends in environmental effects or to discover any new problems. Monitoring is typically required of the discharge agency by the regulatory agency. The discharger either does its own monitoring or else contracts the work out, and reports to the regulatory body.

There are basically two kinds of monitoring: (1) measurements of the chemical quality of the effluent and the flow rate, and (2) measurements of ambient water quality in the vicinity of the discharge and along the nearby shoreline. For large discharges the required monitoring stations may be scattered over 10 kilometers in each direction.

The main purpose of monitoring efforts, it appears, is to determine compliance with regulations rather than for research. For example, measurement of numerous water quality parameters may be required once a week (or more often), but no current data, density profiles, or other information is required even though it might be useful for understanding synoptic conditions at the time the water quality samples are taken. If a discharge is found to be out of compliance at a particular time of sampling, there is nothing that can be done in "real time" (because the offending plumes have already been discharged into the ocean). The fastest response is to start or stop chlorination, or adjust the dose of chlorine, or any other chemical that may be added as part of the treatment process (such as polymers to enhance sedimentation).

Unpermitted doses of toxic pollutants cannot be quickly detected in the effluent nor can the source of them be readily found without extensive investigations. Major points highlighted in this section include:

- o The discharges of toxic pollutants from municipal sewer systems are very unlikely to accumulate to acutely toxic levels. The question is whether existing levels may be chronically toxic. Thus, the best strategy for monitoring the environment is to use tests which are integrative in nature, such as measuring at regular intervals (like a year) the accumulations of trace contaminants in bottom sediments, or in particular indicator shellfish at designated locations (Goldberg's "mussel watch").

- o Control of short-term problems, such as infection by pathogens, must be measured by instantaneous point samples of receiving water at some regular short interval depending on the size of the discharge, the intensity of beach use, and the rapidity with which prevailing currents or stratification may change. Measurement intervals are typically range from daily to weekly.

- The cost of monitoring programs is difficult to determine. The sharply rising unit costs per user as the plant size decreases indicates that monitoring cost is a variable which decreases much more slowly than the discharge. For small discharges especially, it is highly doubtful that the value of the information obtained is commensurate with the costs incurred, simply because small discharges to the ocean represent very small threats in most cases.

- In the past, the design of monitoring programs has included an excess of routine measurements, but insufficient research aimed at identifying new relationships or problems.

Studies Now In Progress

Arctic Seafloor Engineering

The Committee on Arctic Seafloor Engineering is identifying the new knowledge needed to understand those arctic seafloor features and processes that critically affect the design and safety of such offshore arctic engineering projects as steel and concrete structures, pipelines, causeways, wells, and artificial islands. The committee is investigating the value and availability of measurement technologies, with its study focusing on both physical and numerical aspects of the analytical approaches that can provide important seafloor information.

The committee is describing problems presented by undersea permafrost and ice gouging in the arctic offshore environment, and is finding that these phenomena can be detected, described, and accommodated through engineering methods. The silt abundant on the Alaskan coastal seafloor, and over consolidated sedimentary features, however, continues to pose structural design and construction problems. Further research on the mechanics of such seafloor features is needed.

A final report will document the research and development needs in acquiring and analyzing the seafloor data that are critical for timely decisions on major engineering issues in the design of offshore facilities. The report will be published in June 1982.

Criteria for the Depths of Dredged Shipping Channels

Several facts and options must be weighed to decide the optimal configurations of navigational channels. Among important considerations in designing channels for safe and efficient navigation at reasonable cost are specification of the optimal depth and (owing to inaccuracies in the survey and the dredging process, and to the need for a margin of safety) of the depth to be added below that of the design. Contracts between industry and the U.S. Army Corps of Engineers usually specify that the Corps will pay for dredging to two feet below design depth. The "plus two feet" criterion is a traditional rule of thumb in the United States, but it may not always constitute the most economical or reasonable measure.

At the request of the U.S. Army Corps of Engineers, the panel is investigating the criteria used to specify channel depths in the United States, taking into account such considerations as trim, squat, bank and other suction forces, the neutral steering line, vessel attitude, ship-generated waves and surges, ship passing or overtaking, and ship stopping distances. The study will review (1) the criteria and supporting information used by selected foreign countries that have well-developed port and harbor technology, (2) various analytical techniques for deciding the specification of design depths, and (3) the adequacy of criteria now employed in the United States (principally the "plus two feet" specification) in terms of safety, efficiency, and cost-effectiveness.

The object of the study is to provide a technical basis for decisions about the criteria used to determine the depths and tolerances of dredged shipping channels. Publication of the panel's report is expected in late 1982.

Ocean Thermal Energy Conversion

At the request of the National Oceanic and Atmospheric Administration and the Department of Energy, a panel of the Marine Board is reviewing the design (including environmental design criteria), construction, installation, testing, and maintenance of technical structures such as platforms, moorings, and foundations; the seawater system and the cold water pipe, including their connections with the Ocean Thermal Energy Conversion (OTEC) plant; and the electrical cable.

The panel's evaluation covers both floating (moored or grazing) and fixed (continental shelf or dry shore-based) systems. The study does not address institutional and management concerns about the development and implementation of the OTEC program, or the issue of whether OTEC is a promising research and development strategy or national energy option.

The panel will make its assessment through a series of meetings, including a workshop which was held in March 1982 covering each of the technical areas to be assessed. Comments of the engineering community on OTEC ocean engineering have been obtained through document review and workshop participation.

The panel will prepare a final report identifying the engineering knowledge, technology, and practice, as well as the additional ocean engineering research and development that are necessary to meet the requirements of the OTEC program. The report will be published in the fall of 1982.

Ship Collisions with Bridges

As both maritime traffic and the sizes of ships in the world fleet have increased, bridges spanning major ports and harbors have moved farther seaward. Members of the Marine Board have for some time been concerned that the probability of ship-bridge collisions may thus also be increasing, along with the severity of such collisions' effects. Adding to the board's concern is the lack of attention given to collisions in the design criteria for bridges.

The Panel on Ship-Bridge Collisions has undertaken a review of the existing literature. Its study will concentrate on the risks and consequences of ship-bridge collisions in the United States, and on the measures that have been employed worldwide (or that could be employed) to reduce both the risks and consequences. Along with these findings, the panel will present its recommendations. Its report is expected in 1982.

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U.S. EXPERIENCES IN CAPPING DREDGE SPOILS

by

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Introduction and Objectives

Many harbors all over the world require continual and sometimes extensive dredging of contaminated sediments accumulated on the harbor floor. After being dredged, the contaminated spoils must be disposed of safely. In general, we use the containment strategy thus immobilizing toxic substances to protect the marine ecosystem (fisheries) and the anthroposphere. Capping of contaminated spoils with a layer of clean sediments would bury and isolate the spoils.

In recent years in the United States we have had several such experiences. They include the dredging operation in the Providence Harbor and River[1], Stamford and New Haven Harbors[2], and New York Harbor[3]. In Sweden, a capping operation was carried out in a stratified fjord with anoxic bottom water[4]. In addition, Canada has had a reasonable capping success at nearshore disposal sites of less than 20 meters in depth[5].

Now, theoretical studies are going on to plan the spoil disposal in subaqueous depressions (pits) followed by capping[6].

The objectives of the capping are (1) to prevent resuspension of the spoils and (2) to seal the buried contaminants from overlying benthic organisms.

Description of Capping Operations

On the Providence Harbor operation, during December 1967 - September 1970, contaminated harbor sediments were carried to sea in scows of 1500- and 2300-m^3 capacity and were discharged within a 1.6 x 1.6 km dumping area approximately 6.5 km south of Newport, Rhode Island, at the depth of 30 m. The polluted silts contained up to 12% organic matter. The lower Providence River material with less organic matter was used to cover the spoils. A total of 6.3×10^6 m^3 of the dredged material was deposited on the offshore site in the Rhode Island Sound.

The Stamford and New Haven Harbor operation was conducted by the New England Division of the U.S. Army Corps of Engineers in 1979. Since bulk sediment analyses for the Stamford Harbor sediments yielded high metal contents, management procedures were initiated to cap the Stamford material with silt and sand from the New Haven Harbor[7]. The objectives of the capping operation were to evaluate the relative merits of silt and sand as capping materials in terms of coverage, stability, effectiveness in isolating contaminants and benthos recolonization potential.

The initial disposal of Stamford material, 37,800 m^3, took place during

25 March - 22 April 1979. The dumpsite was at 41°08.5'N and 72°52.7'W whose depth was 22 m. The Stamford spoil produced a small mound approximately 200 m in diameter and 1.2 m in height. After 23 April 1979, silt from New Haven, 76,000 m^3, was dumped as capping material. The second Stamford spoil disposal, 26,000 m^3, was carried out by 21 May 1979 at 41°09.2'N and 72°52.8'W at 19 m deep. New Haven sand, 33,000 m^3, from the break water area was used as its capping agent; the work was completed by 22 June 1979. The capping sand covered the Stamford material completely with a maximum thickness of up to 3.5 m. This cap was a smooth blanket of sand that divers were unable to penetrate more than 15 cm by digging with their hands.

On the New York Harbor operation, approximately 650,000 m^3 of material dredged were precision-dumped at the New York Mud Dumpsite, 42°22.2'N and 73°50.5'W, 27 m deep, in the Atlantic Ocean, March - July 1980[3]. The deposit was then capped with approximately 1,400,000 m^3 of uncontaminated material by November 1980. Studies to determine the stability of the capped mound and biological insulation effectiveness of the cap are continuing: their final study reports will be available in 1982. The contaminants concerned are PCBs (polychlorinated biphenyls).

Bathymetric surveys were carried out in March, July, and November 1980. By comparing the surveys of July and November, the New York Harbor material was found to be covered with 1 m or more of capping material[3]. To insure the completeness of the capping operation, 303 individual disposals of capping material were carried out by the hopper dredge GOETHALS. For precise navigation, a Motorola Mini-Ranger navigational aid with an accuracy of within 3 m was used. During each dump, the GOETHALS would navigate to the pre-determined disposal point, stop all engines, and empty all of the hoppers[3].

Findings

The fate and stability of the Providence Harbor material capping operation are yet to be determined.

For the Stamford Harbor operation, the precision disposal resulted in a small compact mound that was readily capped. Apparently, there was little difference between silt and sand to accomplish the desired capping. Silt capping yielded cohesive and thick layer with rough micro-topography[7]. On the other hand, sand capping produced the capping layer not as thick as that of silt, but a smooth and tough blanket over the capped sediment.

The silt-capped Stamford material site was surveyed on 7 November 1979; the survey showed a major change in the topography of the spoil mound. Approximately 10,000 m^3 of the capping material from the top of the mound were lost resulting in the mound height decrease of 1 - 2 m[7]. No comparable decrease was observed for the sand-capped mound. A plausible explanation may be due to the differential effects of Hurricane David that passed over the mounds on 6 September 1979. It appears that the selective movement of silt material is due to the storm waves from Hurricane David acting upon the rough and cohesive silty cap. If this were true, any future capping operations with silt may have to find a way to produce a smooth spoil surface. The frequency of hurricanes to pass over the same mounds is approximately once every 10 years.

The stability study of the New York capping experiment continues; the study was initiated in November 1980. In cooperation with the U.S. Army Enginnering District of New York, the Atlantic Oceanographic and Meteorological Laboratories of National Oceanic and Atmospheric Administration (NOAA) located in Miami began studying the following items[8]:

a. To examine the cap material, the bottom roughness of the cap surface, and the flow regime over the cap,
b. To examine the seasonal response characteristics of the sediment cap to the flow regime, and
c. To elucidate the long term flow climate by studying available historical current meter records.

The NOAA scientists collected bottom sediments, measured flow and suspended sediment concentrations with *in-situ* probes for eight months. They also measured bottom shear stress by SEAFLUME (*in-situ* flume). SEAFLUME is a rectangular channel with walls and sides but no ends or bottom. When it is emplaced on the seafloor, a pump generates a current while camera records the bottom erosion.

On biological consideration, since the cap should prevent any direct contact of contaminated sediments from the benthic organisms at the capping site, there must be a sufficiently thick capping layer to prevent burrowing animals contacting the underlying material. In the Long Island Sound, most benthic organisms live down to the sediment depth of 10 cm[9]. An extreme case reported is vertical mobility of down to 60 cm[10]. Therefore, a cap of at least 60 cm in thickness would be sufficient to insulate the benthos from the contaminated sediments capped underneath.

To determine any leaching of contaminant through the cap, mussels (*Mytilus edulis*) were deployed over the New York capping site and at the reference locations nearby during August 1980 - July 1981. Mussel tissue was analyzed for Cd, Hg, Pb, PCB, DDT and petroleum hydrocarbons. The study result will be issued in near future[3].

Conclusions and Recommendations

The U.S. experiences show that the effectiveness of the capping operation is very good. Sand capping withstood the fury of Harricane David on the Stamford mound. Though eroded somewhat, the silt capping at the same site is still effective. Additional works needed are the evaluation of long-term stability and benthos recolonization effects[7].

Through the experiences, it is clear that capping technology that requires precision bathymetric measurement, positioning and dumping operation is available.

On the expenses associated with capping, suitable capping substances must be obtainable reasonably. A recommended capping procedure may be that heavily contaminated harbor sediments be precision-dumped first followed by sequential dumping and capping of the contaminated with the less contaminated as dredging progresses toward the open sea from the inner harbor.

An innovative approach is that capping dredge spoil at subaqueous (pit) disposal sites[6]. Within the New York Harbor, sand mining operations have left several large pits on the harbor floor. The pits are typically 7 to 10 m deeper than the ambient seafloor with side slope of 10^{o} - 25^{o}. A pit may have a volume of 25 x 10^6 m^3. Engineering assessment on its use has been made already[6]. Additional assessment on the stability of sediment capping in the subaqueous depression in terms of density difference between the two layers and the shear stress along the interface between the layers have been made. The U.S. Army Engineering District of New York already has begun planning the feasibility study of placing the contaminated harbor sediments into the pits and capping them subsequently[3]. The fact that the pits are adjacent to the area to be dredged makes the pit disposal, followed by capping, economically attractive. When needed, pits can be created by dredging, the same way the present-day land burial for toxic substances is carried out.

Acknowledgments

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The World's First Motor-Sails Tanker "Shin Aitoku Maru"

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President
Japan Marine Machinery Development Association

1. The circumstances of the birth of the motor tanker equipped with sail.

(1) At the beginning, I have planned to save energy by equip with sail to the conventional ship but got the approval of only three owners due to the attempt for the first time. And begun the investigation of the plan by the conventional ship "Aitoku Maru" according to the constructive proposal by President Fujiwara of Aitoku Co., Ltd.

(2) But the owner who intend to furnish the conventional ship had a hard time to determine because of about one hundred million yen expenditure for the development including hull reconstruction, docking time of one month long and anxiety for unstable stability of ship by tall sailing gear.

(3) The owner himself who has much active for advanced technique can endure economical situation in case of insufficient effect of energy saving by sail but from technical standpoint the purpose of utilize wind by sail will be faded away. Accordingly, we gave careful investigation and consideration for carry out of our plan.

(4) The owner wished at the beginning to adopt automatic control system not only to sails but also to the main engine in order to save manpower but this system was excluded due to minimize expenditure under the condition of indistinctness of sailing performance.

(5) The owner proposed the suspension of an offer of the conventional ship under an uncomfortable atmosphere of much anxiety for economical problem and safety of the ship equipped with sails. So that I have to change my plan and investigated again from every possible means.

(6) To meet the owner's request, I took approval of the Japan Shipbuilding Industry Foundation to prolong our plan to the two years project. On the other hand, I have proposed again to the owner to furnish the conventional ship because sail equipped ship (Engine main with sail auxiliary) will be prevailed around the world ocean in future take into consideration of rising up oil cost.

(7) Meanwhile, the early spring in 1980 the owner proposed to make energy saving ship by improved navigational performance with utilize wind even if the effect of sail becomes small. And I could get the same opinion with the owner to build as a whole the high economical ship equipped with sail of fine type hull includes bow and stern form, propulsion system with suitable propeller, main engine and main shaft generator system, exhaust gas utilize system and adopts newly developed machinery which were developed by our association. Thus the project forwards one step to the realization of the ship equipped with sail.

(8) I have proposed the alteration of our plan again to the Japan Shipbuilding Industry Foundation and could get the great advance to the realization of the sail equipped commercial ship by the special consideration and assistance toward the tangible plan for the sailing tanker as future ship.

(9) First of all, I have investigated the safety of the sail equipped ship together with the owner and asked to the Ship Bureau, Ministry of Transport because we have not yet the Registration of J.G. for sail ship. Fortunately we could hold "The Committee of investigate the safety of sail equipped ship" under Chairman Dr. Motora, the professor of Tokyo University with a member from Ship Bureau, Ministry of Transport. And got the conclusion that the ship is not passenger ship but the safety is guaranteed according to "the coefficient 1 of safety factor C of passenger ship enter service to international navigation (This is not apply also to the ferry of coastwise service)", so that the ship was built as coastal service.

(10) The building of sail equipped tanker was decided on Feb. 1980 bewteen the owner and Japan Marine Machinery Development Association with extensive support. In September 1980 the world first sail equipped tanker "Shin Aitoku Maru" was launched with eight months only.

An information medium reported to foreign countries via satellite as well as domestic.

But there were some cold wind rather than favorable wind against "50% effective of energy saving".

2. The actual result of "Shin Aitoku Maru"

Sail equipped tanker "Shin Aitoku Maru" has continued the voyage during one and half year since September the year before last without any trouble. So that by inspection of two years after, the durability namely the least of maintenance fee will be confirmed.

When I have planned sail equipped commercial ship seven years ago, I could not get much support. And received many attentions that I should investigate meteorological condition first and favorable navigation route for sailing ship before commencement. In short, there are great many opposit opinions.

When I planned sail equipped ship, I started with the intention of contributing to curtail oil even the slightest amount.

But the actual result of sail equipped "Shin Aitoku Maru" has indicated unexpected excellent perfformance. The ship has an excellent stability at rough weather so that continued to operate up to now without took shelter which these small ships usually have to carry out. This means to execute an unexpected high ratio of operation not only achieved the result to save fuel cost of more than 50 percent.

From operating results, rolling and pitching of "Shin Aitoku Maru" are very small and able to navigate against rough weather of 30 m/sec wind speed and 7 M wave height so that could operate without rest of a single day.

Moreover, the sailing gear of the lifting type hard sail could utilize the wind except from 40° forward that means utilize all of the wind from 360° direction. And this is verify by the fact of better stability of sailing ship when navigated in rough weather of 15 m/sec wind together with the same type sister ship "Aitoku Maru" which is scheduled to equip the sailing gear. As the conclusion, the sailing gear has achieved unforseen important results of energy saving as well as the stability of the ship.

The principal operating results are the followings.

(1) The Sea of Japan during winter season with snowing by 30 m/sec wind which until now such a small ship could not navigate, but "Shin Aitoku Maru" has entered to Niigata Port. It was on 6th January and the reason of excellent stability was not yet elucidated.

According to the captain of "Shin Aitoku Maru", he has received the information about 30 hours before that the unloading will be impossible until next 8 o'clock unless enter into the port till 16 o'clock on 14th January in rough weather of 20 m/sec wind. It has verified the excellent stability and regularity by enter into the port at 16 o'clock 45 minutes on 14th Jan. before one hour and fifteen minutes front of the scheduled time and the ship got high reliability for regularity from shipper.

(2) Even the ship was engine main with sail auxiliary, the operating results without engine and sail only of 3.75 knots speed by 6 m/sec breeze from stem side, two hours more than 8 knots speed by 25 m/sec wind from stern side, and has better stability with comfortableness compare with using engine have been confirmed.

(3) I have received many inquiries about the effect of saving energy by sail and these sailing ships use estimated horsepower which read out from instrument in actual operation. But it was proved 40 ~ 50 horsepower smaller than actual power in case of 900 estimated horsepower according to the calculation by computer which introduced in order to analyze low fuel consumption level of 130 g/psh of the ship.

It has confirmed by comparison of operating results during wintertime with the same type sister ship (not equipped sail now but will equip as soon as sail is completed) that the effect of saving energy by sail only is 30%.

(4) I got the report that at the sea trial of wave height 3 m, wind direction right 45°, wind speed 15 m equipped only one sail gear unfurled on the forecastle of the ship the condition of left 10°, right 15°, period 7.9/s was changed at once to left 15° right 22° period 7.3/s by furled the sail and in case of unfurled, the rolling angle decreased more than 30%, period approached to 8/s with much comfortable condition.

(5) From one year actual operating results, the mean horsepower of this ship was 850 horsepower at 12 knots speed. In case of the same voyage with mean speed of conventional ship the horsepower is 650 horsepower. The mean horsepower was 11,000 and maximum was 1050 horsepower when came back quickly from Formosa at 14 knots speed.

(6) According to the investigation at the dock just one year after, the surface smoothness of propeller was as same as launched time by mean of water grinding due to the idle rotation of propeller when cruising at more than 12 knots by sail only. Based upon this fact and the results from (5), the blade area of propeller was reduced to 20% lighten weight (from 265 kg to 217 kg) and the propeller of 1600 horsepower was replaced by 1200 horsepower propeller which is the limit of common use for the sail equipped ship, and also changed the smoothness of the blade to 6 μ (ordinary 12 μ to 15 μ at brand-new). This new propeller was fitted to the ship in January 1982 and could confirm about 7% less fuel consumption on the same voyage compare with the old one.

(7) Conventionally, the ship has oil purifier and prevent the sludge flows into the main engine. But this ship has homogenizer and can burn the sludge and water which will be about 900 liters by one

year so that also can save the labour and expenditure.

(8) "Shin Aitoku Maru" has on board as much as 936 each of parts and machinery and all of these were controlled by computer as same as the warehouse on shore. In spite of small number of eight crews, the supply and exchange of these parts and machinery can carry out quite simply owing to the input of the software which able to supply these parts and machinery during several years. And by this we can confirm to keep in warehouse the minimum necessary amount of stock for the ship.

Usually, the reports after the delivery of the ship are limited only for accident or trouble. But I must appreciate much for the cooperation of the owner, captain and crews of the ship to collect the data which will be very useful for the next sail equipped ship. And moreover these are fulfilled by only eight crews without any additional investigator.

Noboru Hamada

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Machinery Division, Ship Bureau, Ministry of Transport

1970 Counsellor,
Shipping Bureau, Ministry of Transport

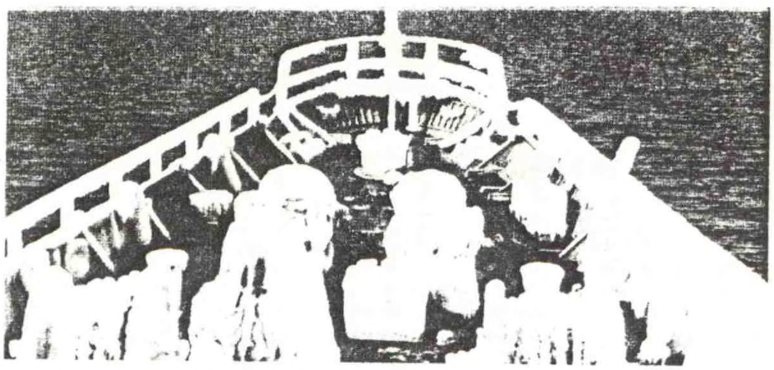
1973 Director,
Ship Research Institute, Ministry of Transport

1975 President,
Japan Marine Machinery Development Association

Heat Pipe De-icing System

— Created with highly refined Space Technology of the U.S.A. —

Fig. 1 Bow bulwark of "Bihoro"



One of the most important problems for ships sailing in northern seas during the winter season is to prevent these ships from capsizing due to top heaviness caused by ice accumulation. For this purpose, many de-icing methods have been investigated and developed in Japan as well as abroad, but have not yet reached completion.

Volcano Co., Ltd. has recently developed a practicable de-icing system for ships under the auspices of the Japan Marine Machinery Development Association (JAMDA) by using a specially-designed heat pipe consisting of high-speed heat conduction elements which utilize liquid evaporating and condensing latent heat.

The phenomenon of ice accumulation occurs chiefly in cloak bow, bridge and upper deck which are splashed with chilled sea water during sailing. Further the ice accumulation is reportedly caused by such ambient conditions as frozen spray, low sea water and air temperature and wind velocity.

In the case of small ships, the ice accumulation on board amounts to about two tons.

The heat pipe was originally developed for satellites by the National Aeronautics and Space Administration of the U.S.A. during the 1960s, and have already been utilized in various fields as heat conduction elements in the applicable temperature ranging from minus 200°C to over 2,000°C.

The structure of the heat pipe is composed of sealed container, porous wick of inner wall, and small amount of working fluid as shown in Fig. 3. Heat is transferred from the corner of the container to another corner by evaporating and condensing of the working fluid. The first step for the basic development to get the optimum design conditions was carried out by Thermo Electron Corp. of the U.S.A. where various kinds of heat pipes ave been put into practical use.

Especially the most suitable construction and materials for the heat pipe to be used for the marine de-icing system were chosen.

Secondly, the de-icing prototype tests were carried out at the cryogenic laboratory of the Ship Research Institute, Ministry of Transport, where the same conditions as those in northern seas can be readily obtained.

The test results prove that the de-icing prototype permits the dissolution of ice accumulation even in extremely severe conditions and also is durable during pitching and rolling of ships.

On the basis of these testing results, the experimental tests of the developed de-icing device was carried out in March 1979 on board the Maritime Safety Agency's patrol boat *Erimo* in the eastern sea area off Hokkaido. On the patrol boat, one set of heat pipe panel with a one square meter surface was installed for this trial. As a result, the de-icing capability was excellent as shown in Fig. 2.

Successively, other sea trials were carried out on board MSA's patrol boat *Bihoro* in March 1980 at the same sea area with a 10 square meters heat pipe panel installed on the inside surface of bulwark of bow. (Fig. 1)

The ice accumulation increases in proportion to relative wind velocity, increasing amount of water spray and decreasing ambient temperature and an ice accumulation of 30 cm thickness at most can be observed. However, only on the surface where the de-icing system is installed, no icing phenomenon is observed.

Generally electricity or steam are utilized as heat source of this system. However, the development is under way for utilization of exhaust gas from the engine for the de-icing system. It is expected to contribute to the fuel-saving of ships.

The de-icing system has no movable parts, thus making it maintenance free. Further, this system is featured with free choice of either panel or tube type.

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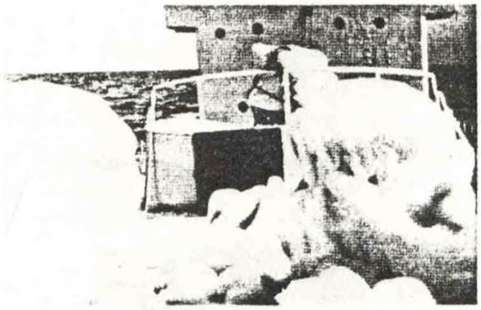
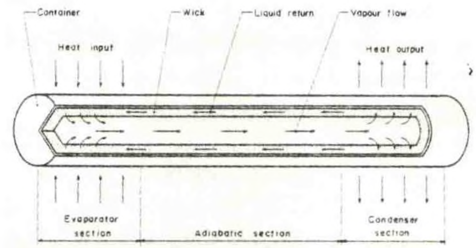
JAPAN MARINE MACHINERY DEVELOPMENT ASSOCIATION

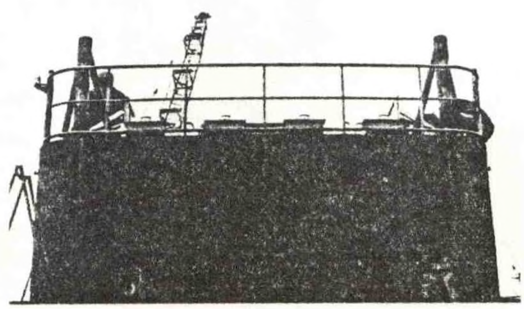
Fig. 2 Panel installed on "Erimo"





The first ship with practical de-icing system

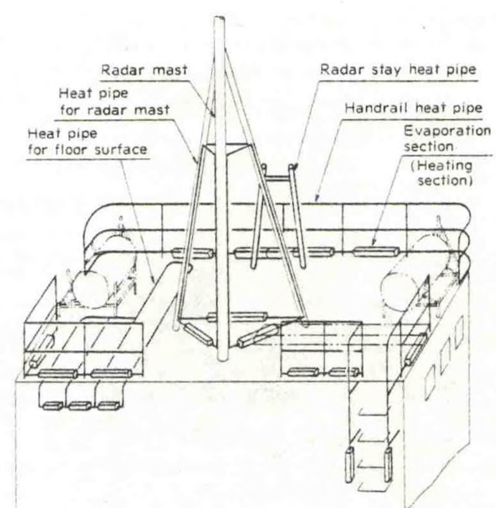
Volcano heat pipe type de-icing system is to be mounted on the handrail located at the steering room top and the radar mast at the total area of about 10 m^2 on 124-ton trawl fisheryboat "NO. 15 TOMI MARU" for the first time as fisherboat which is currently being built by Kushiro Heavy Industries Co., Ltd.



In "No. 15 TOMI MARU" this system is adopted to prevent all handrails (4.5 m^2 in surface area) located at the steering room top, some part of the floor surface (2 m^2), and some part of radar mast (3 m high from floor level $\times$ 3.5 m^2 in surface area) from icing.

And the system is divided into a number of blocks so that its whole performance is not affected should one block be troubled. Besides, handrail and a part of mast themselves are of heat pipe and, on the other hand, heat pipes are configurated in a loop form on the floor. (See Fig.)

Although electricity, steam, exhaust heat from engine, and cooling water from engine can generally be utilized as heating source for heat pipe, VOLCANO system uses an electric heat source (220 V $\times$ 60 Hz $\times$ 3 ϕ) and sheath heater is provided at the evaporation zone of heat pipe every divided block, which is ON/OFF-controlled by action of thermostat so as to maintain the heat pipe surface temperature at 5°C ~ 10°C. This de-icing system is to be mounted on the fisheryboat (TOMI MARU) during fitting work in coming October and the related work is scheduled to complete in February 1982. Many of ship owners show their keen interest in the result of this first de-icing system on board fisheryboat.



Universal Walkway

A number of deep sea oil fields have been developed and are in active oil production around the world at present. On those ocean platforms installed at these deep sea oil fields, many workers are constantly at work, and helicopters are playing a major role in transferring shift workers to and from the ocean platforms.

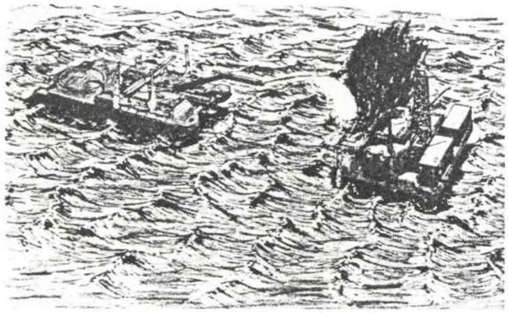
On the other hand, shipborne transport may be considered as an alternative means fit for safe mass transportation replacing the transport relying on helicopters. However, embarkation from water craft to ocean platforms involves extreme difficulties when the sea and weather conditions are serious, and thus constituting a great barrier for this mode of transport by water craft.

The Japan Marine Machinery Development Association and Mitsui Engineering & Shipbuilding Co., Ltd. have jointly developed universal walkway, an innovative means for transfer operation, and completed a series of model tests (Figs. 1, 2, 3) and basic design.

Although it is extremely difficult to apply a bridge between moving objects, the concept of this universal walkway includes the use of semi-submerged catamaran (SSC) having the most typical characteristics of its lesser motions in rough sea for making it to serve as a base for the universal walkway system.

This universal walkway offers versatile other applications than its prime objective of the bridging service for transferring workers to such as fire-fighting operations, transport of men and equipment to an isolated island, their removals therefrom, rescue operation of men in distress from wrecked ships if the universal walkway system is installed in respective ship for specific service (Fig. 4, 5, 6).

Fig. 4 Fire fighting operation of offshore platform



(1) Even to a ship in motions under bad weather and sea conditions, the universal walkway can be safely applied if it is provided with an automatic position control.

(2) By incorporating the automatic position control and a shock-absorbing system, striking impacts at time of bridging operation can be minimized.

(3) All ship motions during and after bridging can effectively absorbed through the functions of the turntable and sliding unit provided in the walkway, and no extra work or power is required.

(4) Since the boarding inlet and exit of the walkway are fixed in such a way that they permit relative turning motions, safe embarkation/disembarkation can be ensured even when the bridging parties are in motions in wind and waves.

(5) As the universal walkway is an integral structure, stable walking along the walkway is available even at time of bridging operation.

Fig. 5 Transport of men and equipment to an isolated island

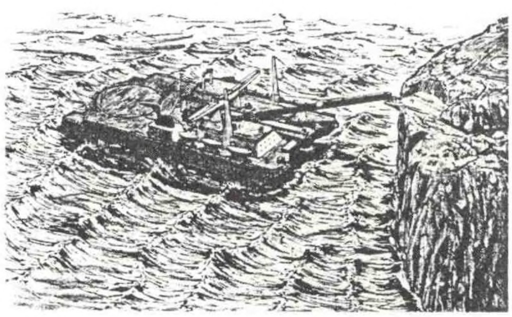
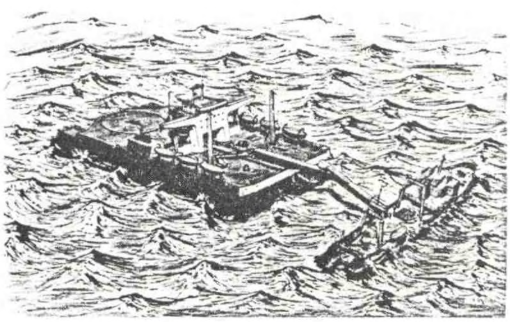


Fig. 6 Rescue operation of men in distress from wrecked ship



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JAPAN MARINE MACHINERY DEVELOPMENT ASSOCIATION

ユニバーサルウォークウェイ

現在、世界各地で数多くの海底油田が開発され、採油が行なわれている。これらの場所に設置された洋上石油生産プラットフォームでは、多数の作業員が働いており、作業員の交代にはヘリコプターが主として使われている。

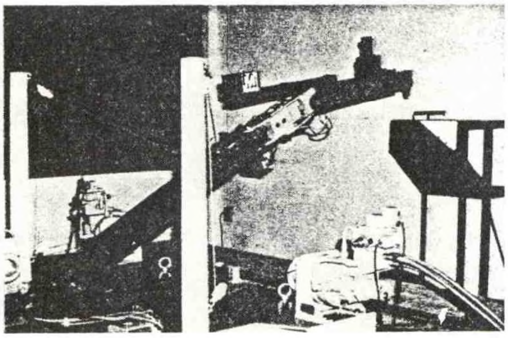
一方、ヘリコプターにかわる大量かつ安全な輸送手段として船舶による方法も考えられるが、厳しい海象条件のもとでの、船から洋上プラットフォームへの乗り移りが、船舶による輸送の場合大きな障害となっている。

今回、当協会と三井造船㈱は共同で、この乗り移り方式として新方式のユニバーサルウォークウェイを開発し、模型実験(図1、2、3)および基本設計を完了した。

揺れ動くものの間に橋を安全に架けることは、非常に難かしいが、少しでも動揺を小さくするために、波浪中でも揺れが小さいことを最大の特徴とする半没水型双胴船に、ユニバーサルウォークウェイを装備することを考えている。

また、このユニバーサルウォークウェイは、消火活動、離島への物資の輸送・陸揚げおよび難破船の救助を目的とする船舶に設置するなど、広範囲な適用が考えられている。(図4、5、6)

Fig. 1 Model of Walkway



① 自動架橋装置の採用により、荒天中で船が揺れていても安全に架橋できる

② 自動架橋装置および衝撃吸収装置の採用により、架橋時のショックが小さい

③ 渡橋中(架橋後)の船体運動は、ウォークウェイ装置の機構(ターンテーブルおよびスライディングユニット)により吸収するため、一切の操作および動力を必要としない

④ 渡橋中に於いては、ウォークウェイの乗込口・出口が回転自在に固定されているため、動揺中でも安全に乗り移りが出来る

⑤ ウォークウェイは、一体の構造となっているため、渡橋中でも歩行面が安定しているので、歩行が容易である

Fig. 2 Motion of Walkway top without an automatic position control

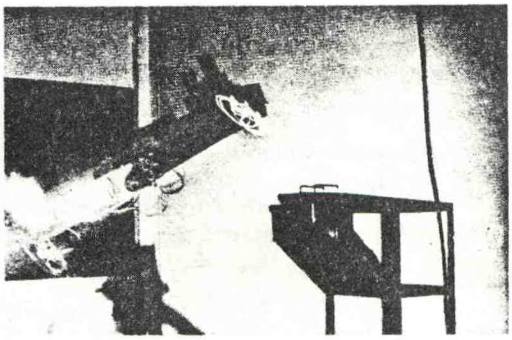
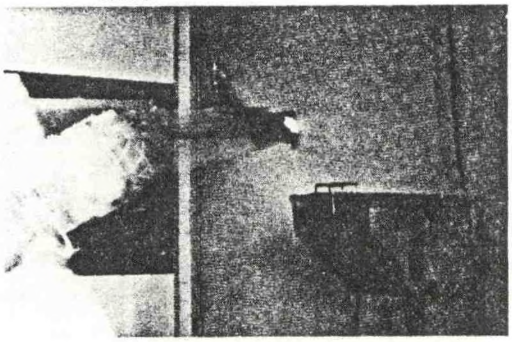


Fig. 3 Motion of Walkway top with an automatic position control



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OCEAN CURRENT POWER GENERATION BY SUPERCONDUCTING MHD METHOD

Masao Yoshiwa*, Akira Iwata* and Yoshiro Saji**

1. Introduction

Japan has little primary energy, but it is surrounded by the sea on four sides. With the view to making the best use of the convenient location, we are studying how to make the ocean energy available, namely, ocean wave power generation, ocean thermal energy power generation and ocean current power generation.

The ocean current power generation means that the kinetic energy of an ocean current is transformed into an electric power or hydrogen gas. Japan, fortunately, has a typical ocean current KUROSHIO in the world, which flows along the east coast of Japan and whose scale is 120 km wide, 1 km deep, 1.5 m/s fast in the limited region and about 80×10^6 m^3/s in flow rate.

As the results, total of the kinetic energy of the current is about 1.9×10^7 watts which corresponds to 10% of the electric power demand in Japan*.

In the light of state of things, we proposed the ocean current power generation by superconducting MHD method several years ago. Since then, theoretical and experimental study has been carried out.

In 1979, we succeeded to generate available electric power and lighted a miniature bulb in the preliminary experiment by the superconducting ocean current power generation method for the first time in the world.

In this paper, a summary of our analytical and experimental work will be presented.

2. Principle of Electromagnetic Ocean Current Power Generation

In principle, ocean current power generation by superconducting MHD method is the same as the traditional MHD generator. But the working fluid of our type is the unexhausted ocean current instead of the plasma flow which is produced by coals, oils and so son, that is, our method is for bringing the new energy source and the traditional MHD generator is for saving energy.

In the method, as shown in Fig. 1, the kinetic energy of an ocean current is transformed into electric power through the process which is consisted of three stages such as speed increasing stage, power generating stage and pressure restoring stage.

In the first stage, the energy density of the ocean current is raised so as to heighten the efficiency of power generation. In the second stage, the electric power is generated by means of the MHD method, and the power is conducted to a load through electrodes.
In the last stage, the pressure of ocean current is restored and the ocean current in the stage flows out to the sea.

2-1 Derivation of Basic Equation

In order to make the analysis short, the following items are assumed;

(i) ocean current is horizontal and in one dimension,

(ii) seawater is uncompressible,

---

* Demand of electric power in 1985 is estimated to be 2.1×10^8 watts.

(iii) cross-sectional area vertical to flow direction is constant in the generating duct,

(iv) magnetic flux density is constant in the generating duct,

(v) frictional loss is negligible besides diffuser loss, and

(vi) voltage drop accompanied with electrolysis is negligible.

Then the basic equations are indicated as follows;
(symbols are given in Fig. 1 and Table 2.)

(i) equation of conservation of energy

$$\rho u \frac{d}{dx}\left(\frac{1}{2}u^2 + \frac{P}{\rho}\right) + H = 0 \tag{1}$$

(ii) continuous equation

$$d\,(uS) = 0 \tag{2}$$

(iii) Faraday's electromagnetic induction equation

$$E = uB \tag{3}$$

The boundary condition is

$$P_1 = P_4\ , \tag{4}$$

and H is given as follows ;

(i) $H = 0$ at $x_1 \leq x < x_2$, (5)

(ii) $H = EJ$ at $x_2 \leq x < x_3$, and (6)

(iii) $\int_{x_3}^{x_4} \frac{H}{\rho u}\,dx = \frac{f}{2}(u_4 - u_3)^2$ at $x_3 \leq x < x_4$ (7)

From the above equations, the speed of seawater in the power generating duct, u_2, can be derived as eq. (8).

$$u_2 = u_4 - A\,(1 - K) + [\{A(1 - K) - u_4\}^2 + \{u_1^{\ 2} - (1+f)u_4\}/f]^{1/2} \tag{8}$$

$$A = \frac{\sigma B^2 L}{\rho f} \tag{9}$$

Then generation characteristics can be made clear from the following Ohm's equation and output power equation.

Ohm's equation : $J = \sigma(1 - K)\,u_2 B$ (10)

output power equation : $P_{OUT} = \int J \cdot KE\,dv\ /\ (DW) = \sigma K\,(1 - K)u_2^{\ 2}B^2L$ (11)

2-2 Output Power Characteristics

In this part, the characteristics will be calculated on the generating duct which is 10m in length, in width and in height.

As shown in Fig. 2, the speed of seawater is the important factor in order to generate electric power as much as possible. The magnetic field flux density is not necessary to be very high and around 3 teslas* in flux density is the most suitable under the condition of 1.5 m/s in seawater speed which can be usually obtained in the Kuroshio current. The reason is that the induced Lorentz's force by high magnetic flux density lowers the speed of seawater in the generating duct, as shown in Fig. 3.

3. Preliminary Experiment

In order to certify the basic analysis, we have carried out the preliminary experiment by the apparatus shown in Fig. 4. In this part, the outline of the apparatus and the experimental results will be indicated.

3-1 Experimental Apparatus

As shown in Fig. 5, the apparatus is composed with a tank of seawater, a pump, a generating duct and a superconducting magnet. Their specifications are shown in Table 1.

In the apparatus, the seawater is conducted into the power generating duct in the test speed which is obtained by the pump. The seawater flow, which is the imitation of the ocean current, is worked with the magnetic field at the right angle to the flow direction. Then, electric current comes out through the electrodes.

3-2 Experimental Results

Fig. 6 shows the output currents and voltages relating to the magnetic flux density. The figure indicates that

(i) output current and voltage do not come out when the magnetic field flux density is under a threshold, but

(ii) when the flux density is over the threshold, the output current and voltage increase linealy with the flux density.

In theoretical, the threshold is the value of magnetic field flux density at which the generated voltage in the duct grows to the voltage for electrolysis which is said to be about 1.6 V. In experimental, the threshold of magnetic field is about 0.3 teslas and the resulting generated voltage is 1.5 V, which agrees generally with the theoretical value.

Fig. 7 shows the output currents and voltages relating to the factor of available voltage. The experimental results agree well with the theoretical results which are corrected with the leakage of electric current and so on.

* tesla : unit of magnetic field flux density in SI units,
1 tesla = 10,000 gauses

4. Concept of 100 kW Generator

As mentioned in section 2-2, in order to generate 100 kW by the KUROSHIO current, the magnetic field as high as 3 teslas should act all over the volume of 10 meters cube.
As the results, the whole shape of the duct is that shown in Fig. 8. Most of the duct is the pressure restoring duct.

General design of generating duct is shown in Fig. 9. The superconducting magnet is about 15 meters in diameter and about 1.3 meters square in cross-section. Heat leakage into the cryostat is assumed to be around 100 watts, and resulting electric power for the refrigerator will be about 40 kilowatts. The power is equivalent to 40% of the generating power. In order to make such a consumption for refrigerator smaller, we think that superconducting magnets working at LH_2 temperature should be developed. Such magnets also make us not to consume helium gas which is very rare and valuable.

5. Conclusion

The study has just started for ocean current power generation by superconducting MHD method. The method has following technical problems in addition to that of superconducting magnets ;

(i) treatment of by-products in ocean current,

(ii) foundation of generator in the sea, and

(iii) prevention of corrosion on electrodes.

But our generating method has many advantages compared with other methods, so we hope that the study on the method will be carried out one by one in view of making the method practicable.

Table 1 Characteristics of apparatus

Superconducting magnet	
coil type	race track
size : bore diameter	1000/200 mm
outer diameter	1200/400 mm
height	60 mm
current density	1.4×10^8 A/m^2
maximum field	4.5 T (at 370 A)
Cryostat	
type	vapor-cooled radiation screen
size : outer	664W, 1464L, 460H
capacity of LHe	100ℓ
heat in-leak	0.6W (without power leads)
Power generating duct	
size : interval between electrodes	900 mm
length of electrodes	240 mm
inner height	32 mm
averaged magnetic flux density	1.3 t
maximum speed of seawater	5.8 m/s
Pump	
electric power	22 kW 3ø
flow rate	10 m^3/min
Tank	
size	1000W, 3000L, 1000H
material	chloride vinyl

Table 2 Notation

A :	$\sigma B^2 L/(\sigma f)$	
B :	magnetic field flux density	(tesla)
D :	internal between electrodes	(m)
E :	electric field intensity	(V/m)
F :	Faraday constant (9.65 x 10^4C)	
f :	coefficient of diffuser loss	
G :	generating rate of hydrogen	(Nm^3/day)
H :	energy transforming coefficient	(J/m^3)
I :	electric current	(A)
J :	electric current density	(A/m^2)
K :	voltage availability	
L :	length of generating duct	(m)
P :	Pressure	(Pa)
P_{OUT}, P_{IN} :	output power, input power	(W)
R :	electric resistivity	(Ω)
S :	cross-sectional area of duct	(m^2)
u :	speed of ocean current	(m/s)
V :	voltage	(V)
v :	volume	(m^3)
W :	width of generating duct	(m)
x :	position along ocean current	(m)
σ :	electric conductivity of seawater	(S/m)
ρ :	density of seawater	(kg/m^3)
η :	power generating efficiency	$(P_{OUT}S_2/P_{IN}S_1)$

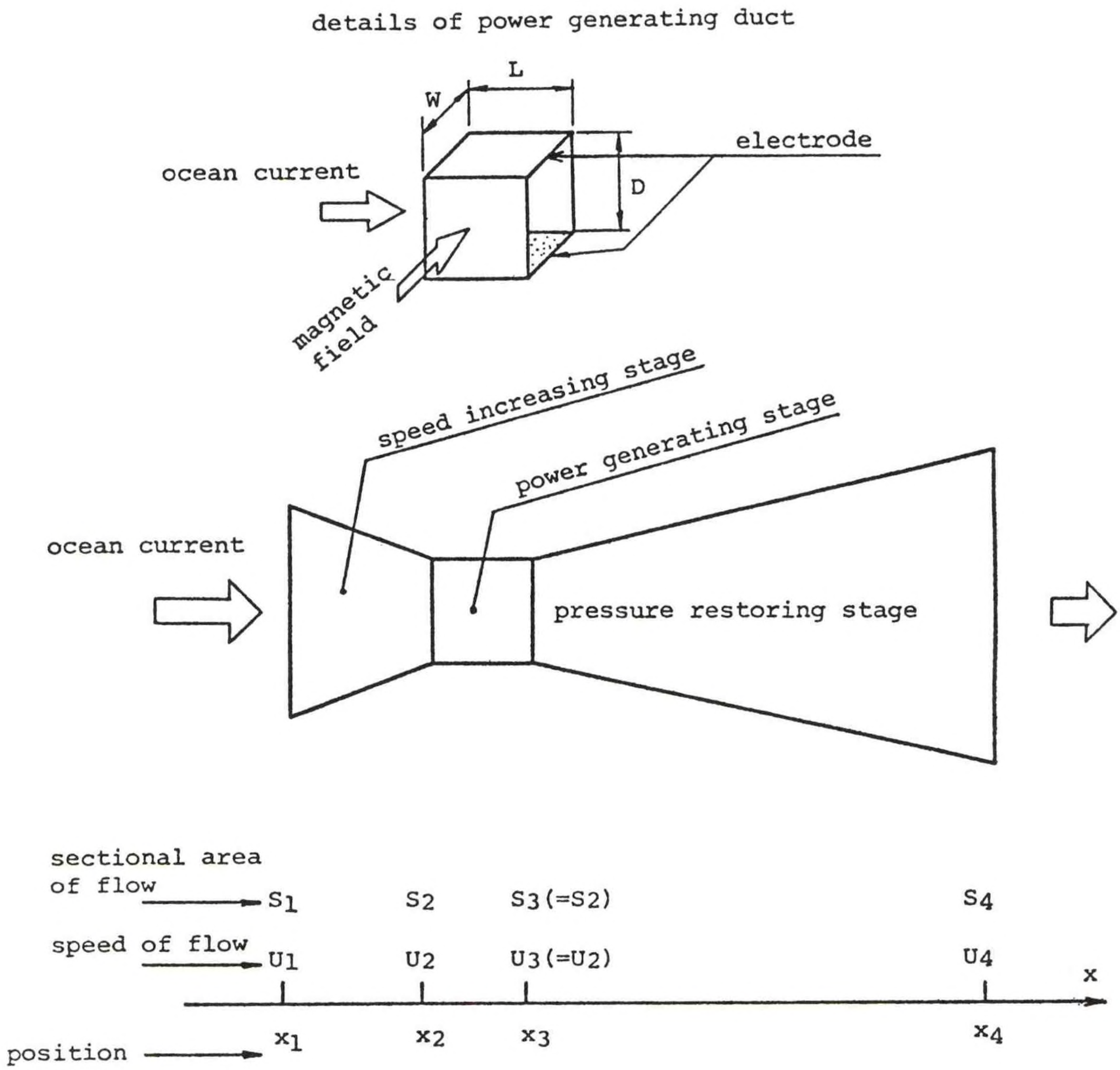

Fig. 1 Explanatory figure for the theory

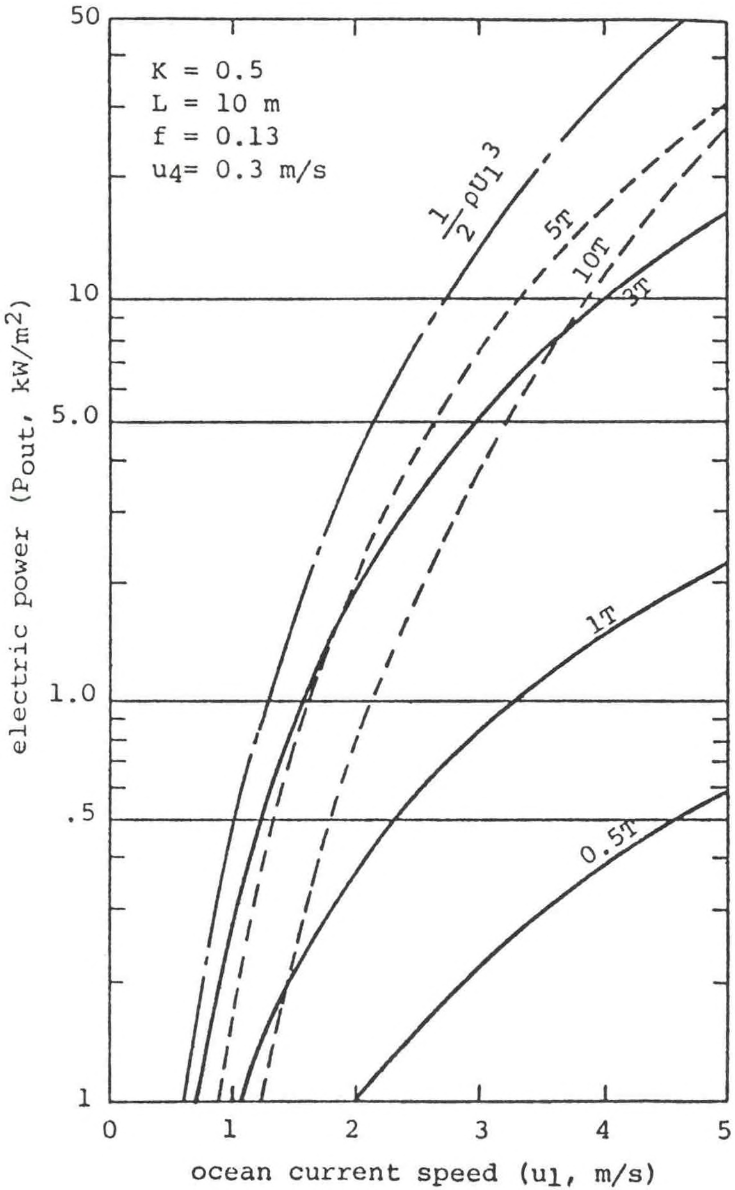

Fig. 2 Relation of electric power and ovean current speed

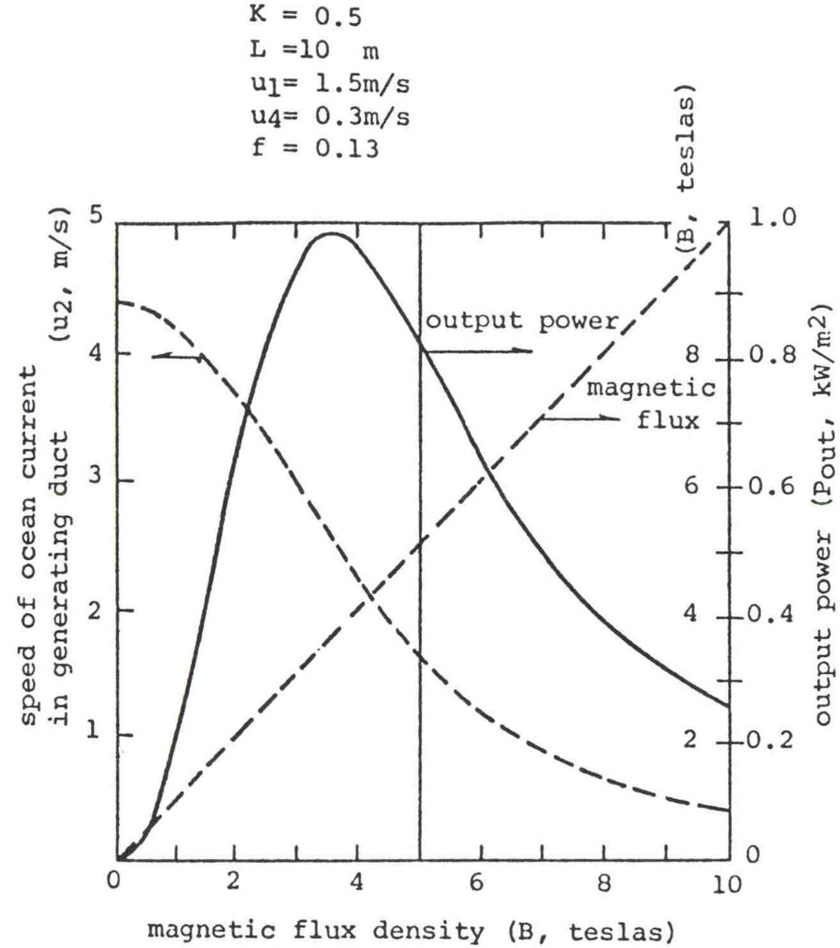

Fig. 3 Correlation between B and P_{out}

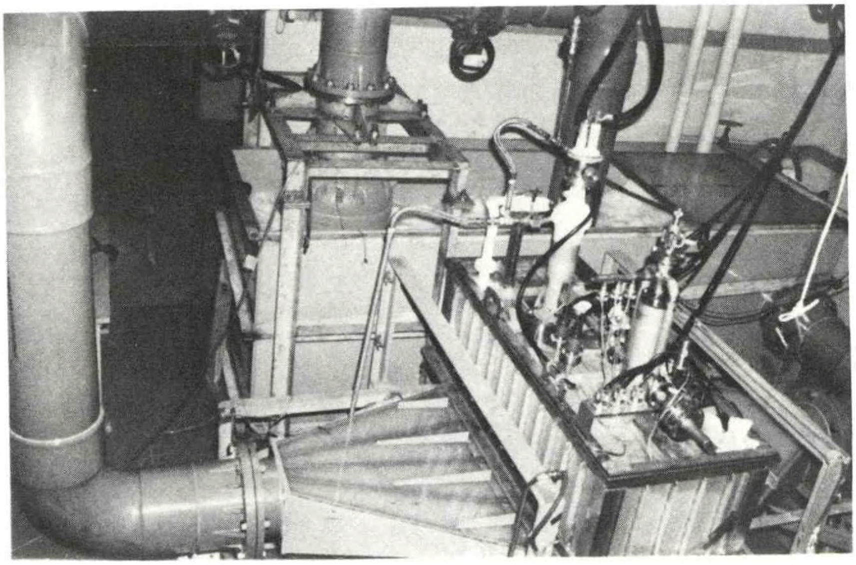

Fig. 4 General view of ocean current power generator by superconducting MHD method

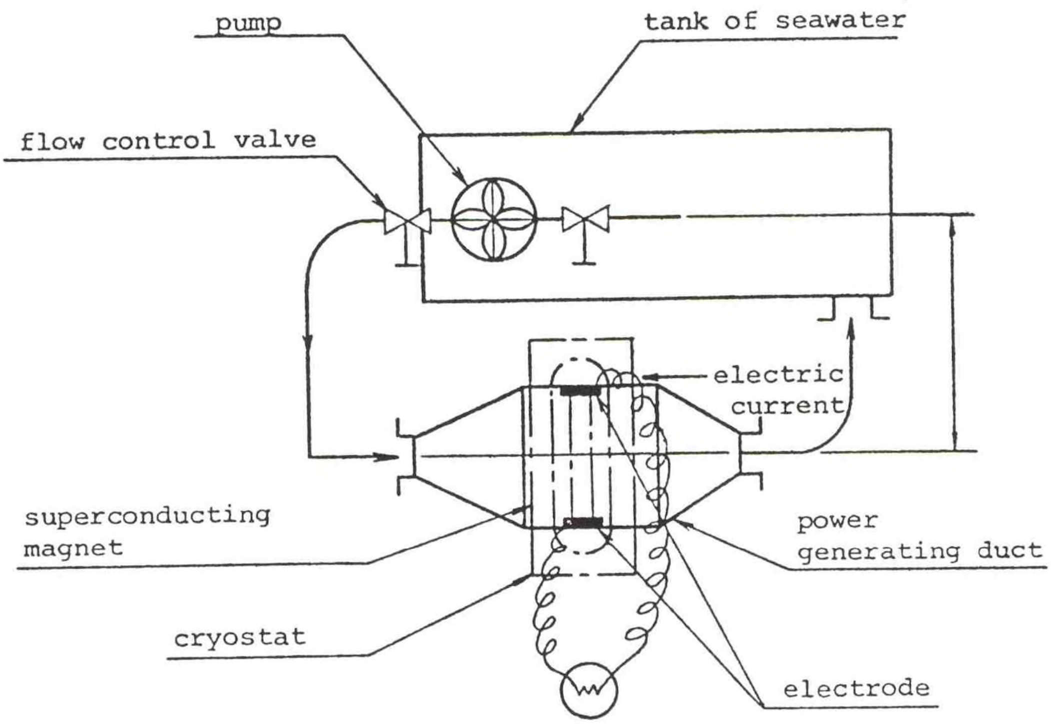

Fig. 5 Construction of the apparatus

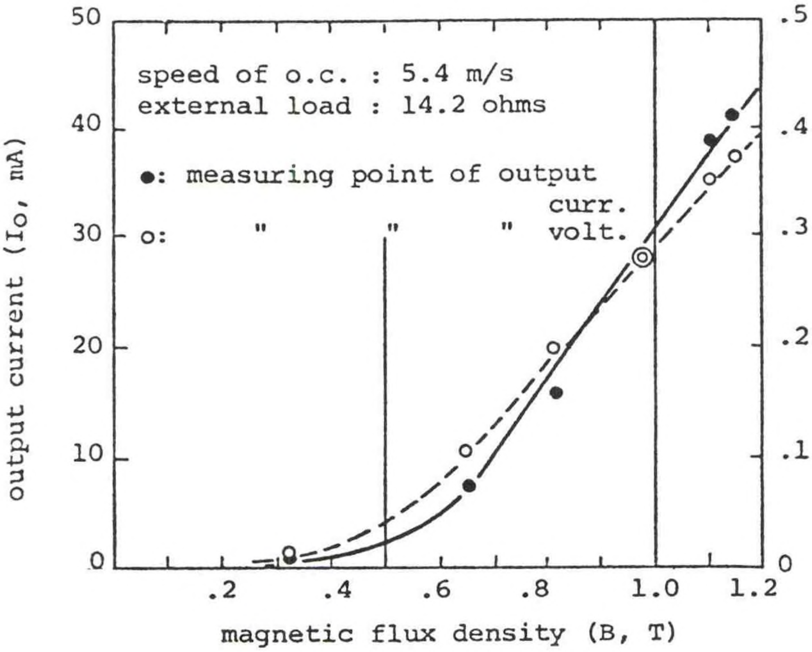

Fig. 6 Experimental results of output current and voltage

items	scale of vertical	measuring points	calculated results
voltage	× 1V	○	—·—
current	× 50mA	●	------
electric power	× 20mW	×	——

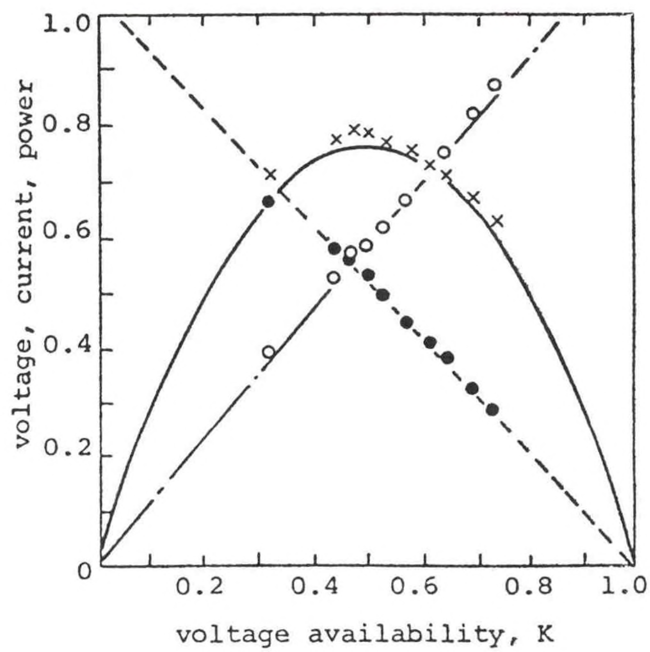

Fig. 7 Comparison of experimental results with calculated results

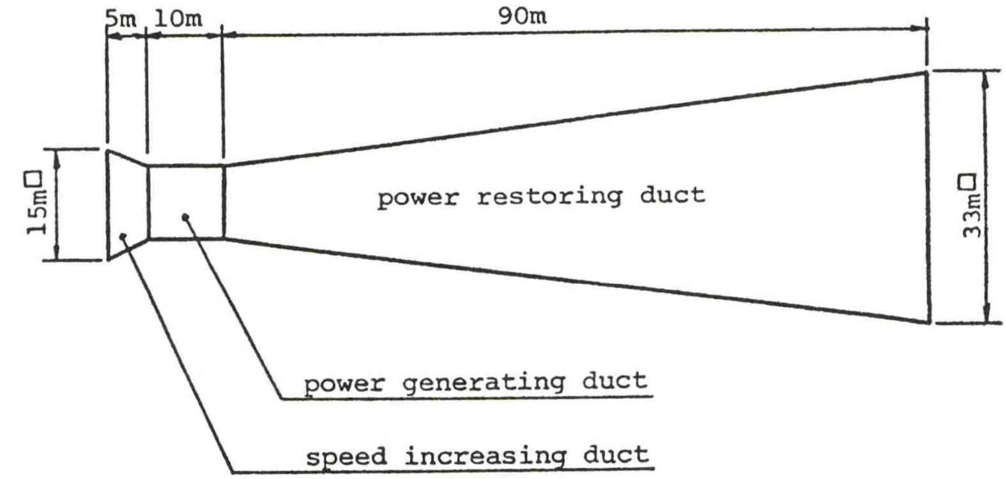

Fig. 8 Whole shap of duct for 100kW generator

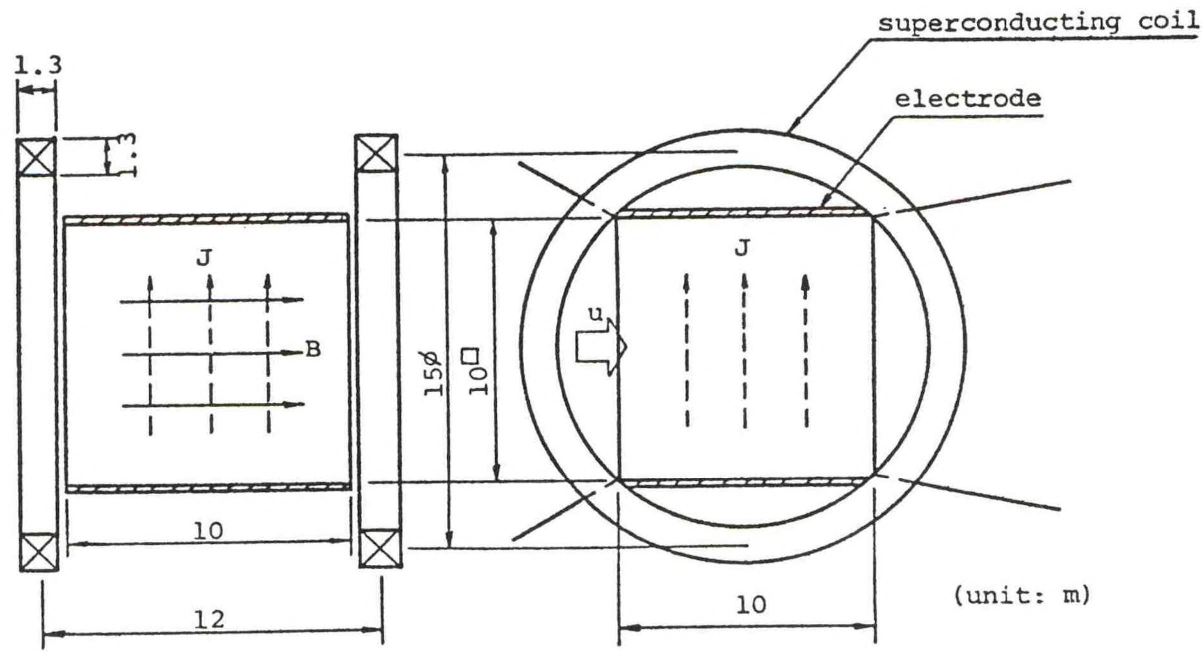

Fig. 9 Outline of generating power duct for 100kW generator

A MICRO-COMPUTER CONTROLLED TETHERED VEHICLE, JTV-1

Mutsuo Hattori, Taro Aoki

Japan Marine Science and Technology Center

ABSTRACT

A micro-computer controlled tethered vehicle JTV-1 (JAMSTEC Tethered Vehicle-1) was designed and fabricated in Japan Marine Science and Technology Center (JAMSTEC). The JTV-1 is capable of operating to depth of 200 m. It is designed small in size and light in weight, so can be transported by 2 or 3 persons. The vehicle has a spherical pressure hull of casted alluminum alloy with a spherical acrylic sector window. Four cylinder type magnetic torque coupling thrusters penetrate through the wall of the pressure hull. The vehicle is equipped with a TV camera (black and white, sensitivity 0.5 lux, ± 60 degree tilt), two 150 watt tungsten halogen lamps, magnetic compass, depth meter and 35 mm still camera. Recently, A TV camera of CCD (MOS) type (Hitachi VKC-1000) was used instead of the b.and w. TV camera.

The system utilizes a micro-computer based control unit which controls 4 thrusters, automatic depth keeping and digital bi-directional telemeter channels.

INTRODUCTION

Since 1978, a micro-computer controlled tethered vehicle, JTV-1 has been developed in JAMSTEC. The purpose is to develope a light weight, small size and low cost vehicle which can be used for geological, biological works and inspection tasks of submarine artificial structures on the continental shelf shallower than 200 m. Because there was not such a kind of vehicle in Japan despite necessary tasks mentioned above.

Therefore, we attempted to develope such a small and light weight vehicle that could be transported by 2 or 3 persons and could operate on a small boat. In order to make a vehicle small and light weight a micro-computer (Z-80) based control and a spherical pressure hull structures were designed.

The fundamental system was completed in the April of 1980. The system is composed of a deck control/display unit (weight 8 kg), power unit (14 kg), main cable (ϕ 16 mm), neutrally buoyant tether cable (ϕ 16 mm) and a vehicle (weight in air 43 kg, buoyancy 1 kg). The vehicle has a spherical pressure hull of corrosion resistant aluminum alloy (wall thickness t=5 mm), with a 90-degree sector angle spherical acrylic window (t=8 mm) and 4 cylinder type magnetic torque coupling thrusters (each 100 volt 70 watt d.c.), two at the stern side and two at the upper part. Those 4 thrusters provide up/down, forward/reverse, side advance and rotation motions. A disired depth is maintained automatically. A TV camera in the pressure hull is capable of being tilted ± 60 degree in the vertical plane and two 150 watt tungsten halogen lamps are attached on the outer wall of the pressure hull. There is a sufficient room in the pressure hull to install 35 mm motor driven still camera which is controlled from surface. A magnetic compass is attached in front of the view port.

The system is utilizes a micro-computer based control unit with 1 K byte RAM and 2 K byte ROM. The micro-computer based control unit which controls 4 thrusters, automatic depth keeping and digital bi-directional telemeter channels (max. 128 channels), provides high reliability and simple circuit design.

There were two vehicles of JTV type, JTV-1 and JTV-2. Sea going tests of those two vehicles were successfully completed at water depths between 24 to 105 meters.

SYSTEM DESIGN

First step of the system design was to decide an image of the vehicle which is highly maneuverable and small in size. The outline configuration, number and position of thrusters are the same as the design by Walrod (1972), so the position of the thrusters is the same arrangement as the RCV vehicle of Hydro Products, but another features are distinctly different from the RCV vehicle.

Maximum operating depth of the vehicle is 200 m in the present stage. A casted aluminum hull of spherical shape is used to get large inside room and buoyancy compared to smaller size.

In order to maintain a highly reliable control and simple circuit design, a micro-computer based control system is developed.

Present system of the JTV-1 is shown in Fig. 1.

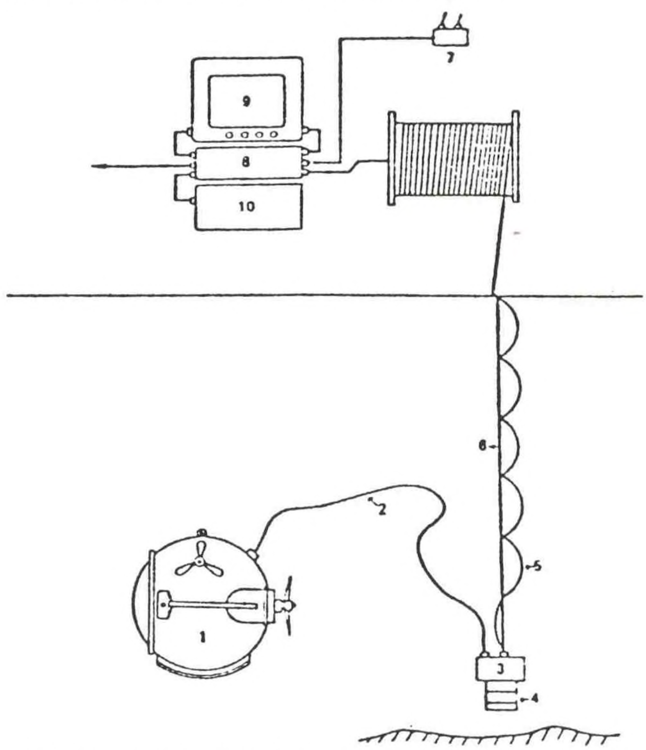

Fig.1. The JTV-1 system

1. Vehicle 2. Neutrally buoyant tether 3. Connector 4. Weight
5. Main cable 6. Rope 7. Control box 8. Control/display
9. Monitor TV 10. Power unit

Specifications of the JTV-1 are shown below.

SPECIFICATIONS

Operating depth	200 m
Dimensions	52(L) x 64(W) x 50(H) cm
Weight	43 kg
Buoyancy	1 kg
Structure	Spherical aluminum pressure hull with acrylic window
Control/display	38(L) x 28(W) x 13(H) cm weight 8 kg plus monitor TV
Power unit	30(L) x 16(W) x 16(H) cm weight 14 kg input A.C. 100V.50/60Hz,1300VA
Thrusters	4 thrusters, each 100 V.70 W cylinder type magnetic coupling
Instrumentation	One TV, lamps 150 W x 2,. magnetic compass,depth sensor 35 mm still camera
Speed	Forward 2 kt, reverse 1.5 kt, up 0.6 kt, down 1 kt,rotation 120^o sec. port/stbd. 1.5 kt
Cables	Main cable (ø 16 mm) 100 m neutrally buoyant cable (ø 16 mm) 30 m

CONTROL/DISPLAY

Control/display weighs only 8 kg and it's dimension is 38(L)x28(W)x12(H) cm. A micro-computer which controls whole system has memories of 1 K byte RAM and 2 K byte ROM. Whole motions of the vehicle are controlled by 2 joistics on a handy control box (21(L)x12.5(W)x7(H) cm, weight 1.2 kg). Each joistic has 2 potentiometers and digitally converted values of potentiometers through A/D converters are read in the CPU by commmand. These digitally converted values of potentiometers are motion parameters of the vehicle. These parameters; J(1)(forward/reverse), J(2)(port/stbd.), J(3)(up/down), J(4)(rotation) are used to calculate speed data of 4 thrusters. Speed data of each thruster which are transmitted from CPU to the vehicle are converted to chopper signals and drive thrusters.

Data transmission between CPU and vehicle is maintained by digital bi-directional asynchronous serial transmission (max. 128 channels). Numbers of channels and priolity of data are changeable by software.

Control/display has 2 digital switches, 2 display port and 10 LED. These include:

--- Vehicle depth display
--- Data display
--- Data select digital switch
--- Balance digital switch
--- LEC; TV on/off, light on/off, error(system malfuction), TV position (upper, middle, lower} and spare.

Control box has 2 joistics and 10 switches. These include:

--- Joistic 1 J(1), J(2); forward/reverse, port/stbd.
--- Joistic 2 J(3), J(4); up/down, rotation
--- Switches Balance, automatic depth keeping, TV on/off, light on/off, camera drive and 5 spares.

Fig. 2 shows control block diagram.

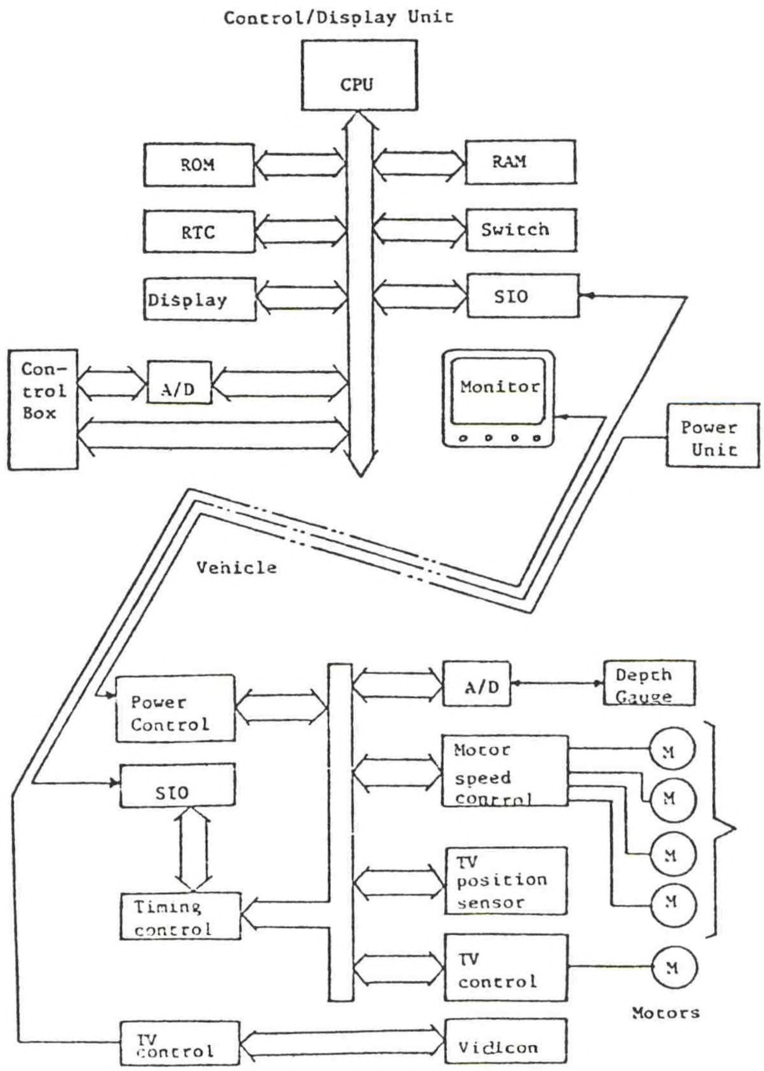

Fig.2. Control block diagram

VEHICLE

Outline configuration of the vehicle is determined to nearly spherical and present operating depth is shallower than 200 m. Therefore, casted aluminum alloy is selected to make pressure hull, because another materials such as FRP, carbon fiber (CFRP) is rather expensive than casted aluminum. Casted aluminum hull is machined to fit acrylic dome port and another parts such as cylinders to fix thrusters, aluminum plates to fix electric connector, lead weight, nozzles of thrusters. Then these parts were welded to the hull. Finally, machined and welded hull was cast sealed (CIDIX cast seal) to fill minor voids. The NUC recommendation (Stachiw, 1973) was adapted to design viewport. 90-degree sector angle spherical window (t=8 mm) was fabricated and installed. About 7 kg of lead weight was fitted at the lower part of the vehicle for buoyancy control.

When whole components of the vehicle such as TV, electronics, thrusters, weight etc. were installed, in air weight of the vehicle was 43 kg and buoyancy was 1 kg.

CABLES

Length of the main cable is 100 m at present and length of the neutrally buoyant cable is 30 m. The diameter of the main cable is 16 mm and the cable is composed of two coax, one twisted pair and 16 power conductors. One coax, one twisted pair and two pairs of power conductors are used.

The neutrally buoyant cable is developed under co-operation between JAMSTEC and Showa Wire and Cable Co. The cable can hold neutrally buoyancy to depth of 500 m. The cable has 2 coax, 4 power conductors and special buoyant material. The specification of the neutrally buoyant cable is shown below:

Outer diameter	16 mm
Weight in air	180 kg/km
Cable density	0.89 (at 0 kg/cm^2)
	1.0 (at 50 kg/cm^2)
Max. tension	150 kg
Power conductor	30/0.18mm x 2
	20/0.18mm x 2
Coaxial	2 (one for TV, one for telemeter)

THRUSTER

Since 1975, we used magnetic torque coupling thrusters. Magnet of early stage were disk shaped and made from ferrite, so they are rather rigid and heavy. Recently, we have used cylinder type Magnetic couplings made from rare earth(Samarium-Cobalt), so they are very small and light in weight.

The specification of the thrusters of the JTV-1 is shown below:

Motor:	70 watt d.c.,100 volt, 1.8 A 1000 rpm
Coupling:	Gap 5 mm
	Torque more than 7 kg·cm
	Outer ring ø44 x ø38 x 30(L) mm
	Inner ring ø28 x ø22 x 30(L) mm
Propeller:	O.D. 152 mm, pitch 126 mm, 3 blade with colt nozzle

INSTRUMENTATION

TV: Vidicon tube of the TV is a National newvicon, wv-1250 A with 8.5 mm wide angle lens (KF-85A), sensitivity of the TV is 0.5 lux, small and compact electronics of the TV is made in JAMSTEC. Sometimes, color TV of CCD (MOS) type (Hitachi VKC-1000) is used.

Light: two 150 watt water tighted silvania tungsten halogen lamps are used.

Compass: magnetic compass for diver is attached in front of the view port.

Depth sensor: Semiconductor type depth sensor (35 kg/cm^2, accuracy $\pm$ 0.05 kg/cm^2)

Still camera: 35 mm motor driven camera is able to install in the pressure hull.

SOFTWARE

The program which controls the vehicle is composed of about 1100 byte and stored in ROM of 2 K byte. For example, thruster control flow chart is shown in Fig. 3.

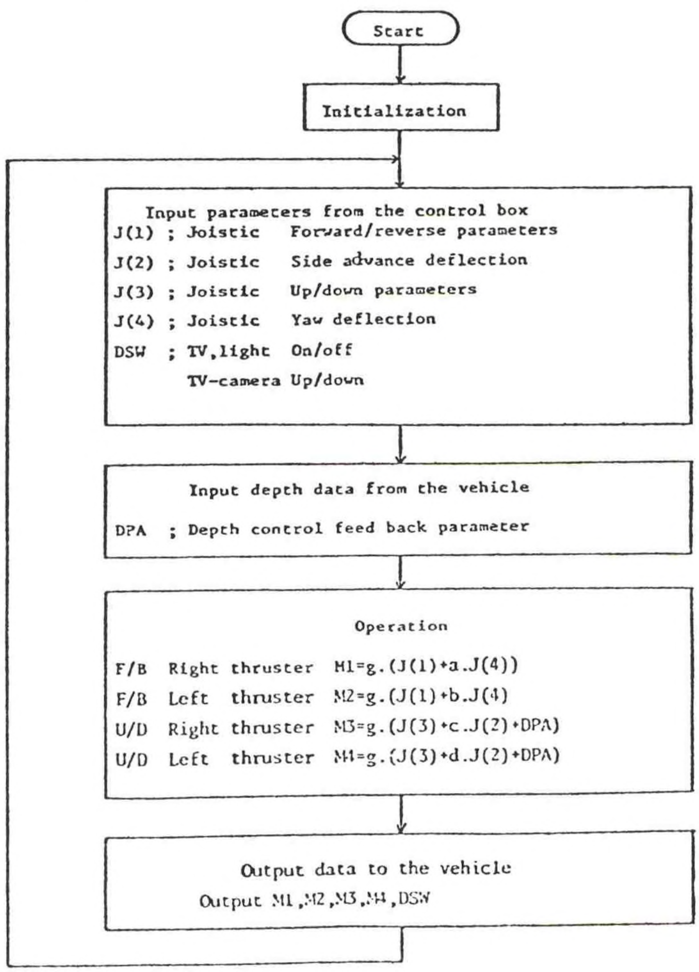

Fig.3. Thruster control flow chart

THE SECOND VEHICLE JTV-2

In October 1981, the second vehicle of JTV-1 type (JTV-2) was constructed by O.I.Co. under permission of JAMSTEC. The JTV-2 is a completed JTV-1 type vehicle for sale and has added specifications such as automatic heading control, display of cable twist, vehicle heading and TV tilt angle etc. The vehicle has an underwater transformer which attached between main cable and neutrally buoyant cable.

TEST RESULTS

In November 1981, these two vehicles were tested at the Sagami Bay depth between 24 to 95 meters and showed superior operability. After this the JTV-1 was used for benthic animal study at the Tokyo Bay and precious coral survey at the Tosa Bay, Kochi Prefecture, depth around 105 meters.

Fig. 4 and 5 show the JTV-1 vehicle.

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Stachiw,J.D., "Recommended practices for the design, fabrication, proof testing and inspection of windows in man-rated hyperbaric chambers", NUC TP 378, 1973.

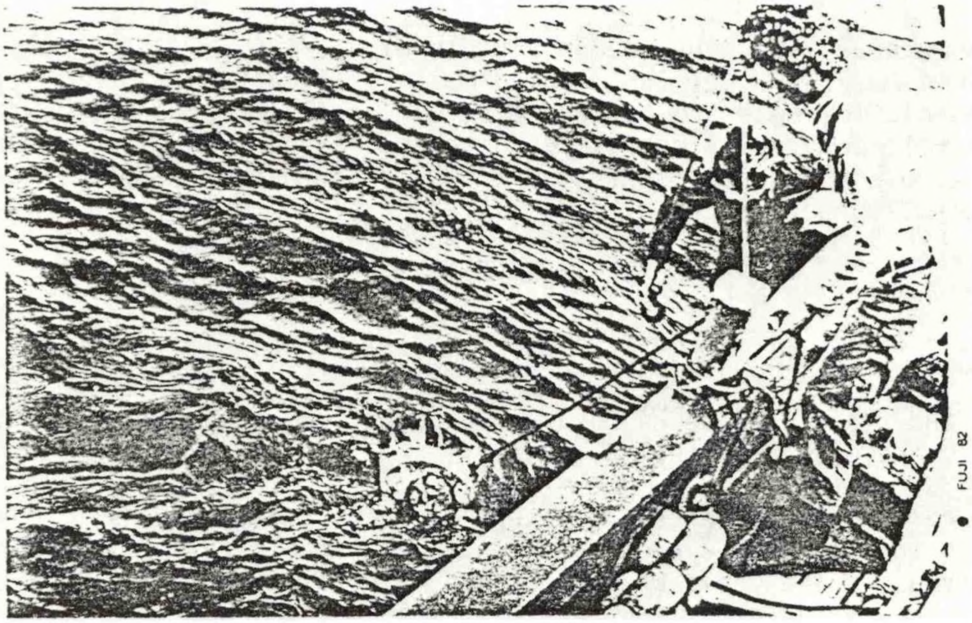

Fig. 4. The JTV-1 under retrieval.

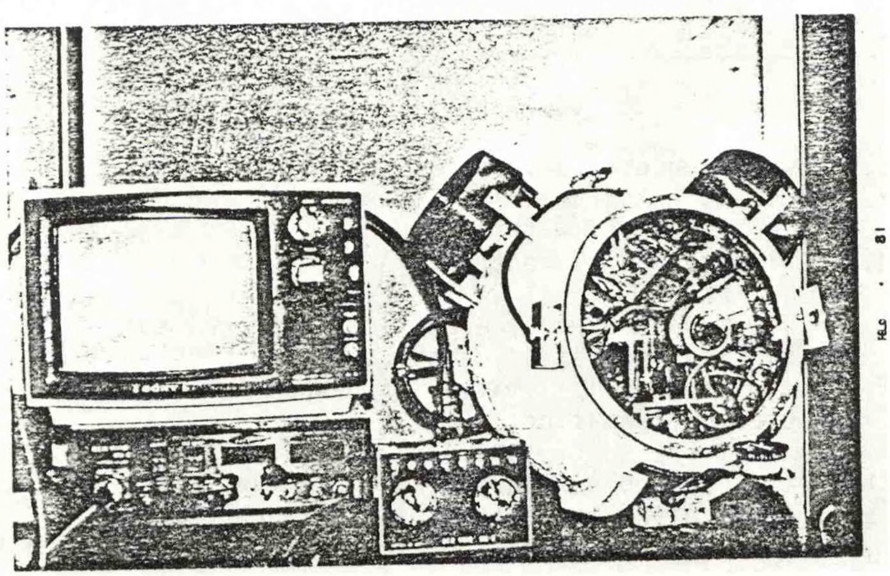

Fig. 5. The JTV-1 vehicle, control/display and control box.

DIVER'S HAND TOOL

by

Hidehiko Kanata
Natsuo Inagaki
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JAMSTEC

Introduction

For the practical use of diving technology, diver's hand tools are the most basic and most important facilities.

Manned undersea science and technology department of JAMSTEC had tried to develop and design the electrical underwater tools in the Seatopia project, and two types of the tools were producted. One is for a grinder or wire-brush, and the other is for a torque-wrench. In 1979, these tools were improved to be much more convenient for divers' work. So we have four electrical underwater tools now.

Research were continued from the standpoint of diver's working capabilities, and then several problems were noted in the use of conventional underwater tools. To solve these problems, we planned to develop the seawater hydraulic tool in 1981, and recently produced the first one in the world.

First Electrical Tools

Electrical underwater tools have the following features:

Merit
1. power sources are very easy to attain, especially on board
2. cable is comparatively light weight, and needs only one cable
3. no pollusion of water
4. no limitation of depth

Demerit
1. diver may be hurt by electrical leakage, so electrical isolation is the critical problem
2. speed control is limited--high-speed revolution causes over-heating

In these type of tools, electrical isolation is the most important problem. But once solved, this tool will be much better for divers' operation. So we made two electrical tools, and their principal particulars are shown in Table 1.

Table 1.

Type	drill and wire-brush	torque-wrench
Motor	Three-phase squirrel -cage induction motor oil-filled, pressure equalizing type	
Power	0.4 kw	
Power source	AC 200V 3 60Hz	
Applications	drill...max.13mm dia. wire-brush ....max.85mm dia	max. size of bolt & nut .....16mm dia.
Weight	abt. 8kg (dry) 5.5kg in water	abt. 10kg (dry) 7.0kg in water
Others	abt. 1,700r.p.m.	max. torque is about 15kg-m at 0 r.p.m.

These are shown in Photo 1. & 2.

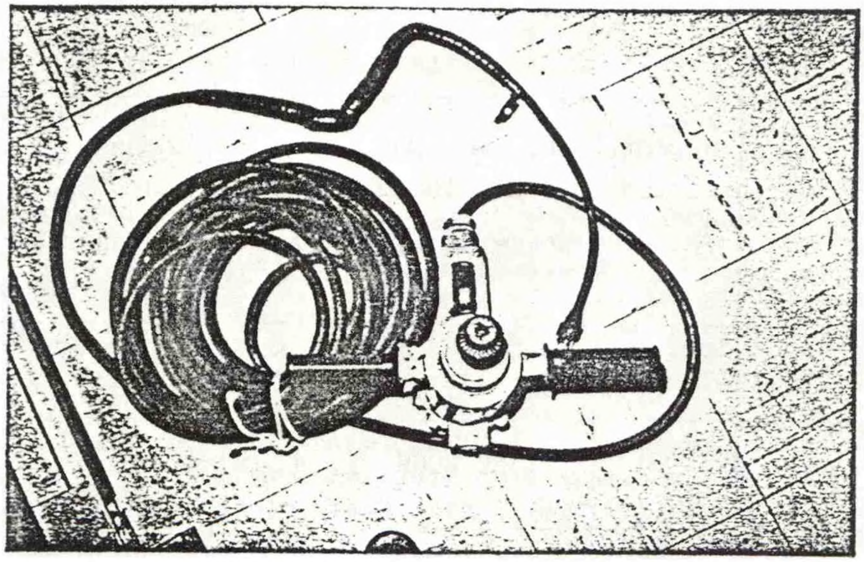


Photo 1. Electrical tool for grinder,
drill and wire-brush

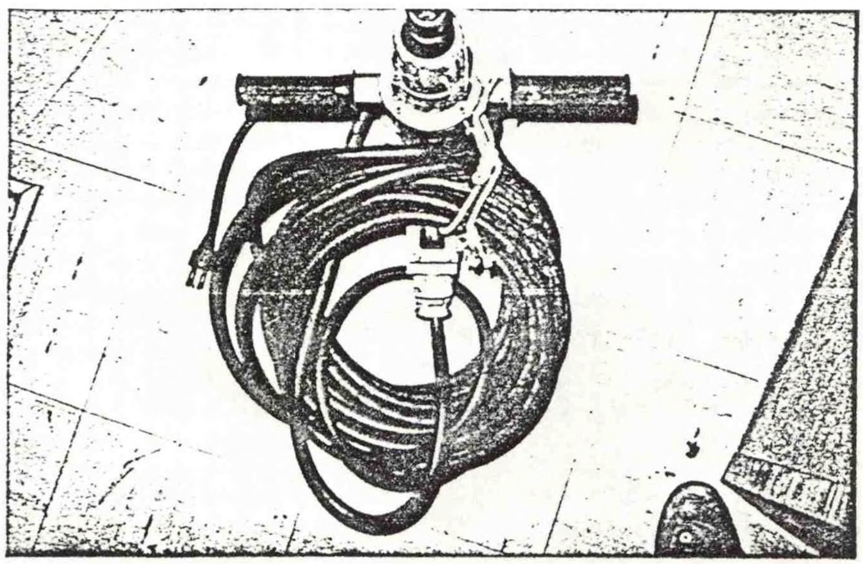


Photo 2. Electrical tool for torque-wrench

Improved type of electrical tools

Some improvement have been made to these tools (Photo 3, 4). The rear grip is made thinner, and the frong grip is able to be turned round the body so the diver can choose his favorite pose in water, and can grasp the tool tightly.

Through these studies, we tested the electrical leakage, and confirmed the safety of these tools. But, though electrical welding is commonly used, many divers have a tendency to be afraid of using these electrical tools.

Seawater hydraulic tool

After production of electrical tools, we wished to develop the new type underwater tools to solve several problems of conventional type.....oil hydraulic, air, electric. In those days, SUGINP MACHINE CO. developed the motor driven by hydraulic water. So, we decided to make seawater hydraulic tools using this motor, and completed the trial production. The view is shown in Photo 5, 6, 7. The principal dimensions are in Fig. 1. This tool is used for grinder and wire-brush.

The body is made from a glass micro-balloon, and the other parts are stainless steel and aluminium alloys. Using another type of motor, it's power can be increased to 2.0 HP at the pressure of 40kgf/cm^2 and the flow rate of 65lit/min. Each handle is able to be rotated around the body, and the front one is movable about 50mm before and behind. But this is quickly fastened by the lever on the ring.

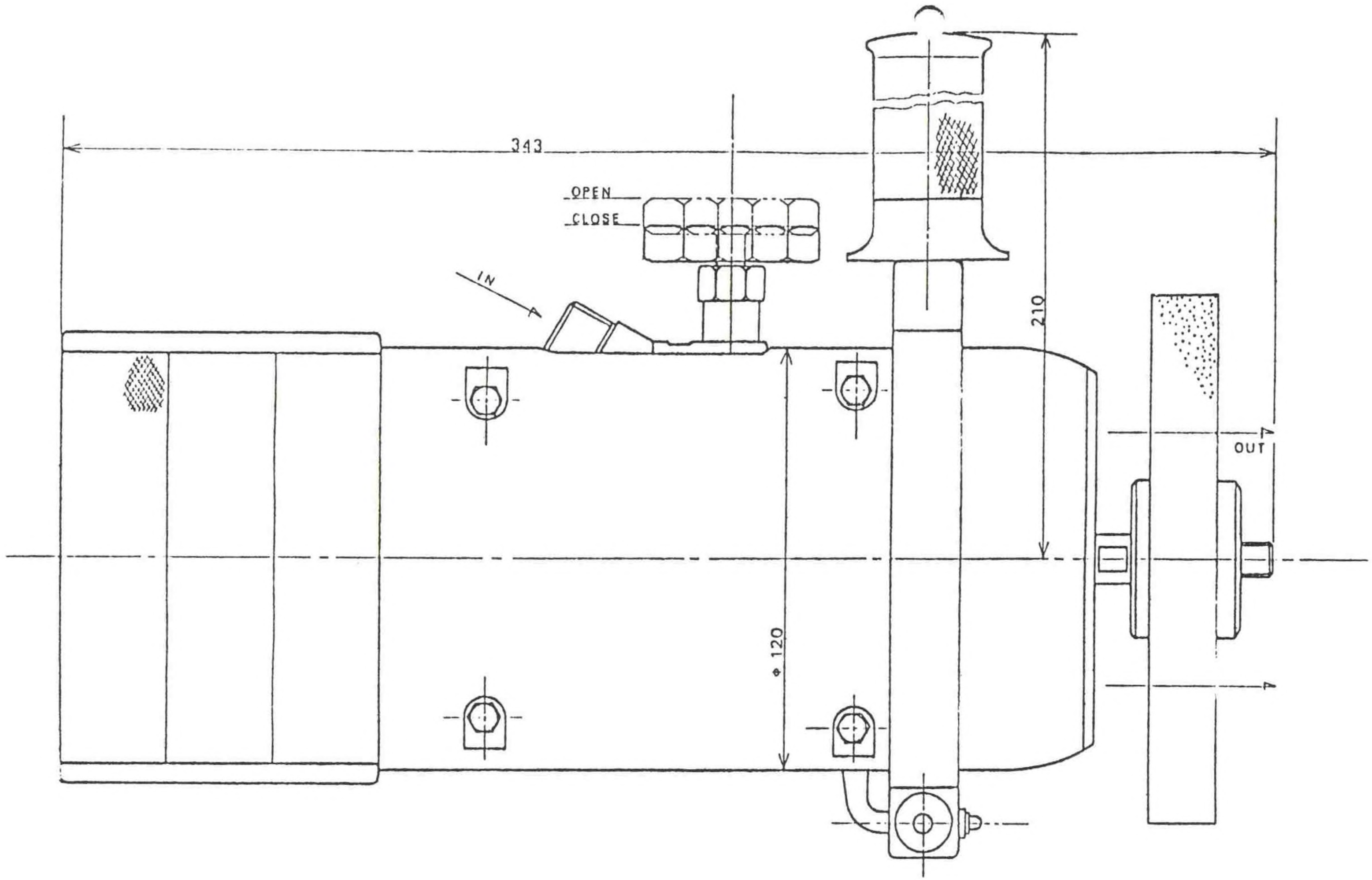
Since the inlet of water has the angle of 30^o to the body, there is no interference between the diver's hand and the hose. Four circular arc slits shown in the front of this tool are the outlet, and they serve to eliminate dust in the sight of the diver.

The merit of this type of tools is as follows.

Using seawater (not oil, air, electricity)
-----no environmental pollution activation fluid
is abundunt in the sea, and needs no stock
no hazard of burning or receiving electrical shock
owing to the low viscosity of water;
viscous resistance in hose is smaller than oil
no limitation of depth can decrease the operation cost

Needless two hoses
-----pump's power is smaller than the one of oil
weight can be lightened
convenient for transportation

Our plan for the next two years will be to make a torque-wrench and drill of this type.



Max. power ----------0.8IP (torque=0.33kgf-m at 1,750 r.p.m.)

Max. pressure--------60kgf/cm^2

Flow rate------------22 lit./min.

Weight---------------4.6kgf (2.0kgf in water)

Fig. 1.

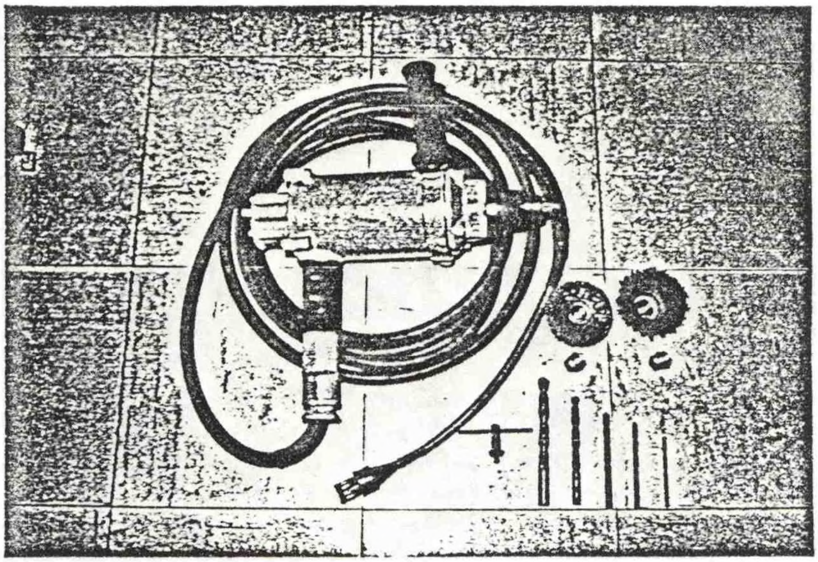


Photo 3.

Improved type, for drill and wire-brush.

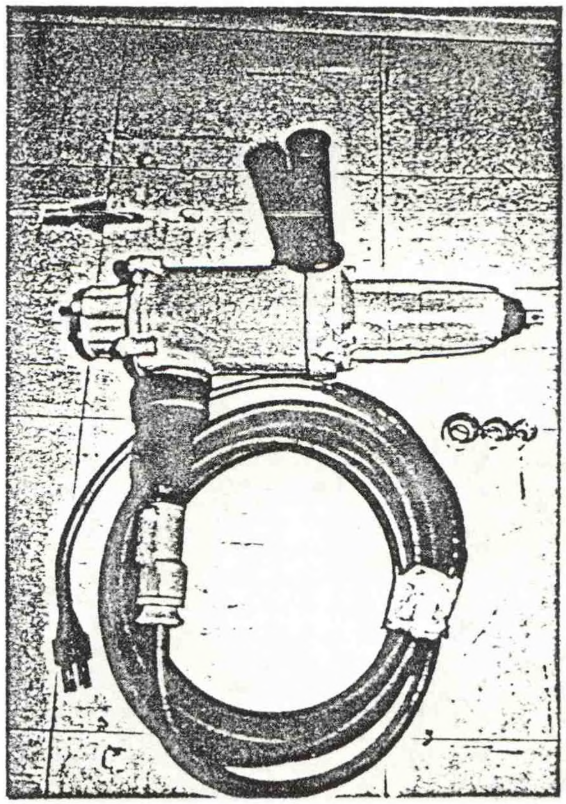


Photo 4.

Improved type, for torque-wrench.

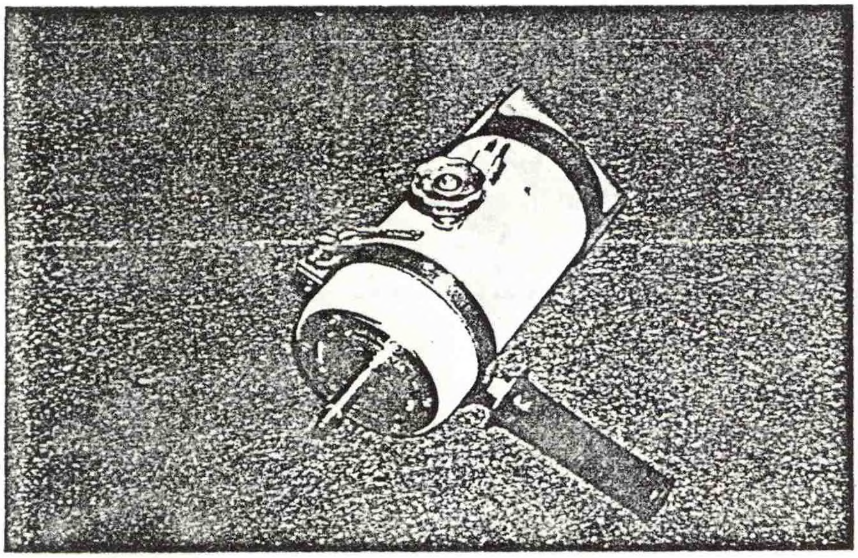


Photo 5. Front view

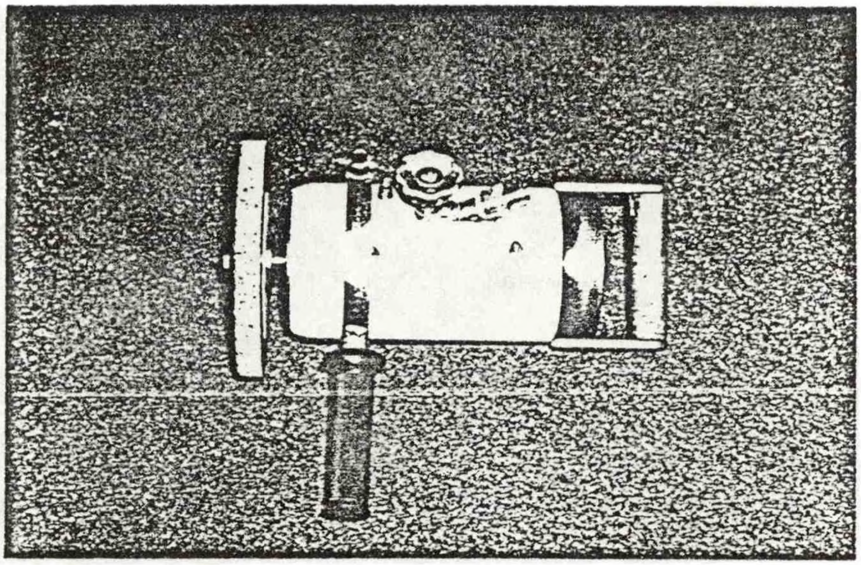


Photo 6. Side view with grinder

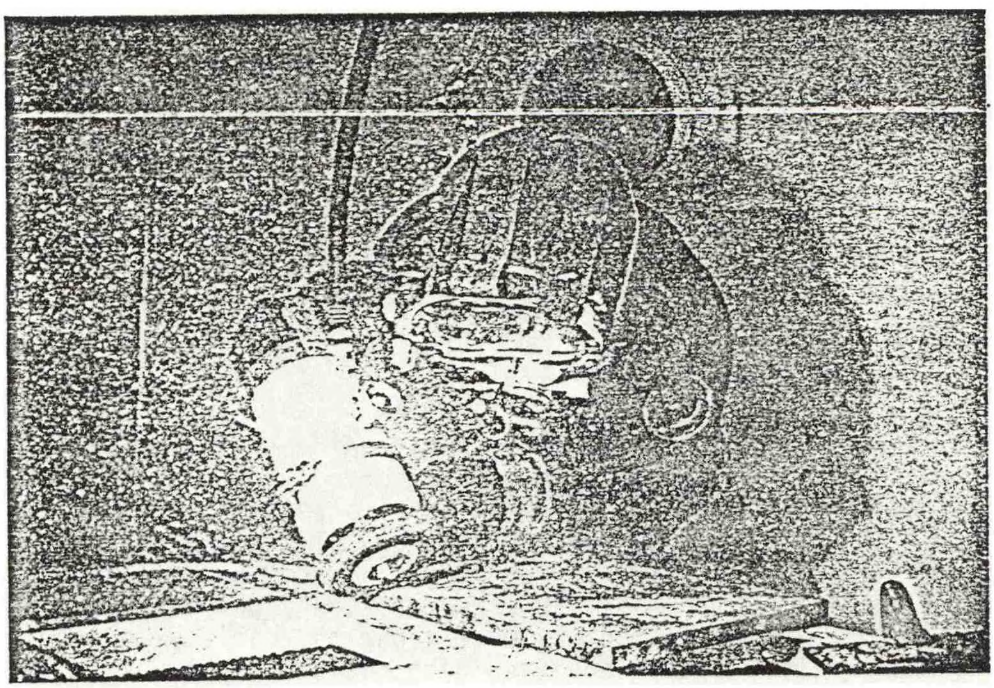


Photo 7. Underwater operation

DEVELOPMENT OF A TOWED OCEANIC DATA COLLECTION SYSTEM AND AIR LAUNCHED EXPENDABLE SENSORS

by

Ken Sasaki

Japan Marine Science and Technology Center

The purpose of development is to provide high-performance oceanic-data-collection systems for the survey and monitoring of the vast ocean space around Japan.

With the towed system, one can perform high-resolution measurement of the conductivity, temperature, and depth from the surface to a depth of 200 m. Table 1 shows the specification of the system. Fig. 1 shows a schematic view of towed system. Fig. 2 shows the data communication system which uses inductive coupling. The initial operational test of the system is scheduled for early 1983.

Table 1 Specification of Towed System

Operating Depth	0-200 m
Towing Speed	12 knots
Cable Length	400 m (faired)
Sensors	Conductivity, Temperature and Depth (Fluorescence and Light Scattering are included as option.)
Sampling Rate	5 Hz
Vehicle Weight	15 kg (without sensors)
Depressor Weight	35 Kg

Fig. 3 shows a prototype of a vehicle with a depth sensor and a thermistor whose signals are amplified and recorded with a cassette tape recorder. In our system the vehicle that carries sensors is not towed at the end of a cable, but it is guided by the catenary of a towed cable whose end is pulled down with a depressor. As shown in Fig. 1 and Fig. 3, the vehicle consists of a cable guide, a wing, an elevator, and a body with a tail. The cable guide helps the vehicle smoothly move along the cable. Inside its streamlined cover, the guide is equipped with two small sheaves in contact with the front face of the cable. The wing is hinged to the upper end of the cable guide. The attack angle of the wing is controlled by means of a small elevator fin supported about one chord length behind the trailing edge.

When the vehicle sinks and reaches the lower limiter (see Fig. 1), its momentum is absorbed by the limiter, and a flexible rod extending from the guide to the elevator transfers part of the impact of the elevator fin. Then the elevator angle is switched to the opposite side, and the vehicle starts rising. When the vehicle reaches the upper limiter, it is forced to start sinking by the same mechanism.

Prototypes of the vehicle have been tested at Sagami Bay, using a four mm diameter steel wire towed at four knots. The depressing force was about 35 kg. Fig. 4 shows a depth recording of the prototype.

Expendable sensors are to be launched from airplanes at selected stations within a 200 nautical mile area around Japan. Table 2 shows specification of the expendable sensor. Fig. 5 shows a view of the expendable sensor, and Fig. 6 shows airborne displays and recorders.

When the sensor is pushed out from the launcher on an airplane, its closed blades are immediately forced to open by the wind pressure, and the rotating blades control the falling speed of the sensor. On the sea surface the buoyancy of the blades supports the transmitter unit for about 20 minutes, while the data from the falling underwater probe are communicated to the airplane to be displayed and recorded there. The underwater probe is equipped with a thermistor, a four-electrode conductivity sensor, hybrid IC's, and lithium batteries. Fig. 7 shows the conductivity sensor.

As a first operational experiment, ten sensors were launched from 300 m height at Sagami Bay, February 1982.

Table 2 Specification of Expendable Sensor

Operating Depth	0-2000 m	
Temperature Sensor	Range	-2 to 35^{o}C
	Accuracy	0.05^{o}C
Conductivity Sensor	Range	25 to 65 m mho/cm
	Accuracy	0.1 m mho/cm
Depth Accuracy	2%	
Falling Speed	10 to 15 m/s in air	
	4 to 5 m/s in water	
Sampling Rate	20 Hz	
Data Resolution	10 bits	
Communication Channels	169.25 and 169.65 MHz	
Weight	3.5 kg	
Length	0.55 m	

Table 2 (continued)

Falling Speed	10 to 15 m/s in air
	4 to 5 m/s in water
Sampling Rate	20 Hz
Data Resolution	10 bits
Communication Channels	169.25 and 169.65 MHz
Weight	3.5 kg
Length	0.55 m

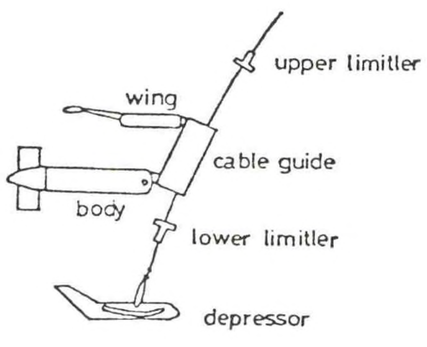


Figure 1 Schematic View of Towed System

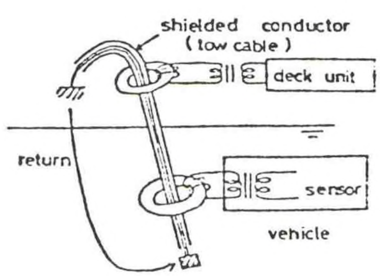


Figure 2 Data Communication System

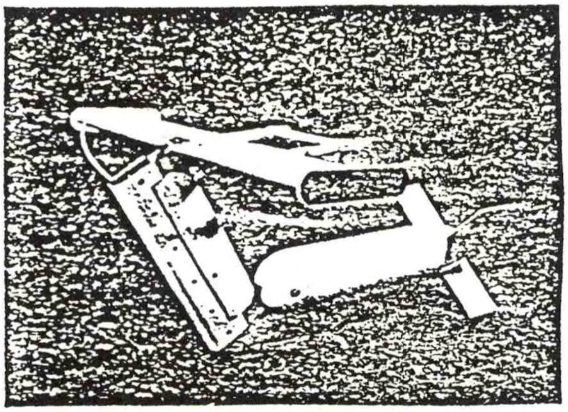


Figure 3 Prototype of Vehicle
(length:0.60m, with:0.60m,
total height:0.34m, and weight:6kg)

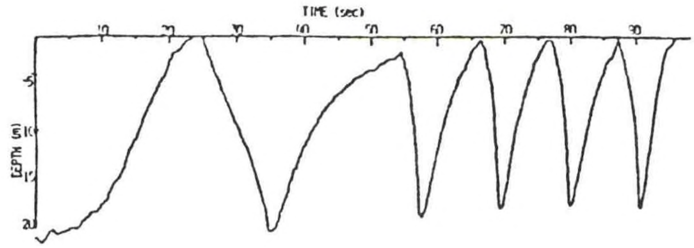


Figure 4 Chart Recording of the Depth of the Prototype

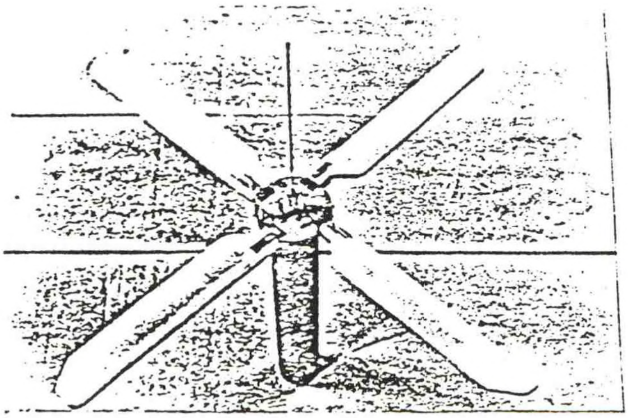


Figure 5 A View of Expendable Sensor

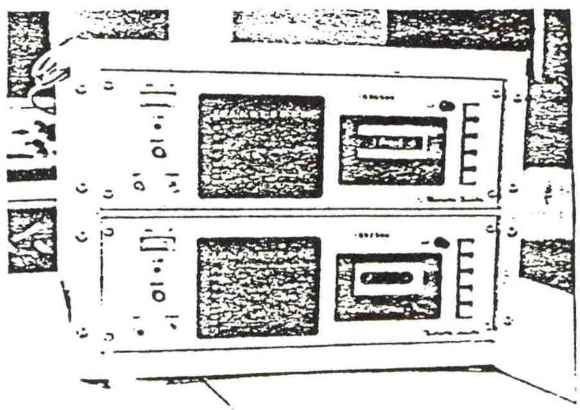


Figure 6 Airborn Displays and Recorders

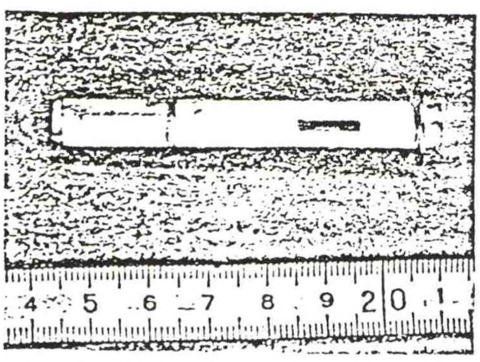


Figure 7 4-electrodes Conductivity Sensor

REFERENCE

Nomoto, M. and Sasaki, K.: Development of an Underwater Sliding Vehicle for Oceanographic Measurement, OCEANS 81 Conference Record, pp.1151-1154, 1981.

JAPANESE MARITIME RESEARCH PROGRAM

by

Ship Bureau, Ministry of Transport

When we want to develop and utilize the ocean, we must know it well beforehand. The circumstances of ocean, however, is so severe that the greater part of its actual condition is still unknown.

In this paper we would explain our attitude to the maritime research and explain the outline of Japanese maritime research program for 10 years from 1981.

I. Necessities of ocean research

In addition to the conventional utilization, the developments of such as manganic nodules, petroleum, natural gas and sea organs, plans of ocean-petroleum-stock and artificial islands, are being proceeded in the ocean.

The following informations are inevitable to promote such developments.

1) Information for safe and economical navigation of ships.
2) Information for efficient fisheries, i.e. consolidation of coastal fishing-ground, promotion of cultivated fisheries and investigation of fishing-ground, etc..
3) Information for selection of proper places, construction and control of marine facilities and active utilization of ocean space including offshore deeper areas.
4) Information for development and utilization of natural resources in the sea and on the bottom of the sea.
5) Information for making various works in the sea safe and efficient.
6) Information for prevention of coastal disasters which would increase the importance in proportion to progress of coastal development and utilization.
7) Information for preservation and consolidation of ocean environment.
8) Information for earthquake forcast and elucidation of unusual weather and weather changing mechanism.

In order to get the various information mentioned above, it is necessary to promote the maritime research positively.

II. Promotion plan of maritime research.

1. Research into the submarine topography and geological structure.

There are some areas around Japan considered as Japanese continental shelves beyond 200 sea miles from territory, such as Oki-daitou ridge, Kyusyu-Palau ridge, Ogasawara plateau and other Japanese south seas.

Therefore, in order to clear the range of continental shelves, exclusive economic zone and territorial waters and consolidate general fundermental data needed for development of these areas, we research submarine topography and geological structure and promote the consolidation of "Basic map of the continental shelf areas" and "Basic map of the coastal waters".

2. Marine geodesy

In order to mark out precisely a range of territorial waters and exclusive economic zone within Japanese jurisdiction and to improvement the positioning precision on and in the sea, we dispose geodesic base point in 61 islands around Japan and establish a marine geodesic network.

3. Oceanographic and maritime meteorological observation

In order to contribute to safe and economical navigation of ships, construction of ports, harbores and various marine facilities and improvement of forecast of marine conditions or weather, we research into oceanic conditions such as ocean wave, sea surface wind, tide, tidal current, water temperature and ocean current, sea water, sea fog and various phenomena in breaker zones.

Especially in the north Pacific, an important sea lane for Japan, weather and maritime conditions are very severe in winter, and many large vesseles such as Onomichimaru were in distress.

We research them with priority by buoy robots which can continuously observe the process of occurrence, growth and extinction of ocean wave grasp the actual condition of unusual ocean wave etc.

4. Research into marine environmental condition

In order to consolidate fundermental information for marine environmental protection, we promote research into the actual condition of pollution in closed waters such as inland sea, the change of pollution level from coast to ocean and the actual condition of bottom sediments in closed waters or effects of their removal and promote the study to establish the forcasting system of drifting courses of discharging oil, etc..

III. Control of data on oceans

When we think of control'of data about oceans, the data can be devided into two kinds, that is to say, real time data and non real time data. Real time data is used for getting prompt information while non real time data, is not required instantly, can be utilized for the long period of time after obtained. As it takes along time and is quite hard to get each data, it needs to keep the data right to use it easily according to the purpose of usage, and we should take into consideration that the data can be used as in many fields as possible.

It is somewhat different between real time data and non real time data in their aim of control and achievement methods. As for real time data control, we should make an effort to collect the information sources for the data and put them together, and also provide users with the data efficiently and speedly. With regard to non real time data, on the other hand, it is necessary that we always take care of the increase of indexes and quantity of the data, and the methods of settlement, keeping and providing system of the data so that it can be multipurposely used.

ADVANCES IN SHIP PROPULSION AND MANOEUVRABILITY

by

Ship Bureau, Ministry of Transport

(1) Resistance and propulsion

Among basic researches on wave resistances, free surface shock waves have been studied, Miyata et al. (J. SNA. 147) investigated the characteristics of free surface shock waves which are quite different from those of former Kelvin type free waves. The line of discontinuous flow velocity across the wave crest and other particular properties enough to clarify the existence of shock waves are found in the near field of ship models. Speed dependences of the shock (wave) angle, the simulation by a shallow theory and analyses by the method of "characteristics" are discussed. Takahashi et al. (J. SNA. 148) studied free surface shock waves generated around wedge-shaped simple models. Varying their wedge angle and draft, a systematic change of shock angle and its significant relation with draft base Froude numbers are investigated. From these results, a new concept "equivalent shallow water depth" that makes the method of characteristics effective for hull form improvements is introduced. Kawamura et al. (J. SNA. Kansai 179) carried out a large number of series tests to get over all influences of hull particulars on the shape and magnitude of free surface shock waves. Generally the decrease in shock (wave) angle leads to the reduction of the resistance due to free surface shock waves. Bulbous bows have also the same effect to reduce the resistance by shock waves.

The velocity potential which satisfies both the nonlinear free surface condition and the hull surface condition was formulated by Shimomura et al. (J. SNA. 146). The wavy source distribution is added to fulfill the hull surface condition in the low-speed theory. The wave resistance, the hull side wave profiles and the velocities around the hull surface were evaluated. The results coincide fairly well with the measured in low speed, especially the humps and the hollows of the calculated weve resistance curves are remarkably reduced. Lin et al. (J. SNA. Kansai 172) presented an improvement of hull forms with less wave resistance by introducing Guilloton's transformation into the optimization program procedure. The method is applied to the refinement of the fore body of a container ship. The effectiveness of the method was acertained by model experiments of resistance tests and wave analyses.

Matsui et al. (J. SNA. 147) developed a method of hull form improvement. Making use of wave-analyzed data of several sister ships with same dimensions but different sectional area curves so as to yield orthogonally different wave amplitude functions, an improved hull is obtained through their optimization, which results in the linear combination of the sectional area curves of the sister ships. The method is applied to a design of a medium speed ship and tank-tested successfully. Miyata et al. (J. SNA. 148) discovered the effectiveness of of stern-end-bulbs (SEB) attached to the rear end of ships. Through tank experiments of three different models, they conclude that about 5% power savings can attained by the reduction of wave resistance partly due to free surface shock waves and partly due to propagating free waves. In the design procedure a computer program is applied for evaluating the wave pattern resistance based upon the approximate formulation as Neumann-Kelvin problem. Sakao et al. (J. SNA. Kansai 179) analyzed hull pressures and stern waves of transom-stern ships. Based upon slender body theories, hull pressures or stern waves of a transom stern is approximated by the flow of traveling pressure distribution. The influence of submergence and slope of transom-part on hull pressures or stern waves is investigated which is in good agreement in tendency with their experiences.

Both fundamental and practical approaches were made on the analysis of viscous flow and its resistance. Nagamatsu (J. SNA. 147) proposed a calculation of viscous resistance of ships using a higher order boundary layer theory where the pressure variation across the boundary layer due to the curvature of the hull surface as well as the displacement effect of the boundary layer on outside the potential flow are taken into account. The calculated viscous resistance for fine ships agrees well with the towing test result while a large discrepancy remains in case of full ships. Regarding the scale effect of form factor K, he derives that larger the model larger the evaluated K, which is common in tendency with experimental experiences. Tokunaga et al. (T. SNA. West 59) studied local effects of hull surface roughness on ship resistance. Systematic resistance tests of full ship models, varying the lengthwise position and area of roughened part, are carried out and found that the roughness effect of the first quarter length of a ship is significantly large (above 40% of wholly roughened). Mishima et al. (J. SNA. Kansai 176) made a statistical approach to the form factor to obtain a substantial predicting formula. The minimum AIC (Akaike's Information Criterion) method is used to choose most effective variables for prediction. Orito et al. (B. SNA 616) reported the speed down of ships owing to the time growth of the fouling. Experiences in MOL are analyzed with references to BSRA and NSRI surveys. Yokota et al. (Sumitomo Rev. 28) investigated the aging of propulsive efficiency of ships. Using a quantity noticed to the "total efficiency" from energy point, the performance of two ships, one with fixed pitch propeller and the other with controllable pitch propeller is compared which results in the less aging of the latter.

Studies on propulsive performances are reported including hull-propeller-rudder interaction.

Saito el al. (J. SNA. 146) presented the results of model tests performed in the towing tank to investigate the effects of afterbody shapes and highly skewed propellers on propulsion and propeller-excited forces. A noticeable reduction of the non-uniformity of wake was reported to be attained by the formier and of the propeller-excited forces by the latter.

Based upon a concept that the assessment of ship resistance should be made at propeller rotating condition, Miyata et al. (J. SNA. Kansai 177) contrived a method of estimating the inviscid resistance of selfpropelling ships where the approximate Neumann-Kelvin solution is applied partially. Its validity is affirmed by model experiments. Physical meanings of the thrust deduction factor are discussed. Lin et al. (J. SNA. Kansai 179), following to the above paper, developed a substantial method of designing hull forms of less inviscid resistance which is applied to the design of aft half body of a certain ship. They are convinced that 10% reduction in BHP is attained with extrapolation of self propulsion tests and simultaneous evaluation of the both wave resistance and pressure resistance changes due to the hull form changes under propeller actions is effective.

Many experimental investigations were made to gather informations for hull form design. Saito et al. (Rep. SRI, Supplement 3) carried out series tests of 9 ship models to furnish the chart published from Cooperative Association of Japan Shipbuilders so as to be applicable to the power estimation of wide-beam shallow draft coastal ships. Ueda et al. (Rep. SRI 17-4) studied the scale effect of power estimation factors and the effect of bossing on resistance and other hydrodynamical forces with regard to a twin screw container ship. 4 geosim models ($L = 4m \sim 12m$) are tank-tested with POT of geosim propellers to establish a reliable prediction of actual ship performance. Yamaguchi et al. (Lecture SRI 36) continued model tests of wide beam shallow draft ships with $C_B = 0.65$, $L/B = 4.5 \sim 6.0$. The authors point out the good accordance of tested results of C_w of three beam series models, a kind of non-dimensional quantity of wave resistance R_W divided by B^2, which suggests as if the wave resistance is proportional to B^2 even in wide beam ships. Terai (SRC Tech. Note 8) carried out model tests of same kind of ships ($C_B = 0.55$, $B/d = 3.4$, $L/B = 4.5 \sim 6.0$). He concludes that wave resistance due to free surface shock waves becomes large for wide beam ships if the hull is carelessly designed. However it may be suppressed by making the entrance of hulls fine. Ohno et al. (SRC Tech. Note 8) performed model experiments on 999GT two domestic tankers, one conventional, the other lengthened for power saving. Ohhashi et al. (SRC Tech. Note 8) conducted also some model tests concerning the effect of bow and stern shape of medium size full vessels ($C_B = 0.8$, $L/B = 5.6$, $B/d = 3.4$). The appropriate bulbous bow, sectional area and waterline curves can reduce the power requirement about 7% while a poor application of slowly rotating large propellers to the unsuitable stern shpae makes considerable worse of propulsive performances. Suzuki et al. (National Research Institute of Fisheries Eng. No. 1) experimented the scale effect of resistance of 5 GT FRP ships using three geosim models. Fujii et al. (SRC Tech. Note 8) measured resistance of a model of hard chine fishing boat attaching chine spray strips. When Fn exceeds 0.43, the effect of chine spray strios on resistance becomes negligilbe and running trim does not vary. Difference is a slight lift due to the lifting force of the chine spray strips. Statistical approaches and data assembling for hull form design have been continued. Takashiro (J. SNA. Kansai 177) improved the classic method of EHP preiction based on the Yamagata resistance chart, adding data of full ships ($C_B < 0.8$) and decreasing interpolation step of B/d correction. Special cares are taken for modern bulbous bows, wake fraction, thrust deduction factor and frictional line. Sezaki (J. SNA. Kansai 179) studied the speed loss or the power increase to be required to maintain the advancing speed of a large car carrier in service with helm adjusts and drifts due to the wind. To evaluate the resistance increase, experimental results in a wind tunnel and a towing tank are incorporated with equations of maneuvering motion. The resistance increase due to the drift and helm adjustment can't be ignored compared with that due to the direct wind resistance. Hirai et al. (SRC Tech. Note 8) continued a statistical analysis on the ship-model correlation of power estimations. Sea trial tests are analyzed using MHI-method and discussion is made on ΔC_F.

(2) Propeller

Ymasaki et al. (T. SNA. West 58) showed experimentally that for MAU type propellers the influence of blade contour and thickness distribution on propeller open characteristics is not negligible and proposed a practical method in which blade element theory is applied to calculate the influence of blade contour etc. on open characteristics. Okamoto et al. (Lecture SRI. 34) showed the design diagram of a six-bladed propeller with high pitch and 80% expanded-area ratio for high speed container ships, and reported that this propeller is superior to the conventional efficiency and the cavitation characteristics.

The 174 research committee of the Shipbuilding Research Association of Japan (Memo. SR. 329) conducted the study of propellers with large diameter where examinations were made upon propulsive performance, cavitation characteristics and propeller vibratory forces. Furthermore, the committee reviewed prediction methods of propeller cavitation, erosion on propeller blades and propeller vibratory forces.

There were reports on unconventional propellers. Chiba et al. (J. MES. 15), making the comparative model experiments on propellers of high speed vessels, showed that the highly skewed propeller reduces propeller vibratory forces without sacrificing any of propulsive and cavitation performances. They reported that high blade stress was measured in the neighbourhood of the trailing edge of the highly skewed propeller. Nagamatsu (J. SNA. Kansai 177) studied the effects of skew on the pressure distribution at propeller blades. He made both measurement and theoretical calculation of the pressure distribution on the 0.7 R section of the highly skewed propeller (skew angle 60°deg.) and compared with the result of the conventional propeller.

There were many reports on stress acting on propeller blade, propeller-excited force and so on. Umeno et al. (Trans. NK. 167) reviewed a stress calculation method on propeller blades. They performed calculation for many propellers installed on high speed ships, such as container carriers, pure car carriers and refrigerated carge carriers as well as ships of full type. They reported that fluctuating stresses acting on the high pitch propellers of high speed ships are much stronger than on the normal pitch propellers of full ships.

As a method of reducing propeller-excited vibratory forces and moments Ueda et al. (Lecture SRI. 16-1) proposed the use of water jet which has an effect of making the wake uniform. They conducted the experiment for a model of ocean going stern trawler and reported that the reduction over 20% of the thrust variation was achieved by using the pump power for water jet by 3% of the main engine's output.

(3) Manoeuvrability

Hirano developed a practical method to calculate the ship manoeuvring motion at the initial design stage supposing that the principal particulars of ship hull, propeller and rudder were given as basic input data. Comparing the computed results with the results of the full scale trial, it was concluded that the calculation method developed in his study would be very useful and powerful for the prediction of the characteristics of the ship manocuvring motion at the initial design stage (J. SNA. 147). Hirano et al. proposed a method to calculate the ship turning motion taking the coupling effect due to heel into cinsideration for such ships as roll-on/roll-off ship and a container carrier which perform large hell in their turning motion. Comparing the computed results with the results of model experiment, it was concluded that the turning motion of a ship with large heel should be treated together with the motion of heel simultaneously, and that the calculation method proposed in their study would be very useful for the analysis of the turning motion of a ship with large heel (J. SNA. West 59).

Inoue et al. investigated the shallow and narrow water effects on stopping motion of a large tanker about stopping path, drift angle, heading angle and speed depended on time by computing the ship motion during stopping in restricted water (T. SNA. West 60).

As for the traffic control at crossing points is congested waters, Kobayashi et al. carried out a simulation study and discussed the required distance to adjust the time schedule at crossing in relation to the manoeuvring characteristics of ships (J. SNA. 148).

As the final report of the study on the ship manoeuvrability in accelerated and decelerated condition, the committee SR175 reported the results of the studies on hydrodynamic forces acting on a ship in accelerated and decelerated condition, mathematical model, simulation study of accelerated and decelerated motion, restricted water effects on accelerated and decelerated characteristics, man-machine manoeuvring simulation, traffic simulation and so on (Memo. SR. 330).

Estimating the hydrodynamic derivatives of a fishing boat by the Inoue's method, Inaba et al. introduced the correction coefficients K_1 and K_2 to fit the full scal turning trial data by means of successive approximation (J. Nav. 62).

Conventionally, the upper limit of wind velocity at which a ship is manoeuvrable is estimated by solving equilibrium equations of steady motion of a ship. Tanaka et al. investigated the manoeuvrability of a ship in wind not only by solving non-linear equations of motion numerically on a digital computer, but also by carrying out a steering test with a manoeuvring simulator, and obtained a more realistic uppoer limit of wind velocity (J. SNA. Kansai 176). Hirano et al. made investigation on ship turning trajectory in regular waves from both experimental and theoretical aspects. The major conclusions are that the deviation of the turning trajectory in regular waves from that in calm water may generally have the tendency to become larger as the wave length becomes shorter with constant wave height, and that the calculation method proposed in their study considering the wave drifting forces would be very useful for the analysis of the turning trajectory in regular waves (T. SNA. West 60).

Hasegawa defined the performance criterion of autopilot navigation as the energy increase from the value of straight sailing in calm sea. Then he carried out tank tests of three model ships and derived each coefficient of the criterion by analysing the longitudinal hydrodynamic force (J. SNA. Kansai 178). Further, by utilizing the performance criterion Hasegawa et al. calculated the propulsive losses of unstable ships under automatic steering by the frequency response analysis, and showed the basic considerations of linear ship control, which are essential to conclude the permissible region of unstable ships (J. SNA. 148).

Notation

J. SNA.	Journal of the Society of Naval Architects of Japan
B. SNA.	Bulletin of the Society of Naval Architects of Japan
J. SNA. Kansai	Journal of the Kansai Society of Naval Architects. Japan
T. SNA. West	Transactions of the Society of Naval Architects of West Japan
Rep. SRI.	Report of the Ship Research Institute
Lecture SRI.	Lecture Note of the Ship Research Institute
J. Nav.	Journal of Japan Institute of Navigation
J. MES.	Journal of the Marine Engineering Society in Japan
Memo. SR.	Research Committee of the Shipbuilding Research Association of Japan
T. N. SRC.	The Shipbuilding Research Centre of Japan Technical Note
Sumitomo Rev.	Sumitomo Technical Review

* This paper is quoted from the magazine published by the Society of Naval Architects of Japan.

DEVELOPMENT IN SHIPYARD PRODUCTIVITY IMPROVEMENT

by

Ship Bureau, Ministry of Transport

At the years of high economic growth in the first harf of 1970's, shipbuilding industries have been improving their efficiency on production under the circumstances of the increase in production volume and ship's size according to the request of shipowners.

However, after oil crisis, they have been promoting to grapple with productions other than ship, to reconsider production system suitable for reduced operation, various kinds of ships and medium sized ships and to make constitution for short delivery.

In construction method, separate method of hull construction and outfitting work suitable for variation of ship's size has made progress instead of combination method which is fitted for large ships.

In welding technology contributing greatly to shipbuilding work, the least necessary investment on building facilities and improvement in production efficiency by making use of present facilities effectively have been taking the place of automatization and high efficiency of large-sized exclusive welding machine.

Just as accommodating above tendency, application of semiautomatic CO_2 gas arc welding is extended notably and various kinds of wires are developed and improved. For example, these are such as solid wire for $ArCO_2$ gas shield, wire for HT-50 grade E, flux cored wire for all position and so on.

As for welding procedure, there are high efficiency vibratory electro gas arc welding, development of TIG (Tungsten Inert Gas Arc Welding) torch for narrow gap, application of high current MIG (Metal Inert Gas Arc Welding) to LPG carrier, application of submerged arc welding with large distance of electrodes to al-killed steels, vibratory electrode submerged arc welding, low pulse automatic welding for all position, local drying underwater welding, automatic tack welder for thin plate and extensive application of semiautomatic welding.

Reserches on construction technology of added value ships such as LNG carrier, chemical carrier, special dredgers and deep submergence vehicle have been carried out very actively. There are studies on Technigas MARK III process for LNG carrier, low temperature fatigue characteristics for fillet joint of LPG tank, strength characteristics for welded joints of pressure hull of deep submergence vehicle, welded joints of maraging steel and so on.

For the purpose of making use of a large quantity of information effectively, electronic computer has been introduced into welding technology. Development of welding procedure system based on experiential information data by determining welding parameters with computer and many rescarches on their programms are being developed in various of welding procedure.

On the other hand, from viewpoint of energy problem with petroleum as the central figure, energy saving methods are being investigated in the fields of shell painting and welding procedure. As for welding procedure, small leg length, narrow gap and semi-automatic CO_2 gas arc welding instead of manual welding have been practically put into operation within the present welding technology. As for automatic CO_2 gas arc welding, there are studies on relationship between shield gas and spatter, addition of Ar to shield gas, low price Ar and flux cored wire from the viewpoint of spatter free.

As for shell painting, many paint manufacturers have recently developed long life antifouling paints which have the characteristics of inhibiting marine organisms by releasing antifouling composition and reducing frictional resistance of hull surface by leaching of colloidal film (self-polishing action). Those paints are contributing greatly to fuel oil saving. In addition, underwater cleaning methods by rotary brush or disc developed recently is enumerated as the method of reducing frictional resistance by removal of fouling such as slime, grass and tunicates.

Aiming at unmanned system and man power saving of welding process, basic data regarding detection method, automatic control, etc. arc published, and full automatic welding machine and welding robot will be expected to be put into practical use.

* This paper is quoted from the magazine published by the Society of Naval Architects of Japan.

THE SAJ SEMISUBMERGIBLE FLOATING AIRPORT
AN IDEA WHOSE TIME HAS COME

by

The Shipbuilders' Association of Japan

Social and Economic Considerations

In the half-century of international air travel that began when Charles Lindbergh piloted his "Spirit of St. Louis" onto a farmer's grassy field outside Paris, virtually everything has changed except the need for large unobstructed areas to land.

Airports constitute one of the basic and most important segments of aviation and by their very nature have to be located near urban centers. This in turn has created a number of problems.

Explosive Growth of Cities

In the 50's and 60's, cities grew as fast as the booming aviation industry; suburbia spread outwards from the urban core in a ripple pattern that like water simply moved around and finally engulfed any obstacles in its path. And in the absence of strict enforceable zoning laws this unharnessed growth saw new housing developments cover rich farmlands, bury marshes and lakes, and encircle industrial areas and airports.

Airport Pollution Problems

In the 70's pollution became a pressing public concern. Industry responded by employing pollution abatement technologies, but air and noise pollution around airports grew ever more serious as the volume of air traffic increased to meet the rapid growth in business travel, charter flights and air freight. Residents in areas near airports effectively prevented the expansion of runways and facilities, and, at the same time, demanded action to limit air and especially noise pollution caused by late-night flights and low fly-overs during take-off and landing.

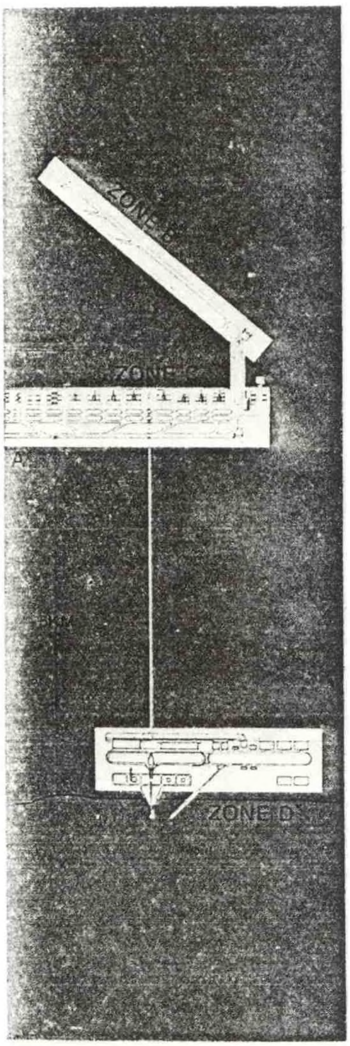
Growing Cities Need New Airports

Osaka's international airport, Itami, is a classic example of today's overcrowded airports. It is the gateway to the prosperous, growing, densely populated and heavily industrialized Kansai region of western Japan. Over six million people live in the Osaka metropolitan area and several million others live in the surrounding Kansai region.

Last year alone, some 10 million people passed through Itami International Airport. More than 10 international airlines fly there from points around the globe, and three of Japan's own flag carriers fly in and out every day. But with the explosive growth of the region and the city, Itami cannot keep up with the demands placed upon it. What makes matters worse, air and noise pollution caused by all the planes taking-off and landing continue to increase in spite of government restrictions.

The Offshore Airport Proposal

In Japan, several ideas have been proposed as possible solutions to the dilemma faced by Itami. The obvious answer is to construct a new airport away from the city. There are, however, no open spaces free of people or natural obstructions within the general vicinity of Osaka. The only place where it is feasible to build a brand new airport is on the open sea. Only an offshore airport would be close enough to Osaka transportation-wise, but far enough away to eliminate pollution problems.



If a plan to build an airport on the sea near Osaka city is realized, Japan will become the first country in the world to construct a floating airport, thereby taking the lead in an exciting new field of offshore development.

Here is what the world's first floating airport will be like.

The SAJ Design

The Shipbuilders' Association of Japan (SAJ) proposed constructing a floating airport featuring Japan's latest steel structure and shipbuilding technologies. SAJ decided to present their design only after making doubly sure that the floating airport would be both technically feasible and absolutely safe. Noteworthy is the fact that the floating airport functions in exactly the same way as a modern airport built on land.

SAJ's floating airport, named the "semisubmergible floating airport," is basically composed of two elements: the huge floating steel structures which make up the airport proper and the mooring system which prevents the structures from floating away. The two floating structures are in turn made up of pre-engineered, prefabricated modular sections consisting of a 10-meter-high box-shaped superstructure and a substructure made up of many 7-meter-diameter, 11.5-meter-high support buoys. The substructure keeps the superstructure some 5 meters above the waterline and each of the support buoys is cylindrically shaped to reduce wave resistance.

The mooring system is known as the dolphin mooring system. Altogether, 22 groups of dolphins are arranged along one end of each main structure and 39 groups along one side. Set up in an "L-shaped" pattern, they keep the airport in place, and are linked to it by means of a flexible connecting rod-rubber damper system.

Five Kilometers Offshore

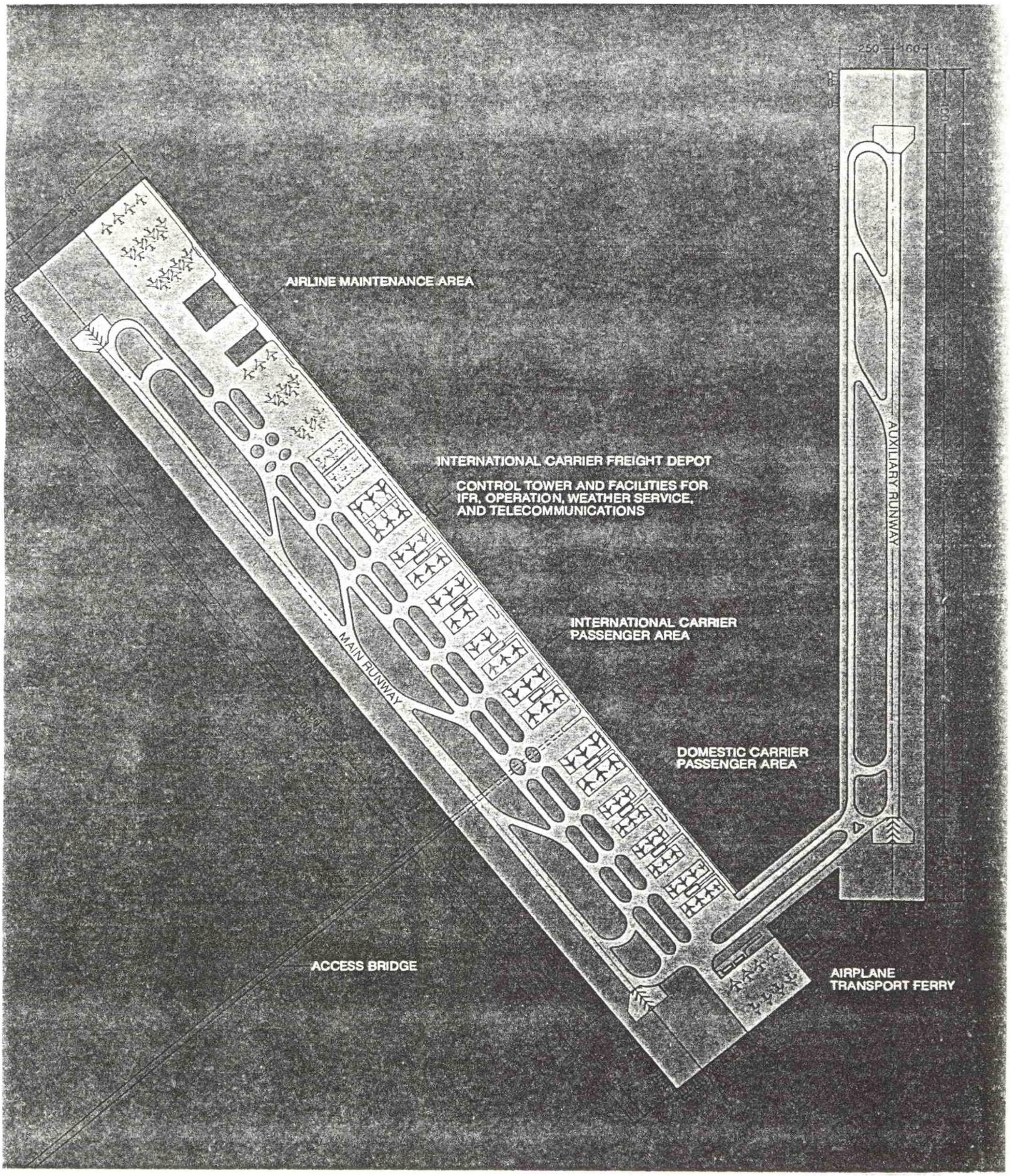
The floating airport will be located about five kilometers from the shore along the coast of Senshu in Osaka Bay. Normal airport facilities like parking lots, airlines offices, and customs and immigration are located on reclaimed land (Zone D). These land-based facilities are connected to the airport by a 5-kilometer-long access bridge. Trains and other vehicles shuttle passengers back and forth via this bridge. It seems very simple, but that's the way many of the best things are—simple and effective.

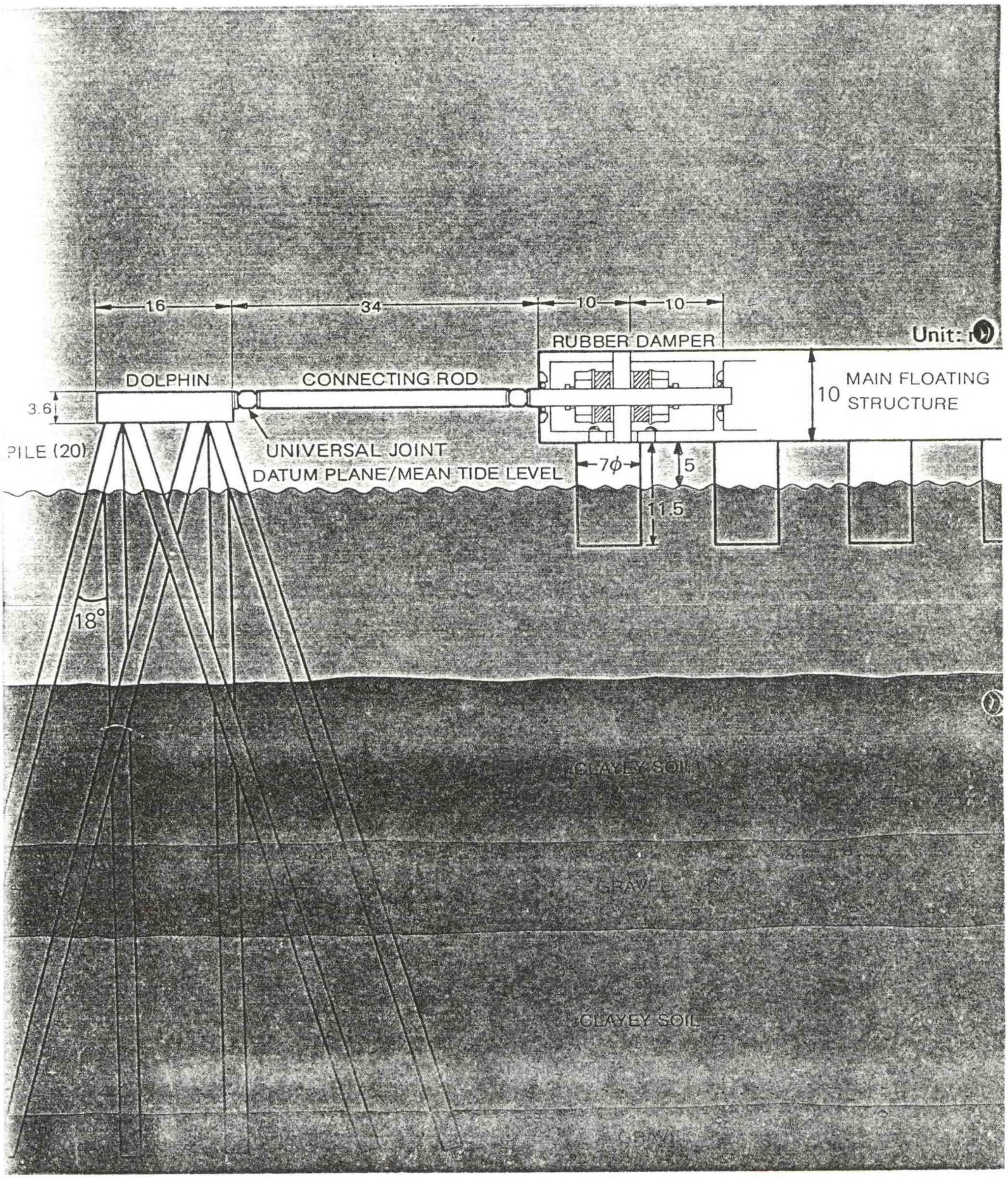
Lots of Space Inside

The huge floating box-shaped steel structures are large enough to contain several three- to four-storey-high buildings. Various facilities can thus be built inside them as in any normal airport terminal—train and bus terminals, passenger lounges, tax-free shops, coffee shops and restaurants, embarkation/disembarkation points. In other areas separated by bulkheads, cargo storage areas, airport maintenance equipment bays, and fuel storage/supply depots can be constructed.

The Floating Airport vs. The "Bellamya"

To build this enormous offshore structure, some 4.85 million tons of steel will be needed


AIRLINE MAINTENANCE AREA
INTERNATIONAL CARRIER FREIGHT DEPOT
CONTROL TOWER AND FACILITIES FOR
IFR, OPERATION, WEATHER SERVICE,
AND TELECOMMUNICATIONS
INTERNATIONAL CARRIER
PASSENGER AREA
DOMESTIC CARRIER
PASSENGER AREA
MAIN RUNWAY
AUXILIARY RUNWAY
ACCESS BRIDGE
AIRPLANE
TRANSPORT FERRY
250
160



16
34
10
10
Unit: m
RUBBER DAMPER
DOLPHIN
CONNECTING ROD
MAIN FLOATING STRUCTURE
10
3.6
PILE (20)
UNIVERSAL JOINT
DATUM PLANE/MEAN TIDE LEVEL
7ϕ
5
11.5
18°
CLAYEY SOIL
GRAVEL
CLAYEY SOIL

This figure is especially staggering when compared to ULCC's, the largest floating structures now in existence. The "Bellamya," the world's largest supership, is only 541,000 tons. Fully loaded, she is equivalent to an 11 storey building over 60 meters wide and more than 400 meters long.

In comparison, the floating airport's main runway (Zone A) is 510 meters wide and 5,000 meters long—more than 8 times wider and 12 times longer than the "Bellamya." The auxiliary runway (Zone B) is 410 meters wide and 4,000 meters long. The facility area (Zone C), 330 meters wide and 5,000 meters long, is off to the side of but joined to the main runway. It is where the aircraft hangers, maintenance areas, and taxi-ing zones are located. The control tower is erected there as well. Zones C and B are connected by a taxi-ing bridge.

As great as these size differences are, there is no great technological "leap" to be made in constructing the semisubmergible floating airport. It's like building a 200,000 dwt VLCC based on the know-how used in constructing a 30,000 dwt vessel.

Absolute Safety

These immense structures are extremely stable even under the most adverse weather conditions imaginable. For example, should a strong wind with gusts up to 25 meters per second blow, the floating airport will move only a few millimeters! And should a typhoon pass through, the kind that comes once in 100 years, creating wave lengths of some 120 meters and wave heights of 4.6 meters, the runways will move only a few centimeters up and down, and about 20 centimeters right and left, back and forth.

When a large jumbo jet weighing 500 tons (150 tons heavier than today's 747's) lands on the runway, the deflection of the runway will be only 3 centimeters.

Earthquake Proof

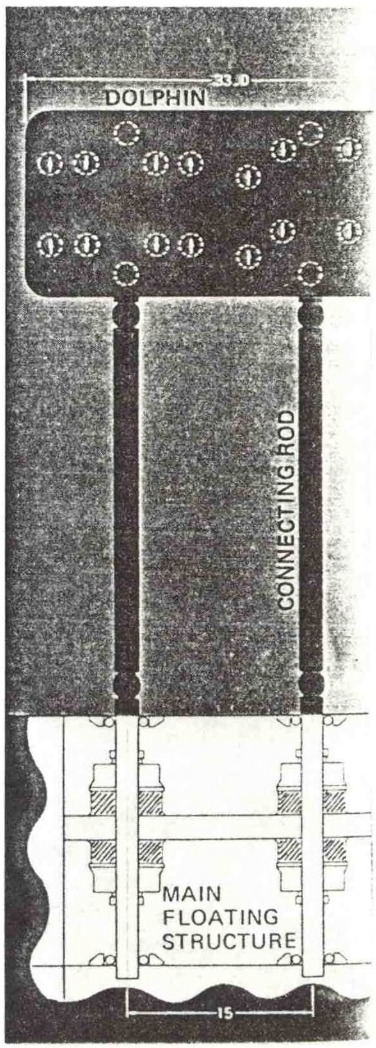
If an earthquake strikes, the dolphins mooring the airport will move as they are set deep into the sea floor, but the vibrations will be absorbed by the dampers linking the dolphins and the floating structures. The damper system thus effectively immunizes the floating airport from the effects of such natural phenomena.

Damage Free

Should a ship run into the floating airport, the damaged area can be easily repaired or replaced since the sections are of modular construction. Moreover, bulkheads and a fire fighting/extinguishing network built into the airport would minimize any damage should a fire break out. And because the superstructure is supported by literally thousands of support buoys the airport cannot sink even if some of them are damaged.

Corrosion Resistant

Because all the exposed steel surfaces are painted with corrosion retarding paint, and all sections constantly in the water are given impressed-current cathodic protection, the airport's service life will be 60 years, the same as a modern bridge. If additional maintenance work is performed, the useful service life can be extended to more than 100 years.



Simple, Efficient Construction Method

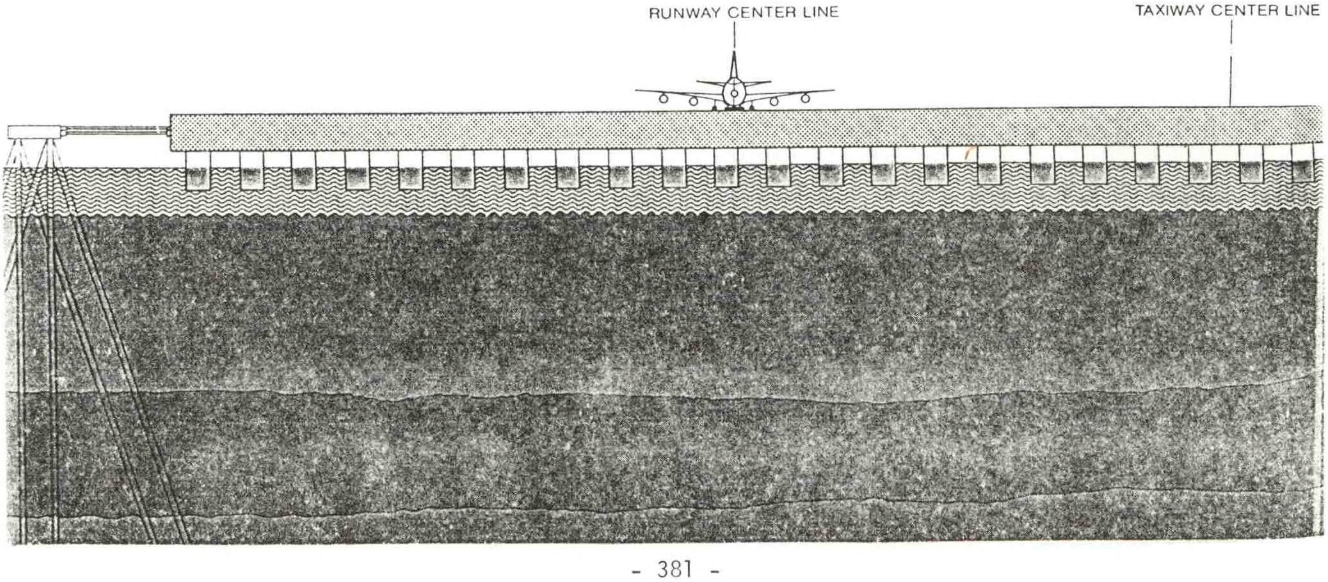
Another key advantage of SAJ's floating airport is that is can be constructed by merely assembling pre-engineered, prefabricated modular blocks. These blocks can be constructed at several shipyards and offshore steel structure fabrication yards and then towed to the site for assembly. This onland construction method has many advantages —strict quality control during fabrication is assured, lengthy, complicated underwater assembly at the site is eliminated, special corrosion-resistant paints can be applied more easily, and all usable interior spaces can be prepared during construction. Another benefit of this method is that the floating airport could be constructed in only three years. And as the SAJ method uses only minimal amounts of sand and soil, sea water pollution is eliminated.

Looking Toward the 21st Century

Throughout recorded history, man has had a natural affinity with the sea. In fact, most of the world's peoples have settled in cities that lie within a short distance of the sea or along rivers that flow into it.

In Japan, long a seafaring nation, an overwhelming percentage of the population lives along the country's extensive coastline and virtually all the major cities are located on the coast. Many of the country's industries are already located in industrial seabelts, and, by the turn of the century, Japan's megalopolises will be further concentrated along coastal zones.

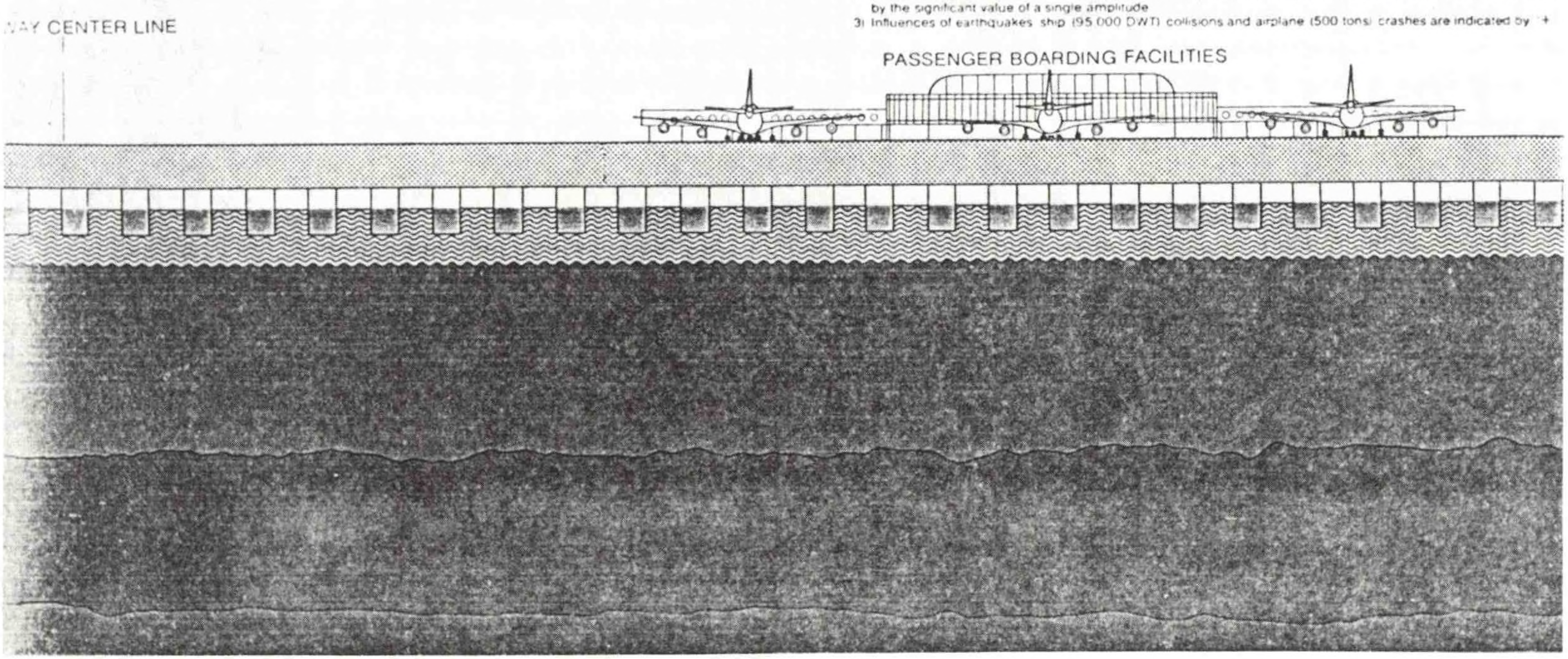
Thus floating airports are in tune with the realities of the present and the trends of the future. The economics are persuasive, the technology proven and the need long overdue.

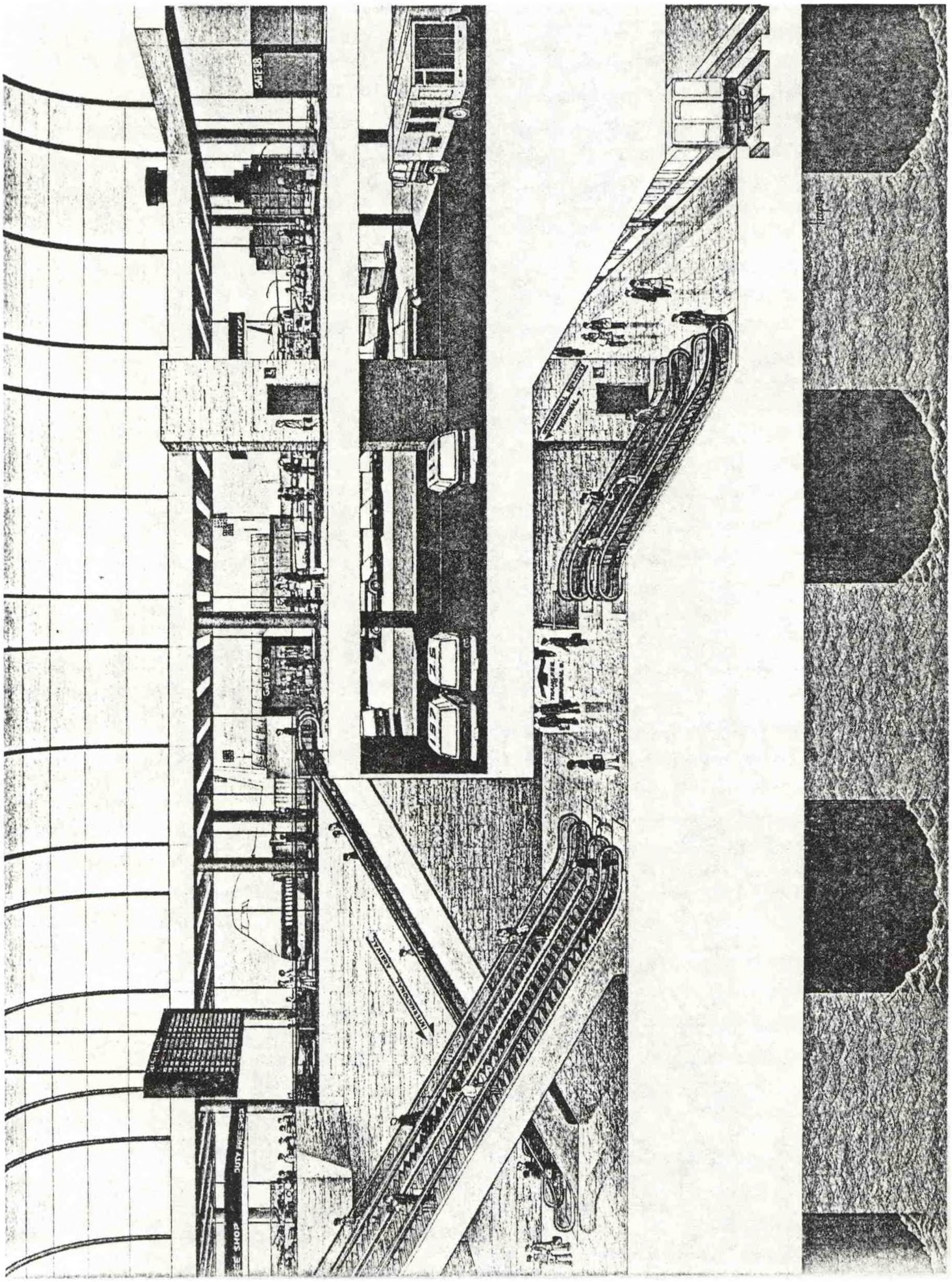


OUTLINE OF MOTION AND MOORING FORCE OF SEMISUBMERGIBLE FLOATING AIRPORT

		DESIGN CRITERIA				VERTICAL MOVEMENT (Significant value single amplitude)				HORIZONTAL DISPLACEMENT (Maximum = constant value + effective value of variation)						ACTING FORCE PER DOLPHIN (ton)
		WIND (m/sec)	WAVE		CURRENT SPEED (knot)	HEAVING (cm)	PITCHING (degree)	ROLLING (degree)	MAXIMUM SECTION END MOVEMENT (cm)	SURGING (cm)			SWAYING (cm)			
			HEIGHT (m)	PERIOD (sec)						CONSTANT VALUE	VARIATION VALUE	MAXIMUM VALUE	CONSTANT VALUE	VARIATION VALUE	MAXIMUM VALUE	
NORMAL CONDITIONS	COVERAGE 95%	10.0	1.0	4.2	0.8	0	0	0	0	2.0	0	2.0	0.6	0.1	0.7	180
	AVERAGE YEARLY MAXIMUM	25.0	2.4	6.5	0.8	2.5	0	0	6.0	4.4	0.1	4.5	3.5	1.0	4.5	370
ABNORMAL CONDITIONS	100-YEAR TYPHOON	50.0	4.6	9.6	2.0	5.5	0	0.015	13.5	18.0	3.0	21.0	6.5	12.5	19.0	1600
	EARTHQUAKE	10.0	1.0	4.2	0.8	0	0	0	0	2.0	0	2.0	0.6	0.1+7.0	0.7+7.0	180 + 770
	SEISMIC WAVE (TSUNAMI)	10.0	1.0	4.2	1.9	0	0	0	0	10.0	0	10.0	0.1	0.1	0.2	810
	SHIP COLLISION	25.0	2.4	6.5	0.8	2.5	0	0	6.0	4.4	0.1	4.5	3.5	1.0+27.4	4.5+27.4	370 + 1600
	AIRPLANE CRASH	25.0	2.4	6.5	0.8	2.5+1.0	0	0	6.0+6.0	4.4	0.1	4.5	3.5	1.0	4.5	370

NOTES
1) Wind speed is the average value over a 10 minute period, wave height is the significant wave height
2) Motion, displacement, deflection inclination and variation of mooring force due to external wave forces are sh[illegible] by the significant value of a single amplitude
3) Influences of earthquakes, ship (95,000 DWT) collisions and airplane (500 tons) crashes are indicated by "+




GATE 38
GATE 39

Chronology of the Floating Airport Concept

In 1935, just eight short years after the "flight of the century" took place, E.R. Armstrong proposed building an airport midway between Europe and North America as a refueling and stopover point for planes flying the trans-Atlantic route.

In 1969, P. Widelinger designed a new airport for New York City a few miles off the coast of Long Island as an answer to the expected overcrowding at J.F. Kennedy International Airport.

In 1971, the Floating Airport Study Group was set up in Japan to initiate research and development into possible methods for constructing airports offshore. They came up with the "pontoon method."

Toward the end of 1971, the Minister of Transport of Japan officially asked the Airport Council, a governmental body, to make a report on "the scale and location of a new international airport for the Kansai region." The council established the "New Kansai International Airport Committee" to secure proposals from interested parties.

In 1973, L. Zeitling Co. proposed employing their newly developed "HYBRID" system for the construction of the new New York International Airport.

In 1978, the Shipbuilders' Association of Japan (SAJ) formally submitted their "semisubmergible floating airport" plan to the Japanese government as an especially promising alternative to the four proposals then under consideration: land reclamation by dredging; land reclamation by filling; the construction of a jetty; and the "pontoon method" floating airport.

1979—the SAJ semisubmergible floating airport—an idea whose time has come.

IP SYSTEM PULP PLANT FOR JARI FLORESTAL E AGROPECUARIA LTDA.

by

IHH Industries Co. Ltd.

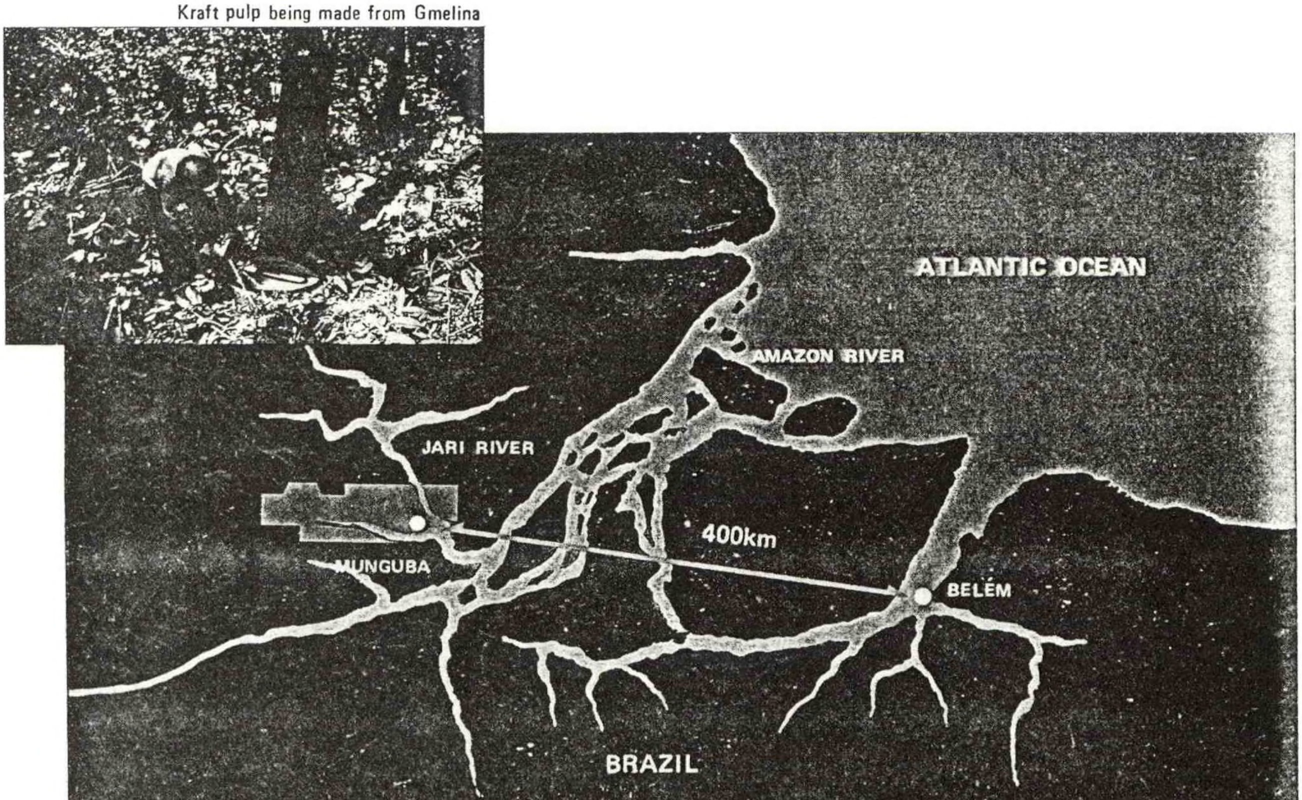
Jari Florestal e Agropecuária Ltda. (JFA), which ordered the pulp plant, is a Brazilian agricultural and forestry development company. In accordance with the Brazilian Government's Amazon Region Development Project, the company had carried out extensive tree planting work in the Munguba District along the Jari River.

With such wood resources available, JFA studied how to make the best use of these resources, and arrived at the conclusion that making pulp for export would be most advantageous. Cutting of the trees around their time of maturity is the optimum time for pulp production. The problem, however, was the construction of the pulp plant. The proposed site is approximately 400 kilometers from Belém, at the mouth of the Amazon, and the area lacks such infrastructure facilities as harbors and roads required to unload and transport the machinery and other equipment needed for the plant construction. The only means of handling and transport from Belém is by the Jari River. However, its water-level variation between the dry and rainy seasons presents difficulties for year-round handling of heavy cargo. Furthermore, it would be difficult to accommodate a large number of workers at such a plant site during the period of construction. Thus, there were many unfavorable factors that might impair the overall viability of the project.

Besides this, the 750 ton/day pulp plant, one of the world's largest of its kind, had to be completed by the time the trees would be ready for cutting.

For these reasons, attention was focused on IHI's IP System in which the principal plant components could be manufactured in a fully equipped factory manned by an engineering staff and skilled workers, and upon completion, towed to the plant site.

Kraft pulp being made from Gmelina



Joint Study with JFA

* Adoption of the IP System:

The pulp plant project was first brought to IHI in the form of a proposed feasibility study. JFA and IHI subsequently proceeded with a joint project study. Various problems were discussed during the study, and the IP System concept began to take definite shape as a large-scale pulp plant. The feasibility study confirmed that the IP System costs much less than conventional methods, offers the advantage of an extremely short construction period, and assures on-schedule delivery.

* Choice of machinery and equipment mounted on two platforms:

Selection was based not only upon the characteristics of the equipment, but also on shipyard construction period and construction and towing economics. Of the facilities needed for the pulp plant, the principal parts were chosen to be mounted.

* Number of platforms:

The question of number and size of platforms to be employed was integrally examined from the standpoints of construction work efficiency, construction period, towing routes, etc. The resulting decision was to divide the plant into two platforms.

* Towing routes:

There were three possible towing routes from Japan to the plant site – through the Panama Canal, the Suez Canal or around the Cape of Good Hope. The Panama Canal was the shortest route, but due to its limited maximum width the plant would have to be divided into three or four platforms, and result in increased construction and towing costs. The other two routes were compared, and in consideration of weather conditions and ship traffic congestion, the Cape of Good Hope route was decided upon. In addition, the idea of a self-propelled platform system was considered, but was dropped because of its high cost.

* Method of setting the platforms at the plant site:

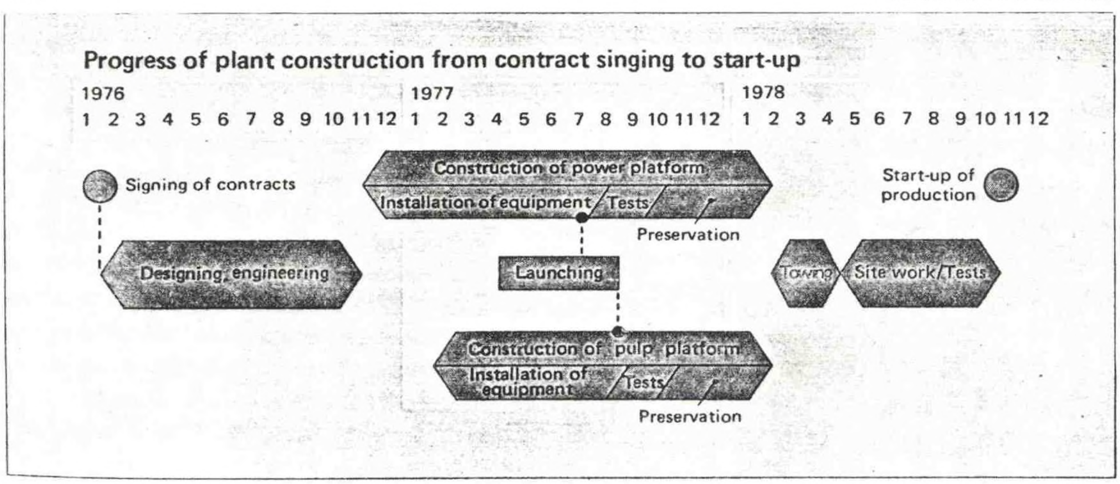
The first method studied was to moor the platforms along the river bank and operate the plant which would remain afloat. However, sheet pulp, the thickness of which must be uniform, was to be manufactured, and since the pulp machinery is extremely sensitive to rolling and pitching motion, such motion would not permit the production of uniform thickness of sheet pulp. For this reason, it was decided that the platforms would be grounded.

* Construction period of the IP System Pulp Plant:

The construction period of the IP System pulp plant was examined from various angles during the feasibility study. As a result, it was confirmed that the construction could be completed one to one-and-a-half years faster than conventional land-based plants of the same capacity, and that the time of operation start-up could be accurately set in advance. This will prove to be the biggest benefit for JFA, the client company.

This project will meet the original requirement of start-up approximately two years and 10 months from the singing of the contracts.

JFA and IHI representatives hold technical discussion before construction starts

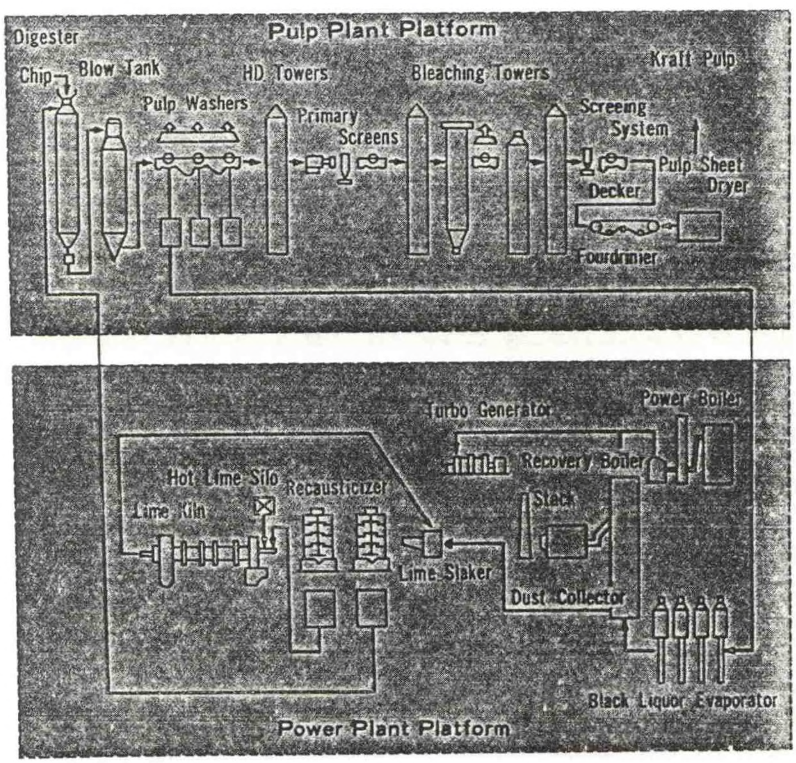


Decision on Basic Layout

The toughest technical task in designing the two platforms was how to position and put together efficiently the various items of machinery and equipment by making vertical and economical use of space according to the required process flow. IHI sought the cooperation of foreign and domestic pulp and paper manufacturers to solve these problems. It also made full use of the technology and concepts of IHI's own shipbuilding and plant divisions. As a result, the basic layout was finally decided upon, and it featured a more compact form for efficient operation and easy maintenance of the machinery and equipment.

Outline of the Plant		
Capacity	:	750 metric tons per day
Raw materials	:	Gmelina (hardwood) and Caribbean Pine (softwood)
End Product	:	Bleached kraft sheet pulp
Process outline		
Pulp process		
Cooking	:	8-batch digesters
Brown stock washing, screening and cleaning system		
Bleaching system	:	5 stages D/C-E-D-E-D system
Pulp machine	:	Trim width = 7,200 mm Basic weight = 800g/m^2 (max.) Machine speed = 150 m/min (max.)
Pulp drying and baling system		
Chemical Recovery System		
Evaporator	:	Sextuple effect
Recausticizing system		
Lime kiln	:	284 t/d, Kiln size 4mx89m

Pulp Process Flow by Two Platforms

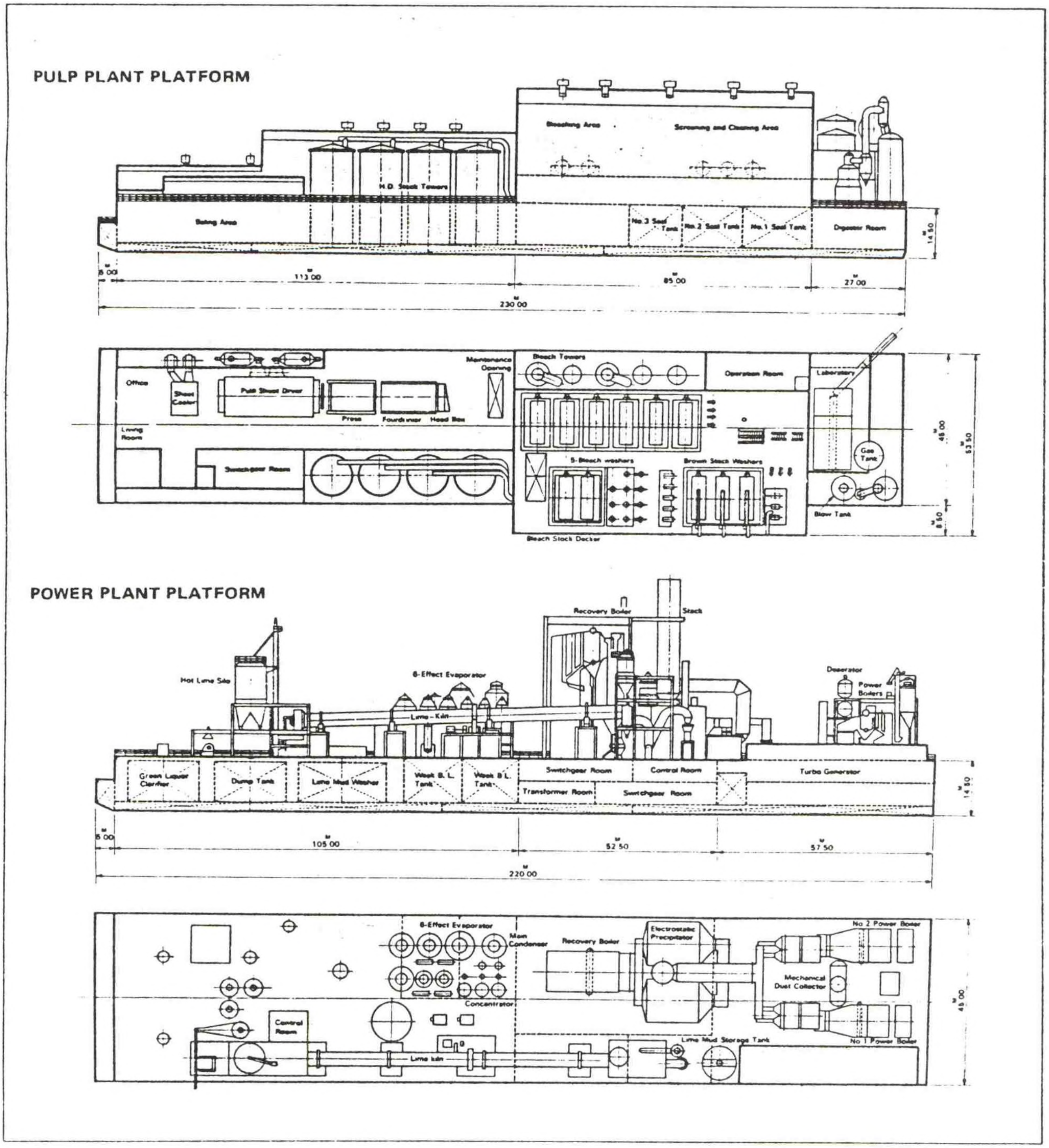


Power generation plant

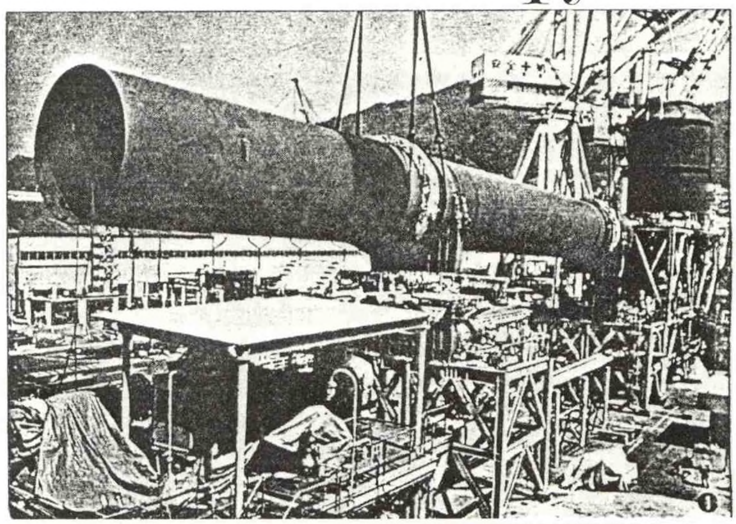
Power boilers	:	Two 140 T/H
Recovery boiler	:	One 208 T/H
Turbine generator	:	One 55,000 kw
Water treatment system		

Platform dimensions

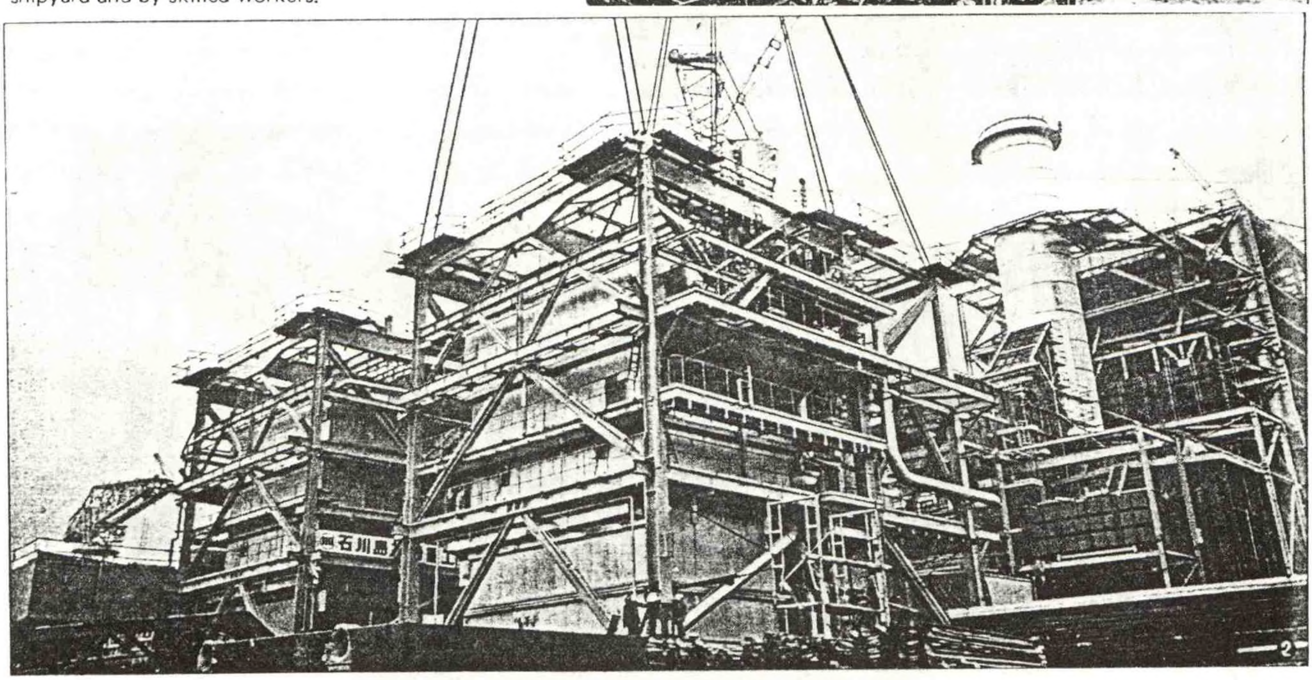
	Pulp plant platform	Power plant platform
Length	230.00m	220.00m
Breadth	45.00m	45.00m
Depth	14.50m	14.50m
Weight (approx.)	30,000tons	30,000tons



Construction at IHI Kure Shipyard

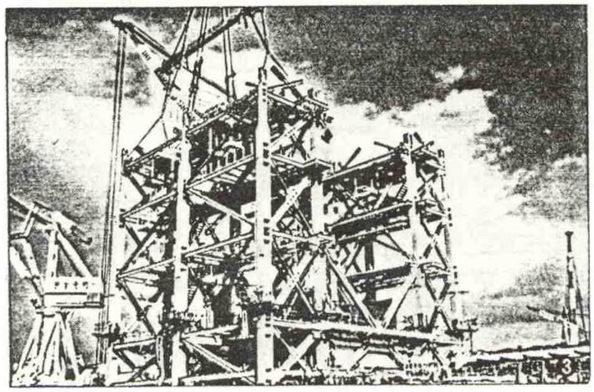


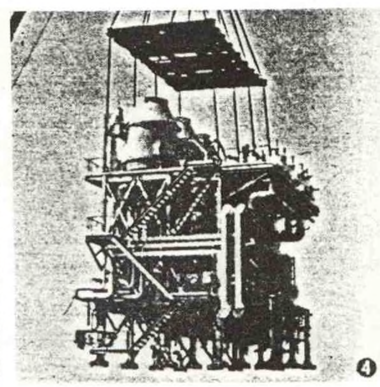
IHI shipbuilding technologies were fully applied in the construction of the platforms, and two popular methods, namely, the block construction and unit outfitting methods were adopted extensively. Machinery and equipment, manufactured at IHI's works and related makers, were positioned and assembled into a number of prescribed units and blocks and then carried to IHI's Kure Shipyard. Inside the dock, these units and blocks were assembled in the pulp plant by the IP System according to schedule. The work was done at the up-to-date facilities of the shipyard and by skilled workers.

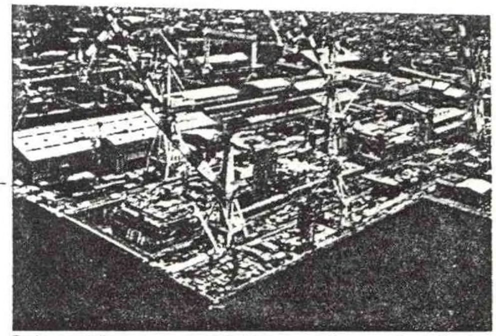


Power Plant Platform

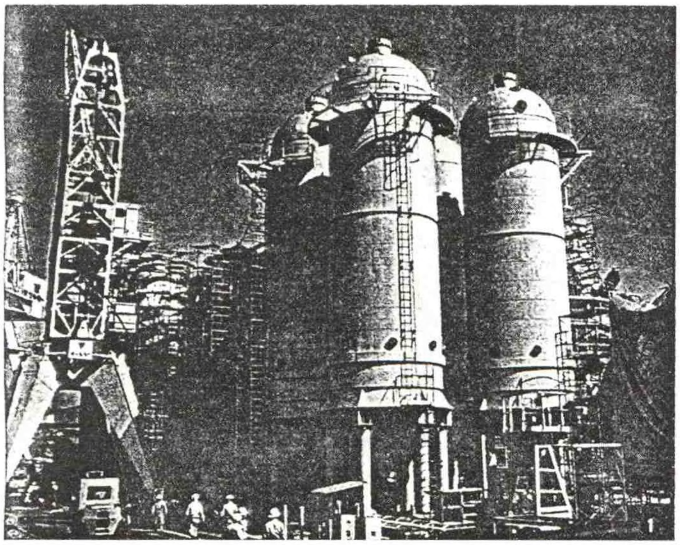
1. **Lime kiln**
   - Block weight 180 tons
2. **Power boiler**
   - Block weight 800 tons
3. **Recovery boiler**
   - Block weight 200 tons
4. **Black liquor evaporator**
   - Block weight 180 tons





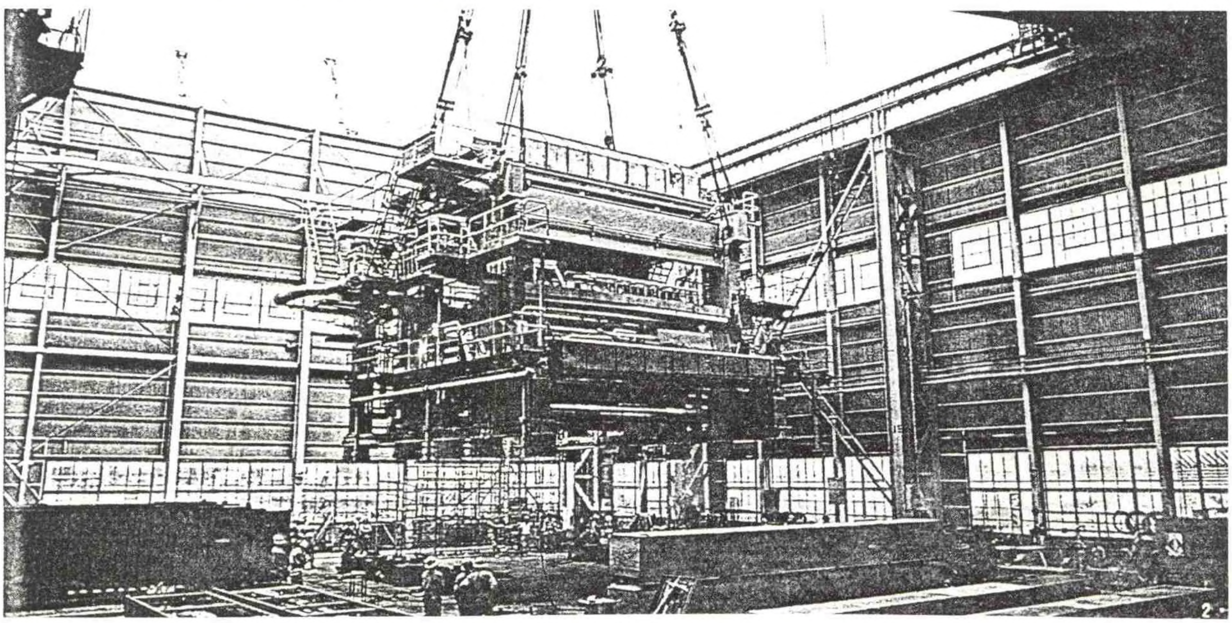


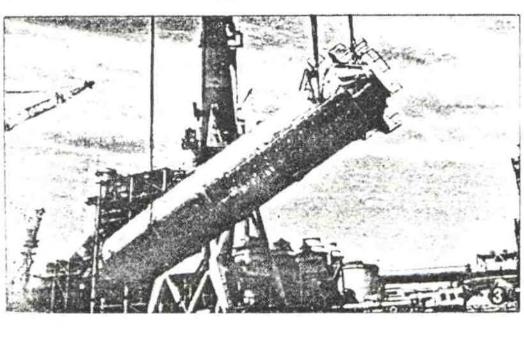
Pulp and Power plant platform under construction by utilizing modern technologies for both ship-building and plant construction

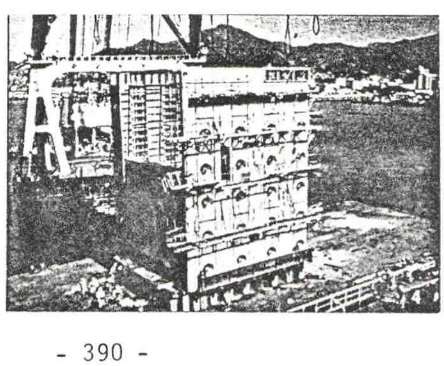


Pulp Plant Platform

1. **Digester**
   * Block weight 110 tons
2. **Pulp machine Press part**
   * Block weight 240 tons
3. **Bleaching tower**
   * Block weight 250 tons
4. **Pulp machine Dryer part**
   * Block weight 250 tons







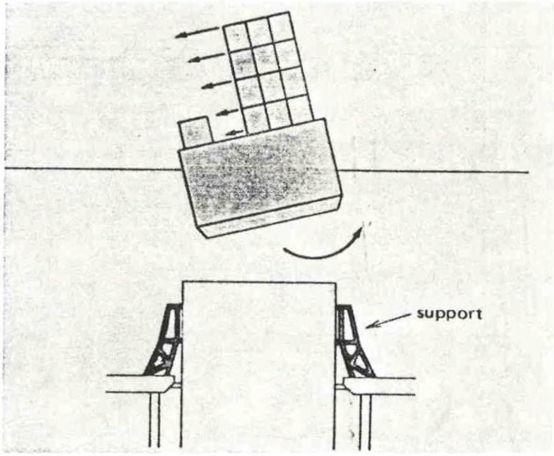
Towing to the Plant Site

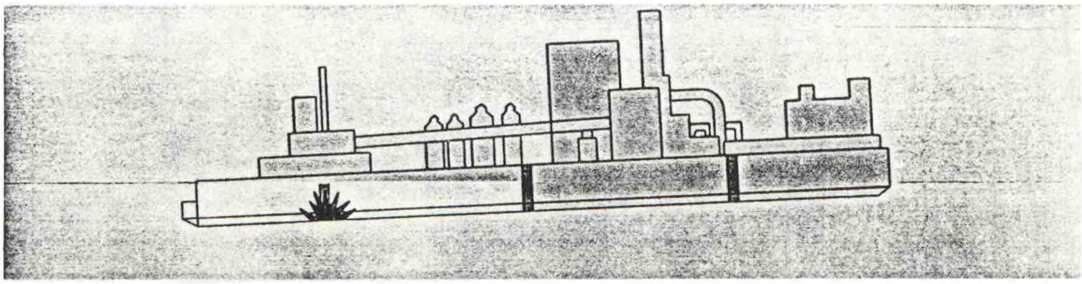
The two platforms, after outfitting and completion of various inspections and tests, were towed to the plant site along the Jari River. The voyage to Brazil was approximately 25,000 kilometers, and took about three months. Many model tests were conducted for about one year in a model basin at IHI's Research Institute on the safety of the platforms affected by waves. As a result, various measures were adopted to assure platform safety during towing.

Example of Towing Safety Measures

Measures against inertial force resulting from rolling and pitching

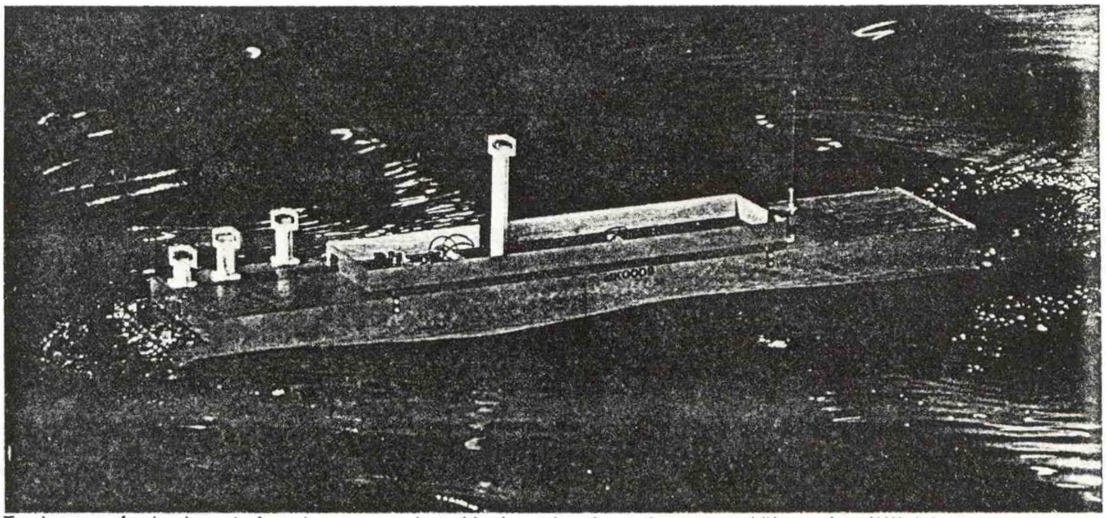
* Elaborate measures were taken to prevent damage of the machinery that might have been caused by inertial force resulting from rolling and pitching.





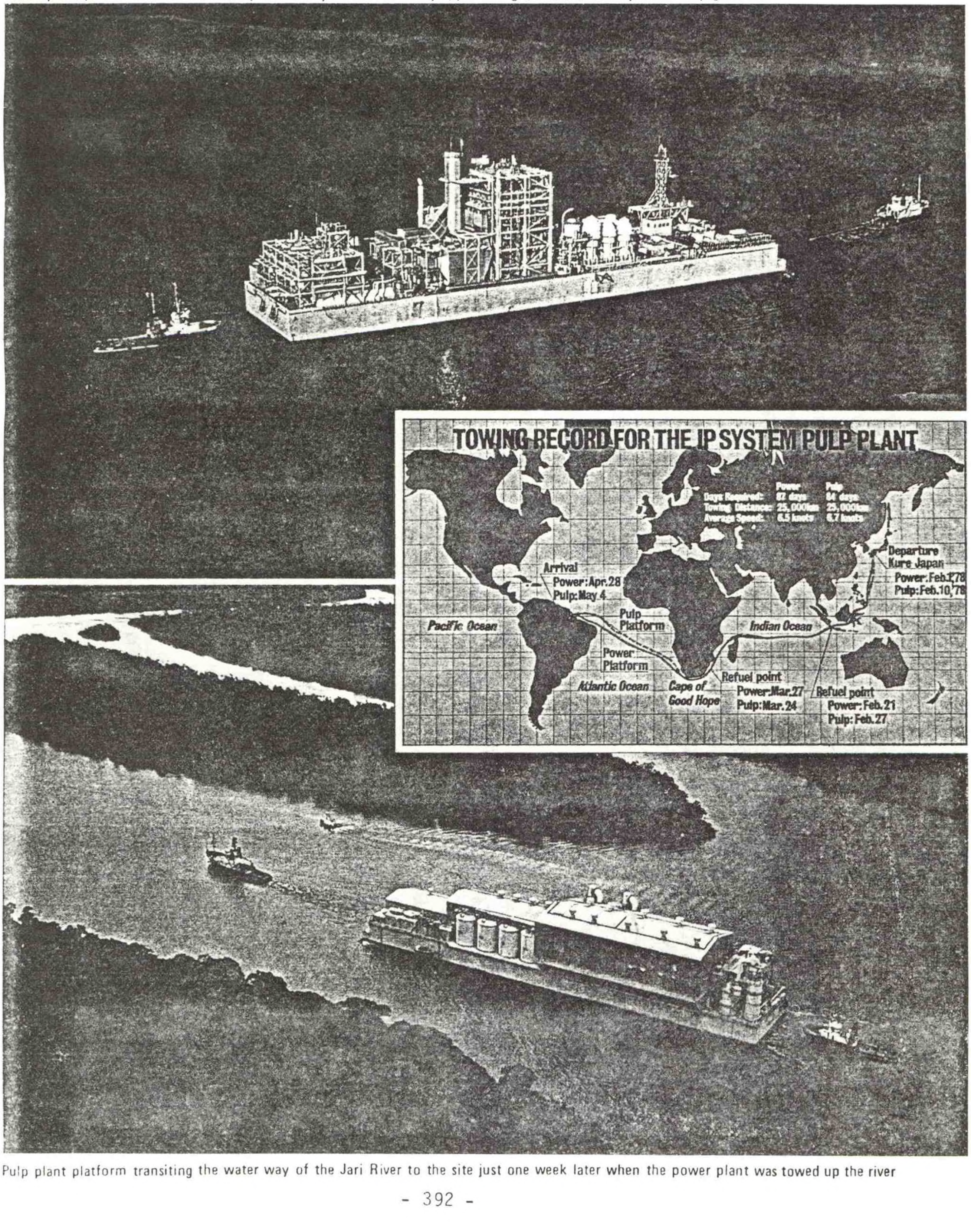
Anti-inundation compartments established

* Watertight compartments were established to protect the platform from sinking.
* Even if two compartments were filled with water, other compartments would remain intact, thus keeping the platform afloat.



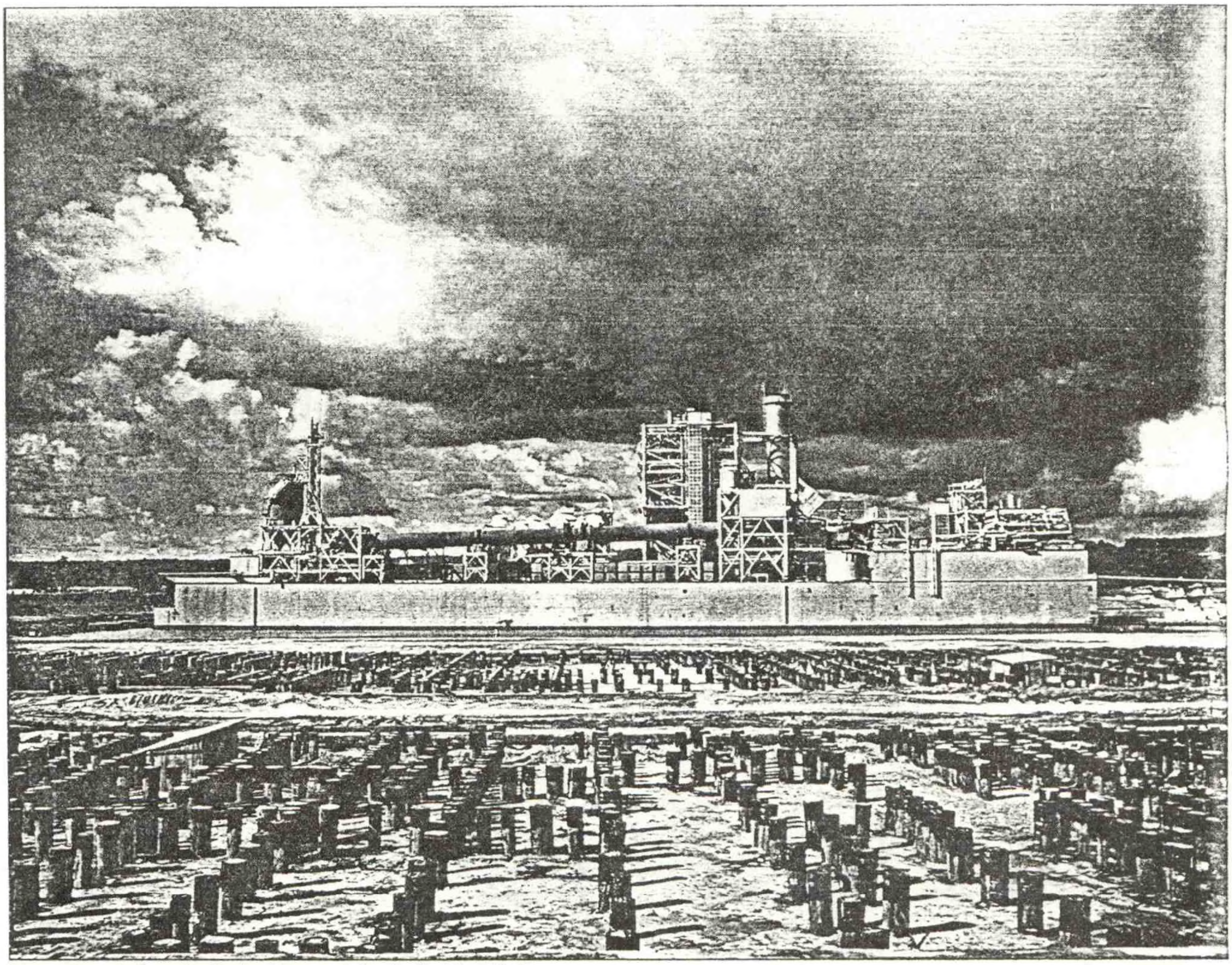
Towing test of pulp plant platform in waves conducted in the seakeeping and maneuverability tank at IHI's laboratory

Power plant platform in the Jari River, a tributary of the Amazon, approaching the site after 25,000km voyage



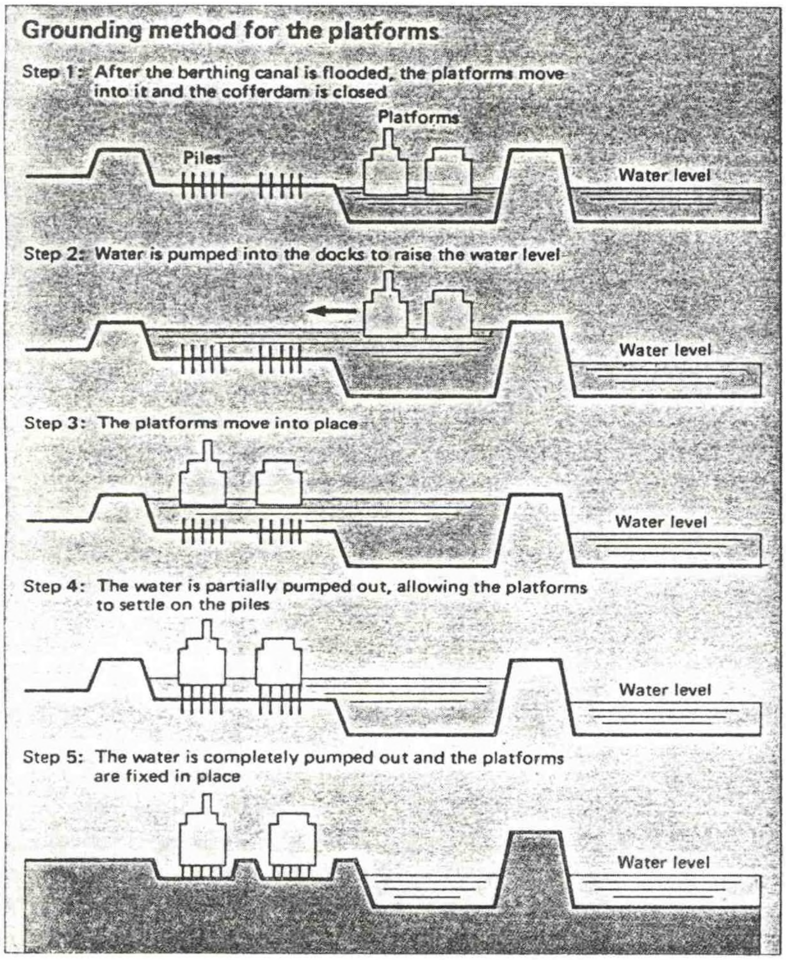
Pulp plant platform transiting the water way of the Jari River to the site just one week later when the power plant was towed up the river

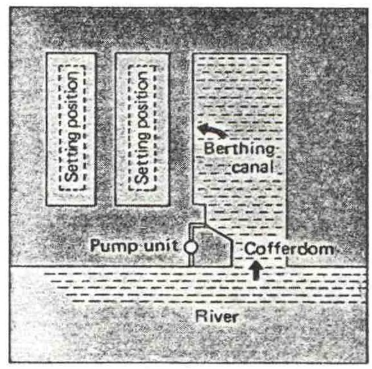
Placement at the Site

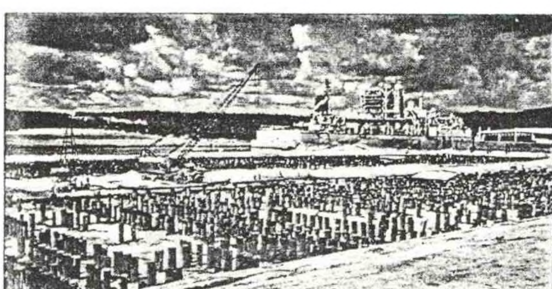


Power plant platform in the berthing canal for its final installation

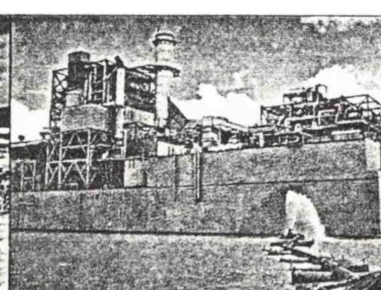
The platforms, after arrival, were grounded on the prepared site and fixed in place. The method of grounding was like the lock system, which is represented by the Panama Canal. The ground was first excavated to a prescribed depth, and piles driven into the earth. Then the excavation was flooded and the platform was moved into the excavation. The cofferdam was closed temporarily, water was pumped into the excavation to raise its water level, and the platform was then moved into place over the pilings. In the next stage, the water was pumped out and the platform was seated on the piles and fixed in place. After that, the supports, protective shields and similar items installed for the voyage were removed. Piping and wiring connections were then made between the two platforms as well as other systems on land. In parallel with this, equipment alignment was checked and tests conducted.



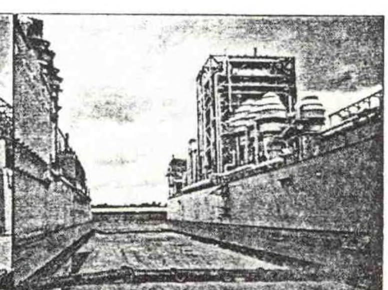




Pulp plant platform entering in the berthing canal (step 1)

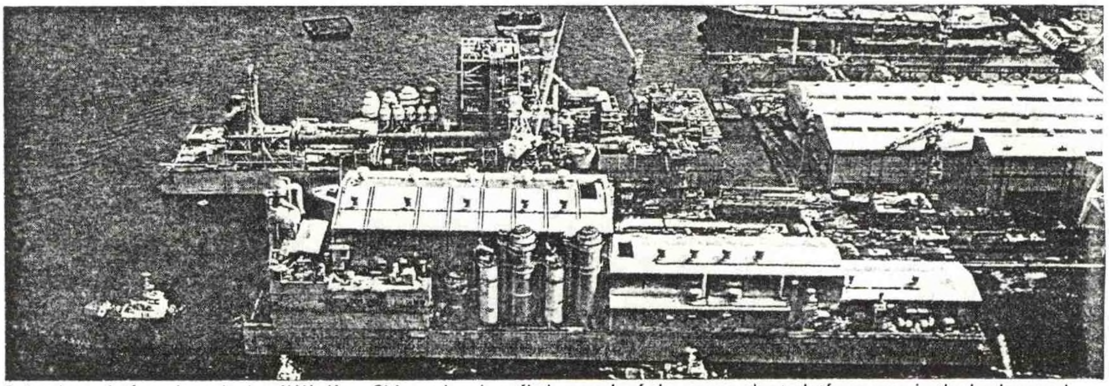


Power plant platform floats over its foundation piles (step 1)



Power and pulp plant platforms set on their foundation piles (step 5)

Construction Record



Pulp plant platform luanched at IHI's Kure Shipyard and outfitting work of the power plant platform seen in the background

*** February, 1976**

An order was received from Jari Florestal e Agropecuária Ltda, Brazil for 750T/D bleached kraft pulp plant.

*** November, 1976**

A ceremony was held for construction commencement of a power plant platform.

*** February, 1977**

A similar ceremony was held for the pulp plant platform.

*** July, 1977**

The power plant platform was launched at IHI Kure Shipyard.

*** August, 1977**

The pulp plant platform was launched at the same shipyard.

*** February, 1978**

The power and pulp plant platforms were left for Brazil.

*** April, 1978**

The power plant platform arrived at the site.

*** May, 1978**

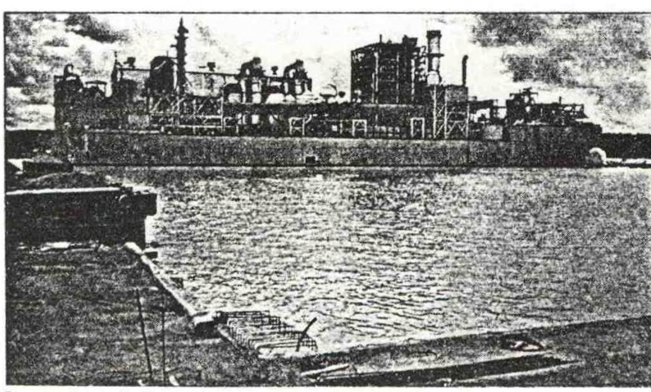
The pulp plant platform reached the site.

*** December, 1978**

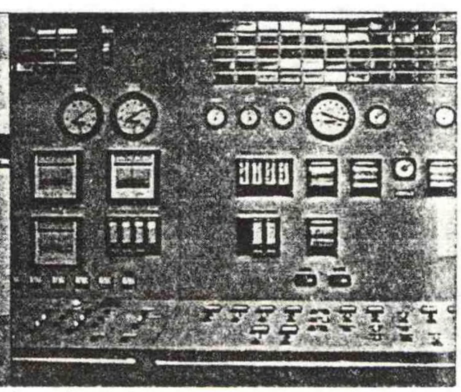
Both the power and pulp plant platforms were connected with facilities constructed at the site, and electricity supply started.

*** February, 1979**

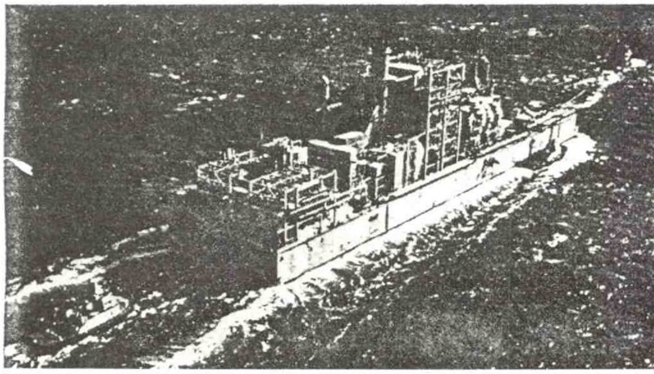
The pulp plant went into operation.



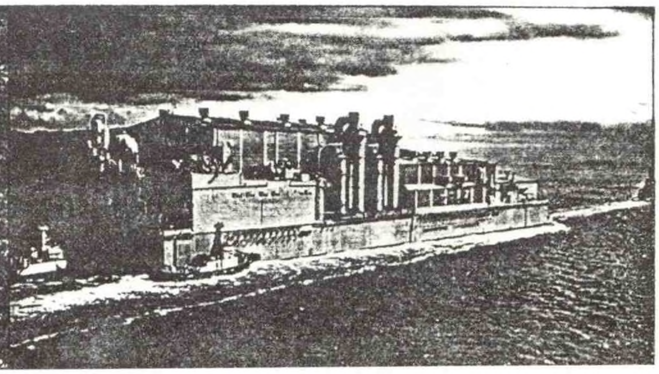
Power plant platform set up on piles



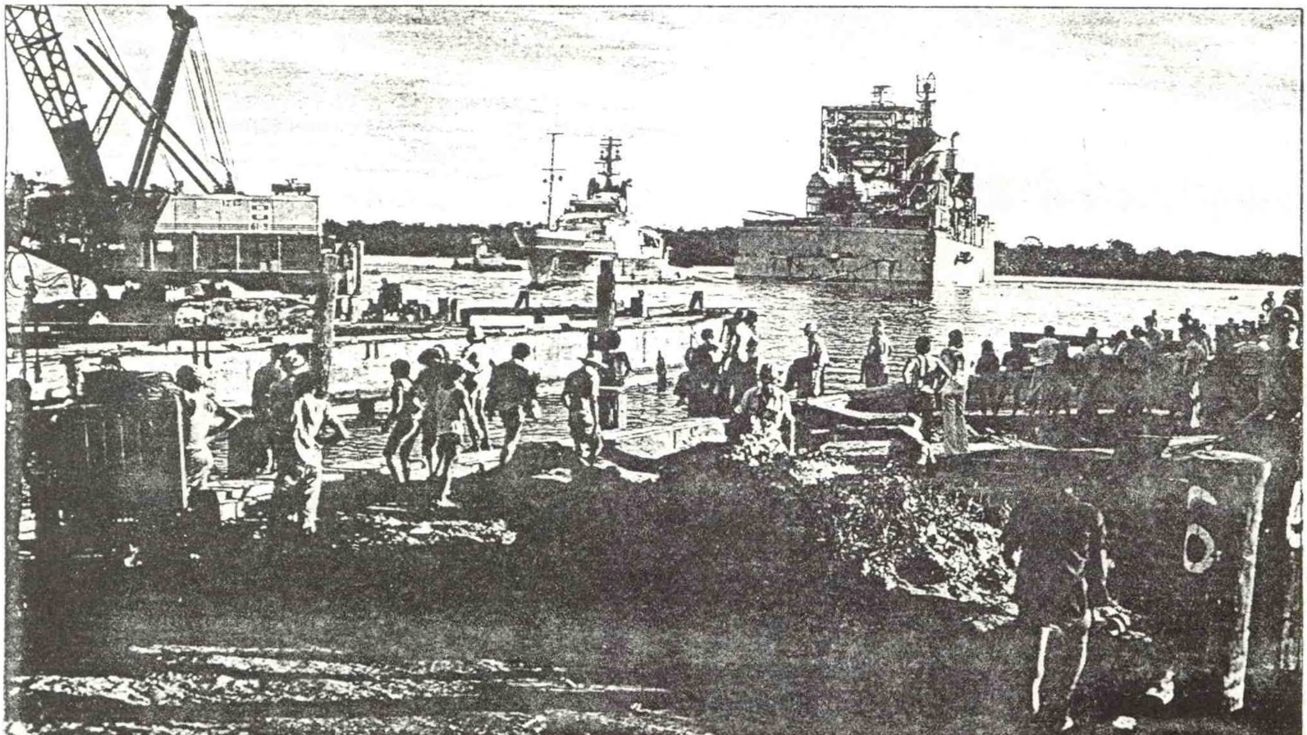
Control pannel



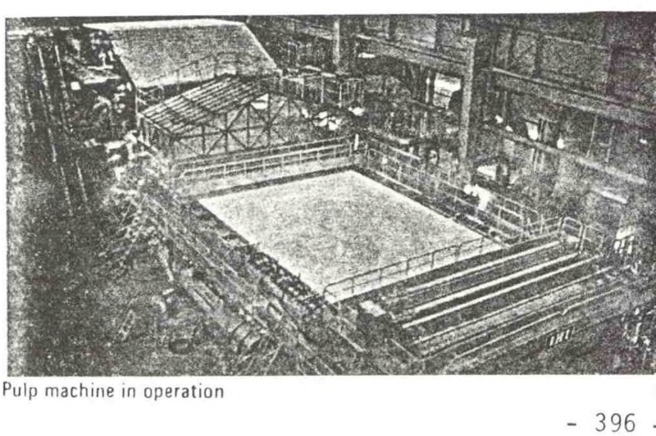
Power plant platform towed in the ocean



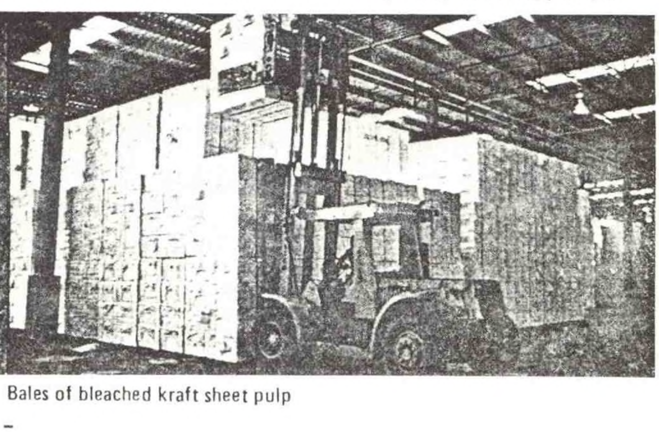
Pulp plant platform on its way to the Amazon



Power plant platform finally reaches the site in ship-shaped appearance and without any exterior damage even after a long voyage of over 25,000 km



Pulp machine in operation



Bales of bleached kraft sheet pulp

DEVELOPMENT OF PORTS AND HARBORS FOR HANDLING IMPORTED STEAM COAL

by

Ryuji Nakamura

Director, Development Division
Bureau of Ports and Harbors,
Ministry of Transport, Japan

The Present Status and Prospects of Supply and Demand for Coal in Japan

Most of Japan's primary energy has been supplied by imported oil, although the Japanese Government has been promoting the introduction of alternative primary energy on account of recent rapid rises in oil prices and agreements reached at Summits and IEA meetings.

"The Outlook on Long-term Energy Supply and Demand" revised in April 1982, indicates that the percent of alternative energy in the total supply is to be increased to over 50% in 1990 (fiscal) and to over 60% in 2000 (fiscal). Further, according to "The Supply Target for Alternative Energy" approved by a Cabinet Council, as well as "The Outlook of Long-term Energy Supply and Demand," it is planned that alternative energy will account for more than 50% in total energy supply. In these Government Plans, the percentage of coal is to be raised to about 40% as alternative energy in 1990 (fiscal) requiring a planned coal supply of 153 million tons.

In 1980 (fiscal), the total demand of coal (including steam coal and coking coal for the iron and steel industries) was 93.1 million tons. 18.6 million tons was supplied for steam (of which 11.4 million tons was domestic product, 7.2 million tons imported). 71.2 million tons was supplied for coking (of which 6.7 million tons was domestic product, 64.5 million tons imported). 3.3 million tons of coal was for miscellaneous uses. Particularly, in regard to imported steam coal, Japan depends heavily on several countries, namely: Australia (60%), China (11%), U.S.A. (10%) and others (19%).

In the Government Plan, it is planned to import over 53.0 million tons from overseas in 1990 (fiscal), about 7 times as much as that in 1980 (fiscal). This is due to the fact that power plants and cement industries, which have been major consumers of oil plan to convert the source of their energy to coal. Therefore, the demand for steam coal is expected to increase further in the future. On account of such a marked planned increase in steam coal supply and consumption, the coal transport system in Japan must be improved to cope with the situation appropriately.

The Bureau of Ports and Harbors in the Ministry of Transport (B.P.H. in M.O.T.) will be required to develop infrastructures for coal transit.

The Present Status and Problems Concerning Ports and Harbors for Imported Steam Coal

There are two basic means of receiving imported steam coal. One is to receive carriers from foreign countries directly at exclusive-use berths of large-scale steam power plants, etc. The other method is to unload coal first at public or private berths and then to convey it to various final users by domestic transportation systems.

In 1980 (fiscal), there were about 40 harbors in Japan suitable for unloading imported steam coal, and the amount of imported steam coal was 7.2 million tons. 3.3 million tons of them were unloaded at public berths and 3.9 million tons were unloaded at private berths.

However, at the existing harbors, there exist the following problems in handling large amounts of imported steam coal:

(1) These harbors have inefficient loading/unloading machinery, and low-capacity coal storage. This is because these harbors were designed to handle only 100 thousand tons of coal.

(2) Most existing berths are not deep enough for the large-scale vessels which are planned to be engaged in coal transportation from foreign countries such as Australia, North America, etc., in the near future. There are only five berths having a capacity of more than 50,000 D/W ship. Most of the berths for steam coal have capacities ranging from only 5,000 D/W - 15,000 D/W; and from a geographic point of view, it can be said that harbors for large-scale vessels are poorly distributed.

(3) In order to handle large amounts of coal, safety and environmental protection measures must be expanded; but, from the viewpoint of location and scale of the berths, we must point out that these measures will be difficult to enact.

Policy for the Development of Ports and Harbors for Handling Imported Steam Coal in the 1990's

(1) Estimate of imported steam coal demand by type.

The various demands for imported steam coal were estimated by using data obtained through hearings involving related industries such as electric power, cement, pulp, etc. The result of the estimate of imported steam coal for the early 1990's is shown in Table 1.

Table-1 The present status and estimate of imported steam coal demand by type. (unit: thousand tons/fiscal year)

Use		1980	1990-1995
For electric power	New	900	40,000
	Existing and conversion from heavy oil	400	
	Sub total	1,300	20,000
Uses other than electric power	Cement	5,700	
	Pulp, etc.	200	
	Sub total	5,900	
Grand total		7,200	60,000

(2) Estimate of imported steam coal in each port.

To cope with rapidly increasing demands for imported steam coal, port authorities and enterprises are promoting and planning the development of port facilities such as breakwaters, waterways, anchorages, wharves, etc.

It is planned that 16 million tons of steam coal will be unloaded at exclusive-use berths for steam coal power plants which are now existent, under construction or in the planning stage. On the other hand, it is planned that 24 million tons of coal will be handled at transit ports, before being supplied to such final users as power plants, cement and pulp industries, etc. However, port development plans other than those outlined above have not been decided upon because of unclear trends in supply and demand for imported steam coal in the future.

In particular, a coal transport system for large-scale steam power plants, to operate in the early half of the 1990's, is under consideration. Therefore, B.P.H. in M.O.T. has estimated, (by the Transport Simulation Method) the amount of steam coal to be handled at each port in the 1990's. Based on the result of this estimation, B.P.H. in M.O.T. will make plans to develop the ports and harbors for imported steam coal.

A. Premise of estimation

According to this method, the amount of steam coal to be handled at each port will be estimated on the assumption that final users select the most economical transit route. Estimation depends on the following premise.

(a) The total amount of imported steam coal is about 60 million tons. Steam coal is supplied from Australia, China, and North America. Vessels of 30,000 D/W - 150,000 D/W class are to be utilized for foreign trade.

(b) As for the domestic transit system, ships (2,000 D/W - 10,000 D/W class), railways and trucks are to be utilized.

(c) After a preliminary examination, 29 out of 61 ports and harbors were selected for estimation. These 29 ports and harbors include those which port authorities or enterprises are planning to construct as coal berths as well as those for steam coal power plants which have not yet determined their coal transit system. The maximum size of vessels for each port have been made in consideration of minimizing the investment needed for developing port facilities.

B. Result of estimation

(a) The total amount of imported steam coal for new coal steam power plants is about 40 million tons. Of this amount, 30 million tons are to be directly unloaded at exclusive-use berths at 13 ports, while 10 million tons are to be delivered by land or by sea from transit ports (Port of Tomakomai, Fukuyama, and Ube, etc.)

Table 2 indicates the number of ports where power plants own exclusive-use berths ranked by coal handling capacity.

The economical vessel size for foreign trade is no less than 60,000 D/W class.

(b) The total amount of imported steam coal for power plants (which are to be converted from oil), cement industry, pulp industry and so on is about 20 million tons.

The coal is to be delivered to final users from the nearest transit ports (15 ports in Japan) by land or by sea.

Table 3 indicates the number of transit ports, ranked by coal handling capacity.

Fig. 1 shows to result of estimation per region.

Table 2 The number of ports by coal handling capacity

Amount of coal handled (unit: million tons/ fiscal year)	Number (unit: ports)
4 -	2
1 - 4	10
- 1	1

Table 3 The number of transit ports by coal handling capacity

Amount of coal handled (unit: million tons/ fiscal year)	Number (unit: ports)
4 -	2 - 5
1 - 4	5 - 8
- 1	5

Policy and measures for the development of ports and harbors importing steam coal

On the basis of these results, the development of ports and harbors for imported steam coal in the 1990's will be promoted progressively and systematically. Policy and measures for the development of ports and harbors are indicated as follows.

(1) The steam coal for new large-scale coal steam power plants is to be directly imported by more than 60,000 D/W class vessels from foreign countries.

To cope with this situation, it is necessary to develop port facilities adjacent to the power plants. The government, in consideration of this, and in order to promote the construction of coal steam power plants, has established "Energy Port Supporting Scheme" to support development of such coal importing ports.

In this scheme, the government subsidizes power electric companies by providing part of the investment for for coal port construction. This scheme will be continued in the future.

(2) Steam coal to be consumed at certain of the proposed and existing power plants (which are slated for conversion from heavy oil to coal), and cement and pulp industries is to be delivered to final users from the nearest transit ports handling directly imported coal.

Accordingly, it is important to gradually develop transit ports keeping in mind the demand of final users near the ports, and taking the following policies into account.

(a) The government intends to enhance private activities, with measures to provide appropriate support and direction. The government also intends to both urge systematic development of private berths for coal and to promote development of public berths.

(b) As for the development of public berths, in order to handle large amounts of coal efficently, construction of specialized coal berths will be promoted, and general public berths will also be constructed if necessary.

(c) As for wharves and handling equipment for coal berths, it is necessary to enlarge and increase such facilities to handle large shipments of coal in the future. Therefore, funds for this development should be ensured.

(d) In order to promote the smooth improvement of ports and harbors for handling coal, it is necessary to take careful measures for environmental protection such as dust prevention measures. Furthermore, in consideration of the harmony of the landscape around the ports, it will be important to appropriately locate a coal terminal and provide sufficient green belts.

DEVELOPMENT OF DEEP-SEA SUBMERSIBLE DREDGE PUMP

by

Jyuntatsu Miyake & Tokuji Yagi
The Japan Workvessel Association

Forward

Recently in Japan an urgent need has arisen for the development of deep-sea dredging systems that can be used for dredging in the construction of harbours and man-made islands in deep-sea areas, taking gravel from the sea bottom, laying of ocean-bottom pipelines, and the removal of sediment from dam reservoirs. To meet this demand, the Japan Workvessel Association in 1979 began the research and planning of a submersible dredge pump. The main feature of the pump that was developed is that it can be safely operated even at a submerged depth of 50m, and it employs a dry-interior-type variable-speed motor that allows easy speed control. This paper presents an outline of the research carried out by the JWA between 1979 and 1981, namely, the development of the new submersible dredge pump, the outline design of the 1000PS pump, and the performance of the model tests that were carried out with the 50PS model pump inside a pressure vessel, and at the dredging site.

Project Schedule

1979 Establishment of project's development aims and outline design of the 1000 PS submersible dredge pump.

1980 Design and manufacture of the 50 PS model pump and the model pump pressure and endurance tests carried out with the pump inside a pressure vessel.

1981 Installation of 50 PS model pump on a large-size dredger and performance of site dredging tests.

1982 Analysis of test results and design of the prototype equipment.

Project Development Aims and the Outline Design of the 1000 PS Submersible Dredge Pump

After carrying out a study of the general world situation in regard to the development of submersible dredging pumps, the aims for the development of the new submersible dredge pump were established as follows:

- o Pump size:

  Large enough to be suitable for use as a ladder pump on 3000～8000 PS class large-size dredgers.

- o Installation depth:

  50m, which is suitable for application in future deep-sea projects.

- Pump driver:

  A highly efficient, submersible, variable-speed motor with a wide range of application extending into other fields.

- System facilities:

  Light-weight compact-size facilities for easy maintenance and inspection.

- Provision of protection/surveillance sensors to raise the system safety and reliability levels.

On the basis of these aims, an outline design of the 1000 PS submersible dredge pump was carried out, the main features of the pump are as follows:

- Pump capacity for slurry with a 1.16 density is $7000m^3/h$; the total head is 21m, and the speed control range is 100~80% in order to cope with a wide range of operating conditions.

- The electric motor, which is of the non-pressurized, air-enclosed type for easy speed control operation, is not subject to loss from rotor rotation.

- The pump and motor are connected by a flexible coupling so that maintenance work can be carried out easily.

- Mechanical seals with excellent sealing properties are employed for the shaft seal parts.

- For safety purposes, double construction is adopted for the motor-brush inspection ports and the parts penetrated by cables.

- Flood, vibration, and temperature sensors are provided where necessary to raise the reliability and safety levels of the facilities.

<u>The 50 PS Model Pump and the Tests Inside the Pressure Vessel</u>

The 50 PS model pump was designed and manufactured according to the pump outline design described above. Furthermore, in order to obtain technical data for the design of the prototype equipment, the shaft seal parts and the inpeller peripheral speed of the model pump were designed to correspond to those of the 1000 PS pump. The general view of the 50 PS model pump is shown in Fig.-1, and the main specifications are given as follows:

- Pump:

  Single-suction, volute-type, centrifigual pump with 200mm bore.

- Electric motor:

  Wound rotor, induction motor (air-enclosed type)
  27kw x 200V x 1455 1165rpm

o Dimensions:

3079mm(l) x 1050mm(w) x 1150mm(h) x 2550kg(wt)

After general characteristics tests were carried out for both the pump and the motor, the model pump was installed in the pressure vessel, as shown in Photo-1, and the pressure and endurance tests were performed. Pressure tests were conducted varying factors such as the pressure in the tank (max. 7.7kgf/cm^2), the imbalance weight of the impeller and the binding of the motor inspection ports; in the endurance tests, the pump remained in a 1000ppm mud-water solution for 40 days. A summary of the test results is given as follows:

- o Pump efficiency was max. 74.7%, which, converted for the 1000 PS pump, would be 80.4%.

- o Adequate water sealing was provided by the mechanical seals in the shaft seal parts, but the pump-side equipment was found to require measures to prevent granular adhesion.

- o The wear of the motor brushes was normal, and judging from the insulation resistance drop due to brush powder artifically added to simulate long-term operation, the motor continuous operation time was estimated at about 1000 hours.

- o The minimum inspection port binding strength secure against water entry was 4.33kgf/cm^2.

- o Protection/surveillance sensors were found to be minimally necessary as follows:

  Flooding/leakage:

  Pump-side mechanical seal parts, motor interior and inspection ports.

  Temperature:

  Motor coil and each bearing.

<u>Dredging Site Test</u>

Because of the inclined position of the submersible dredge pump installed on the ladder of the dredger during actual operation, and because of the external vibration incurred from the cutter's excavation work, the safety and reliability of the equipment had to be verified under actual dredging operation conditions.

The 50 PS model pump was installed on a 4500 PS dredger and site tests were carried out over a 48-day period. (See Photo-2)

Since the model pump could not be installed in series with the 4500 PS pump because of the difference of capacity, the model pump was connected to a branch line running from the main suction pipe, and the discharged water was rerouted back into the main suction pipe.

The site tests were carried out at two locations, namely, the Futtsu areas of Chiba Pref. and the Omaezaki area of Shizuoka Pref. Table 1 shows the test schedule and the composition of the dredged soil.

Table 1: Test Schedule and Composition of Dredged Soil

site	test period	composition of dredged soil		
		description	N value	compression strength
Futtsu	29 days	sand mixed with sea shells.	20 40	———
Omaezaki	19 days	mudstone	———	200 500kgf/cm^2

During the test period, daily measurements were made every two hours during operation of the model pump. In order to obtain transient phenomenon data, integrated measurements using a data recorder an an oscillogram were taken three times during the test period. The final detail analysis of the test results is scheduled to be completed in 1982, but the results obtained up to the present can be summarized as follows:

- o The reliability and safety of the facilities, even under inclined and vibrating conditions, have been verified to be sufficient.
- o the vibration during excavation works, especially when dredging mudstone, exceeded 3G, which indicates that adequate anti-vibration measures will probably be required when the dredge pump is used as a ladder pump.
- o The total amount of leakage from the pump-side mechanical seal during the entire test period was about 5cc, which will present no problems for the actual operation of the full-scale equipment.
- o The motor inspection ports' resistance to water entry was confirmed to be sufficient.
- o There were no traces of temperature rises due to dirt on the surface of motor and its cooler, which functioned normally.
- o Regardless of the fact that the external vibration exceeded expected limits, the motor brushes showed no abnormal wear.

Concluding Remarks

The forte of the new submersible dredge pump developed by the Japan Workvessel Association is that it can be operated at a submerged depth of 50m and can cope with a wide range of operating conditions. Furthermore, this pump is expected to play a significant role in future deep-sea dredging projects and other works such as the extraction of gravel from the sea bottom, the laying of ocean-bottom pipelines, harbour construction works, and the removal of sediment in dam reservoirs.

The research and development of the submersible dredge pump, which was begun in 1979, started with the outline design of a 1000 PS pump and then developed the 50 PS model pump intra-pressure vessel tests and site tests.

The results of these tests verified the mechanical reliability and endurance of the pumping facilities. In the next step, which is to be carried out in 1982, the test data will be analyzed and the prototype equipment will be designed based on the results of these analysis.

This project was partially sponsored by the Ministry of Transport and the Japan Shipbuilding Industry Foundation, and the JWA member companies responsible for the design and manufacture of the pump and electric motor, and the performance of the tests, were as follows:

Design and manufacture of pump: EBARA CORPORATION

Design and manufacture of motor: MEIDENSHA ELECTRIC MEG. CO. LTD.

Intra-pressure vessel tests: TOA HARBOR WORKS CO. LTD.

Site tests: PENTA-OCEAN CONSTRUCTION CO. LTD.

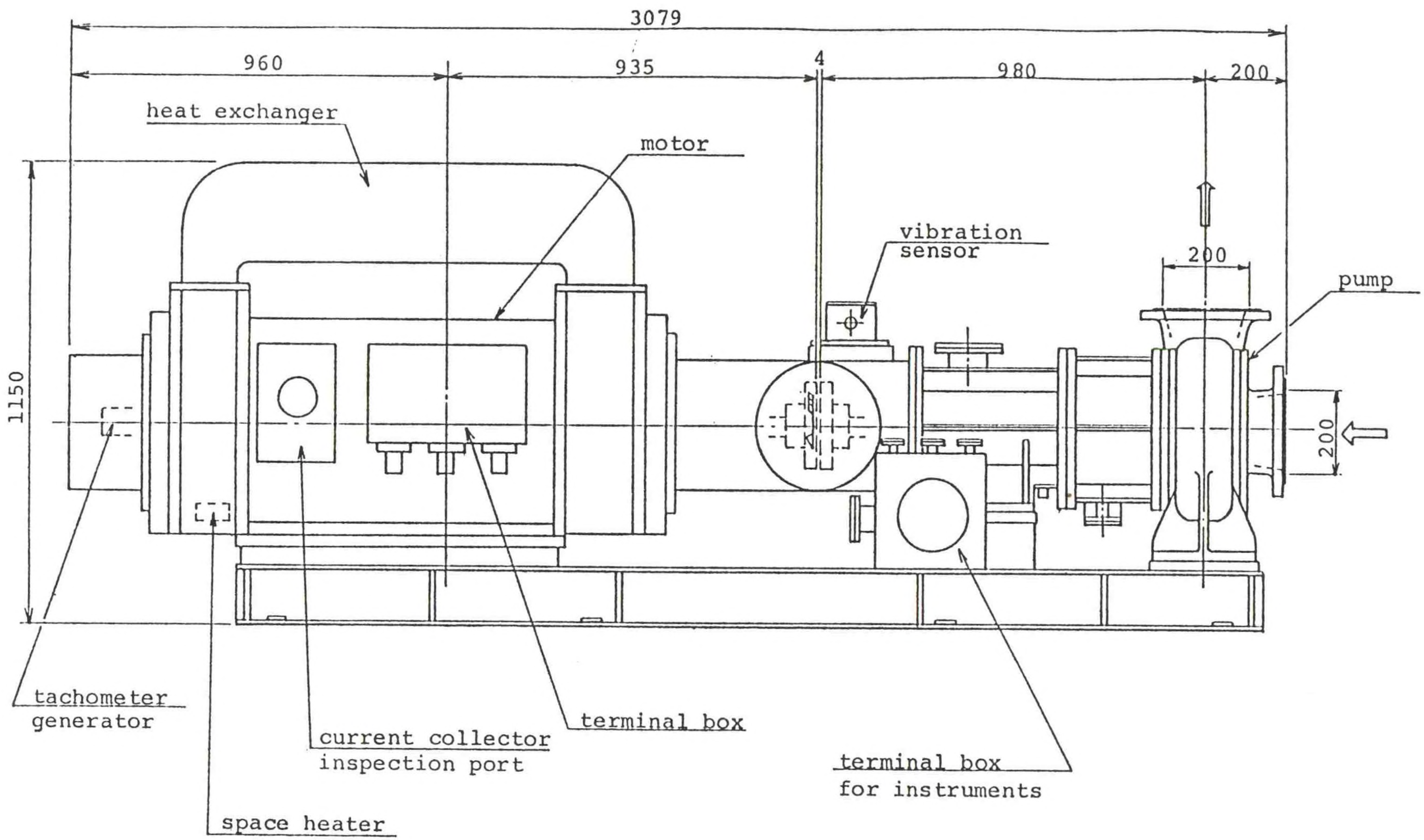


Fig.-1 General View of Submersible Dredge Pump

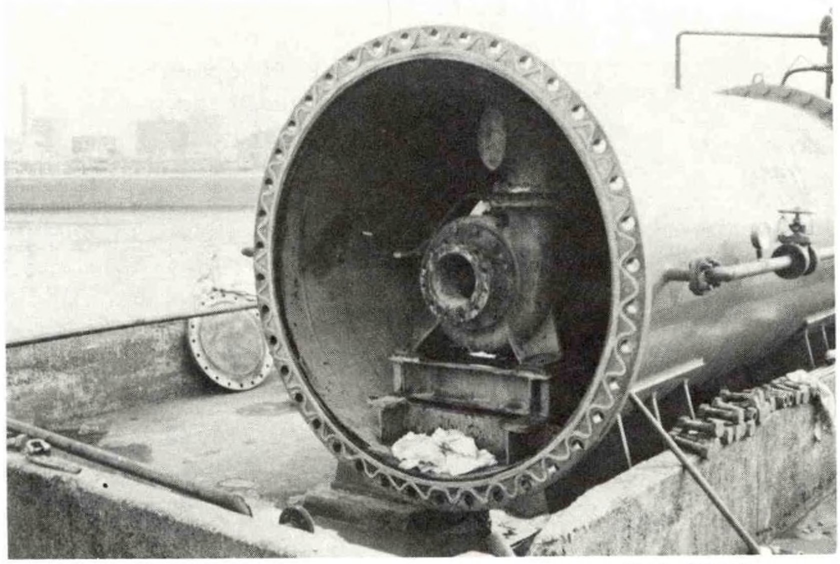


Photo-1 Pressure test inside pressure vessel

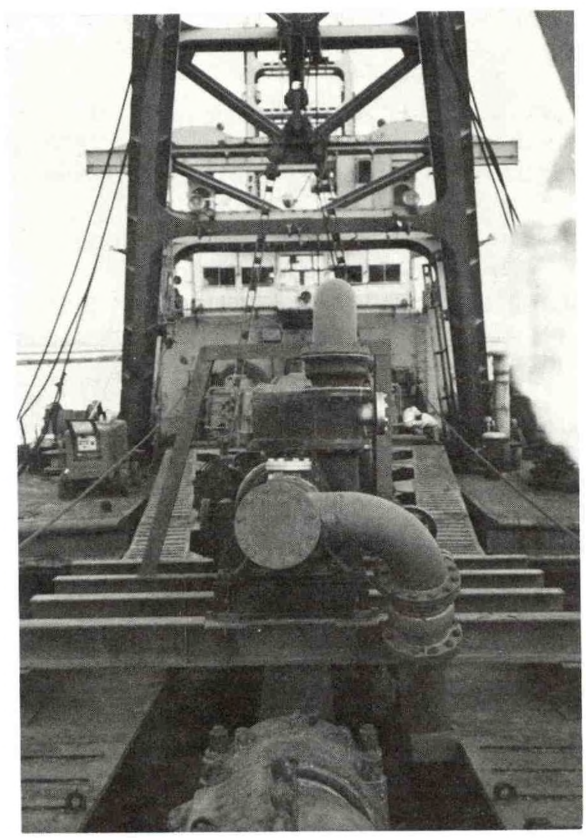


Photo-2 Model pump on the 4500 PS dredger

140 foot (42.7meter) ICEBREAKER TESTING

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To facilitate the movement of goods and materials through the Great Lakes and the St. Lawrence Seaway, the U. S. Coast Guard initiated a program to upgrade its icebreaker fleet in these geographic areas and replace the aging 33 meter icebreaking tugs. This resulted in the design and construction of a new class of icebreaking tug. Late in 1978, the first of these new vessels, the U. S. Coast Guard Cutter KATMAI BAY, was delivered. The principal characteristics of the KATMAI BAY are shown in Table 1.

Table 1

Principal characteristics of 42.7 meter icebreaking tug

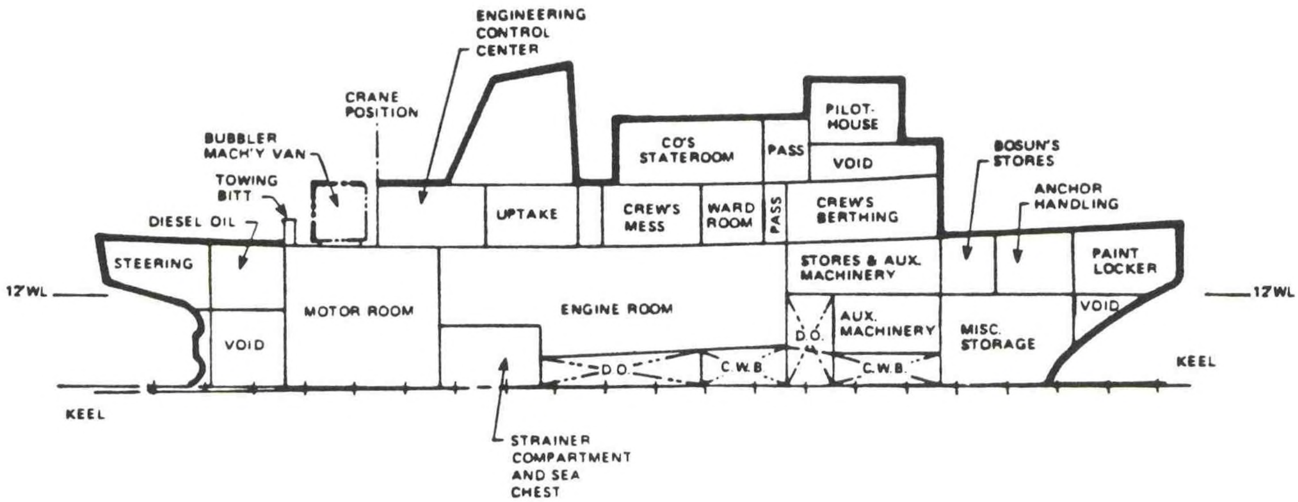
LENGTH OVER ALL	42.7 meters
BEAM	11.43 meters
DRAFT (MAX)	3.66 meters
FULL LOAD DISPLACEMENT	660 Metric Tons
SHAFT HORSEPOWER	2,500 SHP
SPEED, OPEN WATER	14.7 knots

The KATMAI BAY is equipped with a diesel electric propulsion system. Two diesel generator sets are installed driving a single shaft. A hull air lubrication (bubbler) system is installed to provide hull lubrication and as an auxiliary means of improving the icebreaking capability. Large quantities of air at low pressure are forced through holes in the forward portion of the hull. The air then rises along the hull surface causing an upward flow of water which acts as a lubricatant between the hull and ice. In certain circumstances, this action reduces the resistance of the icebreaker to motion thus reducing the amount of shaft horsepower required to move through the ice. The manifolds which deliver the air to the holes are divided into four separate sections. Pilothouse control of the system enables the selection of various combinations of manifolds for icebreaking, for use as a bow thruster, or as an auxiliary turning device. The air lubrication system diesel engine and compressor will be contained in a removable van normally located on the main deck. The portability of the van allows for shoreside storage after the ice season and frees additional main deck area when the system is not needed.

Figure 1 is an inboard profile of the KATMAI BAY showing the location of the machinery van.

Figure 1

Inboard Profile of 42.7 m Icebreaker



Icebreaking trials were conducted in January, February, and March 1979.

The trials investigated level and brash icebreaking and the effect of the air bubbler system on level and brash icebreaking as well as ramming in level ice and ice ridges.

The following are the results of our testing:

A. LEVEL ICEBREAKING - Table 2 shows the effect of the bubbler system on Shaft Horsepower for 30 cm of plate ice and 7 to 12 cm of snow cover. For this ice condition, the KATMAI BAY showed a 10 to 25 per cent decrease in required horsepower when the bubblers were in full operation.

Tables 3 and 4 show the same data for 35 and 40 cm plate ice respectively. The most dramatic effect is seen in the 40 cm ice. This was attributed to the fact that during the period these tests were being conducted, there were significant ice pressures. From this, it appears that the bubbler system is more effective under severe ice conditions. Although the data indicated a decrease in required horsepower when the bubbler system was operating, it did not consider the power required to run the bubbler compressor. If the power required to run the compressor is considered, there are certain conditions when the constant power required to run the bubbler system actually leads to a net power loss. The net losses mainly occur at low vessel speeds.

Table 2

Bubbler comparison for 30 cm plate ice with 7 to 12 cm snow cover

Velocity (kts)	Shaft Horsepower (no bubblers)	Shaft Horsepower (all bubblers)	SHP Decrease	per cent Decrease (SHP)
2	500	450	50	10
4	930	715	215	23
6	1550	1200	350	23
8	2275	1700	575	25

Table 3

Bubbler comparison for 35 cm plate ice with 7 to 12 cm snow cover

Velocity (kts)	Shaft Horsepower (no bubblers)	Shaft Horsepower (all bubblers)	SHP Decrease	per cent Decrease (SHP)
2	570	425	145	25
4	1050	780	270	26
6	1680	1290	390	23
8	2440	1900	540	22

Table 4

Bubbler comparison for 40 cm plate ice and 7 to 12 cm of snow with intense pressure

Velocity (kts)	Shaft Horsepower (no bubblers)	Shaft Horsepower (all bubblers)	SHP Decrease	per cent Decrease (SHP)
2	1150	700	450	39
4	1850	1230	620	34
5	2350	1400	950	40

Our tests indicated that the KATMAI BAY was able to penetrate about 56 cm of snow covered level ice before ramming was required.

B. BRASH ICEBREAKING- The KATMAI BAY had no difficulty going through brash ice up to 122 cm. As was the case in the level icebreaking tests, there were reductions of 224 to 700 Shaft Horsepower to reach the same speed when the bubbler system was in use. Due to the difficulty in quantifying the extent of brash ice consolidation and the degree of refreezing, we are cautious when interpreting the brash ice data.

C. ICEBREAKING BY RAMMING- Data presented by the U. S. Army Cold Regions Research and Engineering Laboratory (CRREL) indicate that the ship can ram through ice 84 cm thick. The data indicate that the icebreaker can achieve maximum impact velocity of approximately 13 kts. in a distance of less than 130 meters. Limited testing indicated the vessel can penetrate pressure ridges up to 152 cm thick. During the testing period, we did not encounter pressure ridges capable of stopping the vessel. The data showed that the bubbler system contributes very little in the ramming mode, however the system was beneficial in backing down from a ramming.

D. COMPARISON WITH 33.5 METER ICEBREAKING TUG- The icebreaking potential of the 2500 SHP KATMAI BAY was compared to that of the 33.5 meter icebreaking tug (ARUNDEL) which the KATMAI BAY was designed to replace. In the brash ice channel on the way to the test site, the KATMAI BAY, at 6/10 power was able to match speed with the ARUNDEL at full power.

The level ice comparison took place in 36 cm of ice with approximately 13 cm of snow cover. After 11 minutes running, the KATMAI BAY was approximately 2 km ahead of the ARUNDEL. The ARUNDEL had to back and ram while the KATMAI BAY proceeded at about 6 kts. with the bubbler system activated and about 5 kts. with the bubbler system secured.

E. MANEUVERING IN ICE- The KATMAI BAY has a turning diameter of approximately 114 to 137 m in about 43 cm of level ice. This compares to a tactical diameter of 148 to 159 m in open water. In brash ice, the turning diameter was nearly equal to the open water turning diameter.

The KATMAI BAY met or exceeded design predictions for performance in all types of ice. The machinery performed well with no instabilities or overloads. The icebreaking ability of this class of icebreaking tug far exceeded that of the 33.5 m icebreaking tug which it is to replace.

As a result of the testing and the experience gained during the winter of 1979-1980, it appeared likely that two 42.7 meter icebreaking tugs working together might be as effective as a single larger icebreaker (WESTWIND 82 m or MACKINAW 88.3 m) assigned to the Great Lakes. To find out, the Coast Guard's Research and Development Center conducted comparison tests during February and March 1981. The following are the results of the testing:

A. CONTINUOUS AND LIMITING ICEBREAKING EFFECTIVENESS- In each of the test runs, the pair of smaller icebreaking tugs proceeded at a speed from 2.9 to 4.6 kts. slower than the large icebreakers. The speed difference did not vary significantly with ice thickness. When the 42.7 m icebreakers were separated by 30 m or less, a single wide track was created which was easy for an escorted vessel to follow. When separated by over 30 m, the small icebreakers left a section of unbroken ice between tracks, however, the unbroken ice was fractured enough for an escorted vessel to transit. When the two 42.7 m icebreaking tugs were running in a staggered formation, the trailing icebreaker could use much less power to widen the track. The power used varied from 400 to 1000 Shaft Horsepower (SHP) compared to 2500 SHP used by the lead ship. Average fuel consumption for the two 42.7 m vessels was as much as 51 liters per kilometer less than the large vessels.

B. BRASH ICEBREAKING EFFECTIVENESS- Considering escort transitting ability, there was little difference between the track left by the two small icebreakers and the track left by the large icebreakers. Operation with the two 42.7 m icebreakers in staggered formation was the best.

C. VESSEL COSTS- The principal characteristics of the icebreakers involved with our testing, acquisition costs, and operating costs for the period from 1 October 1979 through 30 September 1980 are shown in Table 5. (note: These costs are not average costs, but costs for 1980 with a 9.75% adjustment for inflation). The Table shows that operating costs (in 1980) for two 42.7 m icebreaking tugs are about 22% of the operating cost of the WESTWIND and about 29 per cent of the operating cost of the MACKINAW. The acquisition cost (in 1980 dollars) of two 42.7 m icebreakers is about 24 per cent of that of a single icebreaker equivalent to the WESTWIND or MACKINAW.

D. MISCELLANEOUS FACTORS- One of the drawbacks of the KATMAI BAY is the limited crew size which restricts operations to approximately 24 hours between crew rest periods. The large icebreakers have essentially unlimited endurance from a personnel standpoint. The endurance of the 42.7 m vessels could be a significant limitation unless crews are rotated or some other crewing concept is adopted.

CONCLUSION - The Coast Guard has been very impressed with the new icebreaking tugs. Six of these icebreakers are presently in operation. Five are assigned in the Great Lakes and the other is a training vessel. These icebreakers are an asset to our fleet and will make a significant contribution to the state of the art in icebreakers in the future.

Table 5

Principal Characteristics and Costs for Great Lakes Icebreakers

	WESTWIND	MACKINAW	KATMAI BAY	TWO 42.7 meter Icebreakers
LENGTH OVER ALL	82 m	88.3 m	42.7 m	
BEAM	19.5 m	22.5 m	11.4 m	
DRAFT	8.8 m	5.8 m	3.7 m	
DISPLACEMENT	6515	5252	662	
SCREWS	2	3	1	
SHAFT HORSEPOWER	10000	10000	2500	5000
MAXIMUM RANGE	70800 km	75900 km	7400 km	
ECONOMY SPEED	10.5 kts	9 kts	12 kts	
MAXIMUM SPEED	16 kts	18.7 kts	14.7 kts	
RANGE AT MAX SPEED	29600 km	18500 km	4185 km	
NUMBER OF OFFICERS	14	11	3	6
NUMBER OF ENLISTED	127	106	14	28
TOTAL CREW	141	117	17	34

* THE FOLLOWING FIGURES ARE BASED ON FISCAL YEAR 1980 ACTUAL COSTS + 9.75% INFLATION FACTOR (IN THOUSANDS OF DOLLARS) *

	WESTWIND	MACKINAW	KATMAI BAY	TWO 42.7 meter Icebreakers
OPERATING AND MAINTENANCE COSTS	911	581	170	222
FUEL COSTS	264	237	76	124
TOTAL	1175	818	246	346
COST FOR NEW SHIP	$ 125 m	$ 125 m	$ 15 m	$ 30 m

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Overview of United States Coast Guard Advanced Marine Vehicle Program

by LCDR K.G. ZIMMERMAN, USCG AND LTJG J.A. BUDDE, USCGR

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The United States Coast Guard (USCG), an agency of the Department of Transportation, is responsible for enforcing government policies and providing humanitarian services on and near the territorial and contiguous zone waters of the United States. Although quite independent of the U.S. Navy which is under the Department of Defense, the two agencies often work in close cooperation.

The United States Coast Guard utilizes marine vehicles, ships and boats, to conduct its many missions. Although varied, the missions can be simplistically protrayed as a four sided figure. Side one is the enforcement of laws and treaties. This implements the Coast Guard's role as the government's marine police force. These missions include enforcing fishing rules and regulations, enforcing drug smuggling laws and the prevention of illegal alien immigration. The fisheries regulation enforcement takes Coast Guard vessels up to 200 miles offshore. Side two represents the humanitarian aspect of the service. These missions include searching for and rescuing people lost at sea from small boats, yachts, merchant ships, and aircraft. Towing disabled craft, and providing fire fighting and dewatering assistance to ships in need also fall within this category. The Coast Guard also places and maintains some 44,000 navigational buoys and other aids to navigation. The third side of the Coast Guard endeavors to protect natural resources. This field includes monitoring, containing, and assisting in cleaning up oil and hazardous substance spills. Oceanographic research and water quality monitoring are also included among the missions in this area. The fourth side of Coast Guard missions is military readiness. In time of war, the U. S. Coast Guard joins the U.S. Navy and carries out military operations.

It is against this background of Coast Guard multiple mission requirements that potential replacement vessels are tested. Vessels are sought which are capable of executing these multimission aspects.

The reason for this look at Advanced Marine Vehicles is that most of the Coast Guard fleet is scheduled for replacement in the 1990's. This will require the systematic reappraisal of the way at-sea missions are performed in what is likely to be a resource and manpower short era. Several different advanced marine vehicle concepts, some presently operational and some developmental, appear applicable for improving the efficiency and effectiveness of Coast Guard operations. To place the scope of this project area in perspective it should be noted that approximately eighty WPB Coastal Patrol Boats must be replaced in the early 1990's. In addition, about fifteen High Endurance Cutters, twenty Medium Endurance Cutters, thirty Harbor Tugs, and sixty-seven Buoy Tenders and miscellaneous vessels will reach obsolescence in the 1990-2000 time frame.

The fundamental premise on which the program is based is that there exist, or are being developed, marine vehicles which can have a positive effect on the way USCG conducts its missions at sea. These advantageous effects may be in terms of speed, seakeeping, energy efficiency, manpower requirements, maintenance support requirements or characteristics and capabilities that are yet unforseen.

The intent of the Office of Research and Development through the Advanced Marine Vehicle program is to seek out, evaluate, and present analytically supportable information to the Coast Guard decision makers. The program pursues two objectives which work toward this goal.

The first objective is to develop, analyze, and interpret technical information for project officers responsible for new cutter procurements. This technical information, analyzed on the basis of cost-benefit ratios, will be used by the acquisition project officers to support their decisions as to choice of vehicles.

The second objective of the program is to establish a technology base for advanced marine vehicles, derived from both analytical and experimental data. Advanced marine vehicles in this context are defined as non-conventional vessel concepts such as surface effect ships, hydrofoils, small waterplane area-twin hull ships, air cushion vehicles, and high speed planing craft. This technology base provides the state-of-the-art cost and performance inputs for the consideration of alternative marine vehicle concepts applied to evolving Coast Guard missions. The selection, testing, and analysis of specific vehicles provides technical data input to the analyses of the first objective. This information base includes characteristics of both existing (for use as baseline) and advanced marine vehicles and operational concepts.

In support of program objectives, the project is divided into four (4) project areas. The first of these is called Vessel Acquisition Support. It addresses tasks required to meet the first objective of the project. The process which it outlines must be repeated for each replacement capability acquisition. It begins with a review of the acquisition project officer's administrative requirements, mission needs and program standards. These serve to set the stage of the effort. Subsequently, baseline data is collected. This includes: the historic use of CG assets to satisfy the particular mission needs; the historically encountered or expected environment in the operating areas; the support facilities in or near the operating areas; the availability of quantitative human factors guidelines applicable to the associated operational tasks; and energy, manning, and materials considerations.

Techniques to use the input from the data bases are provided by the analysis section, and include the use of mission scenarios and life cycle cost methodology for the Coast Guard. The development of mission measures of effectiveness completes the operations analysis effort. This analysis forms an essential input which must precede the cost-benefit analyses for each replacement capability acquisition. The project output from the first objective is completed with the interpretation and presentation of results to the appropriate acquisition officer.

The next project area, called Technology Assessment, addresses the second objective of the project, the establishment and maintenance of a technological data base. It provides the vehicle characteristics input to the first objective of the project through a catalog of existing and advanced marine vehicle cost and performance information. This recorded technological data base is updated periodically with the characteristics of both existing and advanced marine vehicles. The data is used as necessary during cost-benefit analyses. The vehicle characteristics are obtained through literature searches, field testing, and analytical means. The development and maintenance of evaluation tools support the analytical and experimental evaluation aspects of this project area. A general test plan has been developed to provide guidance in conducting a technical evaluations (TECHEVAL) or operational evaluations (OPEVAL). The procurement of selected AMV's for test and evaluation is covered under a separate project element. The goal of an AD HOC project area is to support special project requirements arising from multiagency or multinational agreements.

The last two project areas are designed to support the technology assessment effort by providing for subsystem development, and operational concept evaluation. The concept evaluation area includes a project element which provides a mechanism for expanding the scope of the project if future requirements so dictate.

Various vehicle concepts presently identified for evaluation are: surface effect ships; small waterplane area twin hull ships; hydrofoils; planing craft; conventional monohull displacement vessels; air cushion vehicles; all terrain vehicles; and search and rescue boats.

Advanced Marine Vehicles under consideration such as hydrofoils, air cushion vehicles, and large fast planing boats in commercial and military service worldwide now number in the thousands. In military applications, these craft generally serve as rapid troop transports or as weapons platforms. Of significance is that the reliability of these craft is now widely considered acceptable and their cost-effectiveness is becoming sufficiently attractive to supplement capital ships in many missions in the world's navies. Recent Japanese development of SWATH (Small Waterplane Area Twin Hull) vehicles has proven the commercial viability of this concept.

The project relies heavily on U.S. Navy developed technologies, assessing and applying those elements which are appropriate to Coast Guard mission needs. It concentrates on mature, practicable concepts. While U.S. Navy TECHEVALs, i.e., performance tests, are usually directly applicable to Coast Guard data requirements, OPEVAL data usually is not. U.S. Navy OPEVALs are generally utilized to gain approval for service use of production-ready vessels, boats, or components. Because of its multimission nature, Coast Guard OPEVALs fall into two categories. The first is based on operational deployments to assess suitability of a vessel concept for Coast Guard missions. The second category of OPEVAL is similar to that employed by the U.S. Navy which is the determination of mission deficiencies by an operational crew performing different mission scenarios under realistic environmental conditions. Also, the Coast Guard goes one step further and places the prototype vehicle in service for a limited period.

The Coast Guard's interest in high performance watercraft began more than ten years ago when potential replacement for our aging WPB fleet began to be explored. Previous test and evaluation efforts included:

a. The SK-5 air cushion vheicles used primarily as search and rescue vehicles under Coast Guard Group San Francisco, CA, from 1 July 1972 to 15 June 1973.
b. TUCUMARI (PGH-2), a U. S. Navy hydrofoil, deployed to the Coast Guard. With its Navy crew, Coast Guard liaison and observers on board, it operated in limited Coast Guard scenarios off the northeast coast of the United States in late 1972.
c. FLAGSTAFF (PGH-1), a U. S. Navy hydrofoil, was on loan to the Coast Guard from 8 November 1974 through 18 February 1975. Coast Guard commissioned and staffed, FLAGSTAFF was evaluated in real and simulated Coast Guard missions operating out of San Diego, and other Southern California ports.
d. HIGHPOINT (PH-1), a U. S. Navy hydrofoil, on loan to the Coast Guard was commissioned and Coast Guard staffed from 4 April 1975 to 5 May 1975. HIGHPOINT was tested and evaluated in real and simulated Coast Guard missions operating out of San Francisco.
e. CPIC (Coastal Patrol Interdiction Craft), a U. S. Navy experimental planning hull craft, was observed by the Coast Guard hydrofoil test and evaluation team for four days in March 1975 in operations off San Diego, California.

Additionally, independent and/or unsolicited studies of the utilization of high performance advanced marine vehicle designs have been conducted. These include:

a. July 1975: The Center for Naval Analysis completed an independent study on hydrofoils for the Fisheries Law Enforcement mission of the U. S. Coast Guard.
b. September 1977: The Boeing Company submitted an unsolicited three-volume study of a patrol hydrofoil cutter (WPHC) for use in Alaskan Fisheries patrols. The proposed cutter is a modification to the U. S. Navy PHM and an adaptation of the commercial Boeing jetfoil. This is the same as HMS SPEEDY which is currently in use by the British Navy in the North Sea.
c. December 1977: The Grumman Aerospace Corporation submitted an unsolicited proposal for U. S. Coast Guard hydrofoil cutter. Their proposed cutter was an adaptation of the FLAGSTAFF Mark 2 design patterned for Coast Guard mission requirements.

Subsequently, other advanced marine vehicle designs have been examined which include the small waterplane area vessels (SWATH) with surface penetrating wings supporting two submerged pontoons and an elevated bridge deck structure. An extensive set of trials were conducted in the Spring of 1978 involving side-by-side steamings of a 3100 ton, 378 foot Hamilton class cutter; a 106 ton, 95 foot patrol boat; and the 215 ton, 89 foot U. S. Navy SWATH vessel KAIMALINO. The trials compared seakeeping and measured human factors data on six crewmen on each vessel performing identical tasks. The KAIMALINO had equivalent or better seakeeping and human factors when compared to the large cutter and significantly improved performance over the 95 foot patrol boat.

In 1978 a joint venture between Bell Aerospace and Halter Marine was formed for the purpose of producing a low-cost, operational rigid-side hull Surface Effect Ship for use primarily by the commercial offshore crewboat industry supporting Gulf of Mexico oil development. The outgrowth of this venture was the formation of the Bell-Halter Corporation. This company produced the Bell Halter 110-foot Surface Effect Ship (BH-110) which received its Coast Guard certification for commercial use in the fall of 1979. Subsequently, the BH-110 was used as a company promotional vessel around the Gulf Coast and leased to Exxon Corporation for an extended evaluation as a crewboat. At the time of construction, Bell-Halter advertised that they could build these vessels, in quantity, in the neighborhood of $4,000,000 a ship. This was considered very attractive by the industry at the time. Being built entirely of welded aluminum construction, the vessel was fairly light weight, easily handled and maintained by a small crew, with a large load-carrying capability and high speed potential. Shortly after Christmas, 1979, the Coast Guard and Urban Mass Transportation Administration contracted with Bell-Halter to lease the vessel for a period of one month for engineering evaluation in the Norfolk-Chesapeake Bay area.

In 1980, performance tests were conducted on the 110 foot BH-110 Surface Effect Ship. The vessel's performance was sufficiently attrative to result in an extensive evaluation of the concept. The vessel, commissioned the USCGC DORADO (WSES-1), was acquired for a six-month OPEVAL.

On June 20, 1981, the USCGC DORADO (WSES-1) began six months of service. During the evaluation, she participated in numerous missions demonstrating the usefulness of this craft concept for Coast Guard duties in the Gulf of Mexico. On December 15, 1981, USCGC DORADO was decommissioned, and the ship returned to U. S. Navy custody. The six month operational evaluation of the USCGC DORADO proved that the SES concept can be valuably employed as a Coast Guard resource. The craft proved equal or more capable in conducting most of its missions than comparable Coast Guard cutters. While problems and limitations with the concept and this particular vessel exist, solutions are not beyond the reach of technology.

In 1981 a technical evaluation was conducted with the 45 ton, 64 foot SWATH vessel SUAVE LINO. The vessel demonstrated seakeeping characteristics representative of much larger vessels and sustained the seakeeping performance demonstrated by the KAIMALINO. More extensive assessments of the SWATH concept are planned.

In February 1982, side-by-side trials of three rigid-hull inflatables (RHI's) were conducted on the Columbia River bar off of Cape Disappointment, Washington, off the northwest coast of the United States. The Coast Guard is interested in determining if these craft are suitable for surf and coastal rescue missions. Their speed, seakeeping qualities, and initial low cost make them excellent candidates for inclusion in the fleet as motor rescue boats. The data is still being analyzed but preliminary findings seem to indicate that an RHI tailored to the Coast Guard's needs could perform suitably in a variety of missions.

During January and February 1982, the Coast Guard began testing the concept of using a small air cushion vehicle (SACV) as an ice rescue craft in the Great Lakes. It was found during tests on Lake St. Claire that refrozen brash ice presents an almost insurmountable barrier to the craft as it was initially configured. Severe damage to the skirt system occured due to the sharp ice edges. Modifications to the undercarriage may be possible however, and may reduce the possibility of damage. These tests are not yet complete and although initial findings are negative, it is possible that SACV's may yet be a valuable resource during the winter months.

Surface piercing hydrofoils are another craft of interest. Equipped with diesel propulsion and less sophisticated controls than fully submerged hydrofoils, they offer an intermediate step in the advancement of technology of high speed patrol craft. In pursuit of this concept, the U.S. Coast Guard, in conjunction with U.S. Navy and U.S. Urban Mass Transportation Administration will conduct field tests of the Rodriquez RHS 200 hydrofoil in Messina, Italy in April 1982. These trials will be technical in nature, assessing items such as fuel economy, ride quality, and maneuverability.

Other future activities of the advanced marine vehicle program follow it's objectives both in terms of hardware and concept developments. Early support will be provided to the project officers responsible for the acquisition of future buoy tender vessels and patrol craft, with other vessel replacement projects being supported as they occur.

Technology to assess vehicle potential will continue to be developed. Studies into fields such as human factors, seakeeping, ride control and dynamic stability of advanced marine vehicles will be conducted. The results of these studies, in most cases, will be applicable to more than one vehicle concept.

Development of operating concepts and methods will also be studied. Ideas often generated from operational trials will be evaluated with the thought of maximizing effective utilization of resources. Such potential concepts include the use of a large platform as a mobile base to extend the "home port" of smaller craft into regions not previously patrolled by these vessels. Another concept is the development of methods to exploit craft characteristics, such as speed, and apply them to operational missions in ways different from normal utilization of conventional craft.

Hardware related developments are also planned. Items to enhance particular vehicle capabilities will be investigated. Examples of such enhancements include rudder roll stabilization for conventional cutters, and a ride control system for surface effect ships to alleviate objectionable heave vibrational motions.

Study of the SWATH vehicle concept is also planned. World wide construction of these vessels is very limited, with the most recent activity occurring in Japan. The world population of these craft is six, two in the U.S. and four in Japan. The SWATH concept looks desirable for use in some Coast Guard deep ocean missions. Study of this concept may result in construction of a full size test vehicle.

In summary, the status of advanced marine vehicle research in the U.S. Coast Guard is active and continuing. While not a great deal of pure research is being conducted, the concepts are being evaluated with their practical application to Coast Guard missions as the predominant factor.

SIMULATOR RESEARCH AND TRAINING

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Introduction

A major new era in shiphandling technology started in 1967. In that year the SOGREAH facility near Grenoble, France began training with 1/25th scale ship models in which a man could sit. This system was the first to combine realistic human skills with ship motion technology. In that system shiphandling events occur five times as fast as at full scale. Now sit-in ship models are also used for training at Warsash in the U. K.

In 1970, the Institute of Mechanical Constructions in Delft, Netherlands began building electronic simulators which operate at real time, but depend on mathematical models of ship motions rather than physical models. Perspective views of the external scene were produced by point light source projection techniques. Although radar simulators and bird's eye view simulators had been available for many years, such views could only exercise the intellectual part of human shiphandling. Visual perceptual skills are also critical.

Today about twenty visual ship simulators exist worldwide. These have an enclosed "bridge" often with real radars, steering stands, compasses, engine telegraphs, communications devices, and indicators. One sees projected ships, land, and aids to navigation in perspective through the bridge windows. Apparent motions and instrument readings are driven by computer. Several imagery and projection systems have been used effectively.

Research Applications of Ship Simulators

Modern ship simulators are laboratories where many aspects of ship safety can be studied in controlled experiments. This allows a major new maritime use of classical scientific methods.

Validation of such simulator experiments is complicated. The motion equations and hydrodynamic coefficients must be accurate. The people must be real mariners experienced in (or at least trained for) the simulated operation. Their performance on the simulator must be shown to be similar to their performance at sea. The visual scene projection must contain the perceptual cues used for realistic shiphandling. Finally, the scenarios used must reflect situations or problems that do occur in real operations.

*Facts and opinions stated in this paper are the responsibility of the author; they do not necessarily represent U. S. Coast Guard policy.

These simulators have been used to study the design and modification of harbors and channels. They are useful in studying accident situations, such as difficult bridge passages or encounters between fast container ships and tankers. They can be used to find out the value of different types of navigation equipment on a ship's bridge. We have recently evaluated the safety of navigational approaches to the Louisiana Offshore Oil Port by simulator. During this research, we found that all of the practising VLCC masters in the experiment agreed that the simulated ship behaved like a real supertanker in maneuvers that ranged from sea speed ahead in deep water down to slowing, stopping and backing in shallow water.

One of the major areas of U. S. Coast Guard simulator research involves placement of buoys and beacons used as short range aids to navigation. Determining the proper numbers, types, and arrangements of these aids in any location has involved highly uncertain judgements. Through many carefully controlled experiments, knowledge is being gained to produce clear guidelines that can narrow the demands for judgements.

Training Applications of Ship Simulators

Most existing ship simulators are used for training senior mariners. This training can be useful to refresh skills that are not used often enough at sea to keep proficiency at a high level. Training can also be useful to teach the use of new types of equipment, such as rate of turn indicators.

One of the major concepts of simulator use is for prospective masters of large ships or vessels with unusual handling characteristics to learn how to handle their ship in advance. This is expected to lessen the danger of accidents having a high risk of pollution or of spilling dangerous chemicals.

Since 1978, the U. S. Coast Guard and Maritime Administration have pursued a large research program in simulator training. Our early study compiled information about the tasks and skills used in navigation watchstanding. The capability of simulators to train these skills was evaluated, along with the training technology available.

A second phase of research evaluated simulator design features for their training effectiveness. The major finding was that features such as color, large field of view, or independently maneuverable traffic vessels have much less to do with training value than the instructors have. Subtle differences between two highly qualified professional instructors were found to cause large variations in training effectiveness.

Simulator schools will have to devote more attention to methods of instruction, to training techniques and to the instructor-student relationship. It is not enough to have a good simulator with very accurate ship motions. The exact realism of the outside view is not as important as the instructors' manners and methods of teaching.

In this research project, we addressed training of maritime cadets for the first time. After successful research experiments, ongoing simulator training has been established for students at the National Maritime Academy and the U. S. Coast Guard Academy.

Future Work

New areas of ship simulator research and training will involve even more exacting models. We will experiment with simulator training for ship pilots. The Dutch have had a successful simulator training course for Europort pilots for several years.

We will also be working with more complex motion models. We will determine hydrodynamic coefficients for push tows and barges on rivers and inland waterways. Apart from model tests and mathematical estimation, we will use real time data collection on actual towboats to estimate hydrodynamic coefficients.

In conclusion, ship simulator technology is now well established for both research and training. Advances in ship motion modeling and in visual scene projection are making more new applications possible every year. Care in the use of this technology will receive greater attention in the future.

Our aids to navigation research will focus on short range electronic aids and radar piloting. Simulator validation will also be important.

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UTILIZATION OF WIND ENERGY AT LIGHTHOUSES

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I. Introduction

The U.S. Coast Guard currently operates 65 remotely sited lighthouses powered by diesel-electric generators. It is concerned about the escalating costs of diesel fuel as well as the shortage of trained personnel needed to maintain these lighthouses and generators.

The Office of Research and Development initiated a project in late 1979 aimed at developing alternate power sources to supplement the existing diesel-electric generators. The specific goals of the projects were to develop an overall system design which would:

A. Reduce overall costs of supplying electric power to remote lighthouses

B. Reduce the amount of diesel fuel consumed

C. Increase periods between routine maintenance and decrease the number of man-hours required to perform such maintenance.

The design concept for the proposed alternate energy source was to be modular and capable of meeting the following requirements:

A. Allow for all combinations of various energy conversion techniques including wind machines and photovoltaic (PV) arrays

B. Allow for interchanging various sizes of modules to fit different power level requirements and available natural energy resources (e.g., average wind or solar insolation levels).

C. Allow for possible substitution of subsequent technological improvements developed by industry.

An important long range objective of the Coast Guard is that any new components to be used as part of an alternate power source for lighthouses must be compatible with the standardized lighthouse equipment which now exists.

II. Project Progress and Major Findings

The project has been divided into a series of phases, each one requiring between one and two years to complete. Phase I of the project was a feasibility study[1] which was completed in February 1981 by the Johns Hopkins University, Applied Physics Laboratory for the U.S. Coast Guard

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[1] W. Richard Powell, R. J. Taylor, J. L. Baron, E. E. Mengel and J. C. Ray of the Johns Hopkins University, Applied Physics Laboratory, "Alternate Hybrid Power Sources for Remote Site Applications," 1981 (Coast Guard Report No. CG-D-06-81, available from NTIS, AD A099471).

Office of Research and Development. This study primarily analyzed the technical and economical aspects of using wind energy and PV arrays at lighthouses in conjunction with diesel generators. To perform this analysis a computer model was developed that simulated the technical performance of alternate power sources at lighthouses. All aspects of the lighthouses and alternate power sources were modeled. The important aspects of the lighthouses and how they were addressed in the model are briefly summarized below.

Load Requirements - The overall electrical requirements at lighthouses and the power required by individual components of the lighthouse were studied in great detail. In addition to the light signal, most lighthouses also have sound signals which are operated during periods of fog, and radio beacons which transmit for one minute every six minutes. There are also a number of other components, such as a radio link set, a fog detector, and electronic logic circuitry to control the diesel-electric generators and signal equipment. A general description of the range of power needed by different components currently being used by Coast Guard lighthouses is shown in Table 1.

TABLE 1

	Peak Power (Watts)	Av. Power (Watts)
Light Signals		
a. Small non-rotating	500	500
b. Large non-rotating	1000	1000
c. Small rotating	1470	1470
d. Large rotating	2470	2470
Sound Signals		
a. Small (single)	1632	426
b. Large (double)	3264	852
Radio Beacon		
Several transmitter sizes are used		173-385
Other Lighthouse Components		
Radio link set, fog detector and electronic logic		345

The daily load at any specific lighthouse is dependent on the size of the components in the lighthouse, the number of nighttime hours and the number of hours of fog. The size of the components at any site are determined by the navigational requirements for the range of the light signal, sound signal and the radio beacon. The seasonal variation in the number of nighttime hours is dependent on latitude and season of the year. In general, fog is more common in the fall and early winter, more common on the east coast than the west coast and more common in the north than in the south. As fog is strongly influenced by local conditions, site specific records are essential for accurate predictions. The computer model was capable of simulating any load requirements, however, for simplicity in carrying out a parametric analysis of various alternate power sources the model considered only three generic power levels as shown in Table 2.

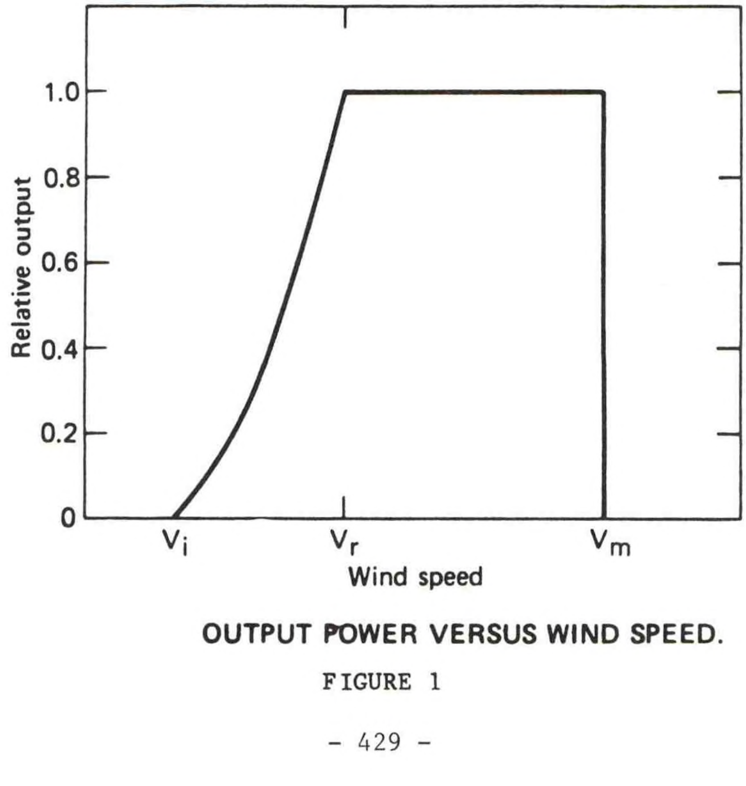
TABLE 2 — GENERIC AVERAGE POWER LEVELS OF LIGHTHOUSES (WATTS)

	High	Medium	Low
Night	3000	2000	650
Day	500	500	100

The hourly power requirements for each of these three power classes is automatically constructed for each day within the computer model using the site latitude and the day of the year to compute the number of hours of nighttime.

Natural Energy Resources - Although any meterological data describing wind speeds and solar insolation could be included in the model, a simple generic approach was again chosen to model the natural energy available at lighthouse sites. Six different generic locations were defined relating to three latitude groups (Southern, Northern, Alaskan) that could further be divided into two different wind regimes (coastal and offshore). The model thus considers six generic climatic sites. All of the Coast Guard's 65 remote lighthouses lie in one of these generic locations. Winds at coastal sites often show significant diurnal variation in strength and direction due to the differential heating rates over land and water across the shoreline.

Wind Machine Output - Based on test results obtained by the U.S. Department of Energy, an appropriate model of a wind machine was selected. The output of a typical wind machine is represented in Figure 1.



OUTPUT POWER VERSUS WIND SPEED.

FIGURE 1

Wind machines can generally be characterized in terms of five parameters: (1) the cost of the wind machine and tower, (2) the minimum wind speed necessary to begin producing power, V_i, (3) the rated speed, V_r,(4) the maximum speed permitted before mechanical shutdown to avoid damage, V_m, and (5) the full output power rating, P_r. The computer model was capable of varying all of these parameters, however, it should be kept in mind that there is a limited selection of high reliability wind machines being manufactured. Therefore, for the purposes of the study, wind machines were modeled with characteristic sizes and performances of commercially available machines.

PV Array Output - The results of the study showed that Photovoltaic (PV) Arrays were only economically practical in a limited number of sites and even there the expected power obtained from the array was not significant. The computer model calculated both the hourly average and the statistical characteristics of the output from a PV array in any of the six climatic regions. Based on these results, the present plans are to focus attention on the use of wind machines. If the costs associated with PV arrays drop dramatically in the future, the Coast Guard will reconsider their use, but for the present, wind machines appear to be more cost effective.

Battery Storage and Control Models - The storage of energy generated by the wind, PV array, or diesel-electric generator can greatly reduce the overall amount of diesel fuel used at a lighthouse. For purposes of the study, it is assumed that when the diesel is off, the storage system carries part or all of the load whenever the power supplied by the wind machine or PV array (or both) is inadequate and the batteries are not fully discharged. When the batteries become fully discharged, the diesel generator is started and operated at its most efficient load level. The output from the diesel generator in excess of the load requirements is used along with any energy being produced by the wind machine or the PV array to recharge the batteries. The batteries were assumed to have a charging rate limit that at times prevent operation of the diesel at its full output. To account for this, a set of diesel control laws were developed and incorporated into the model. In the study, only lead-acid batteries were considered as they offer a significant advantage over other types. However, nickel-cadium batteries, although relatively expensive, may offer some cost advantages due to their outstanding cycle life and wide range of operating temperatures. Future analysis of battery storage will include both types.

Diesel-Electric Generators - The present mode of operation at remote lighthouses is to run the diesel generator on a continuous basis leaving the light on at all times. This avoids having to automatically start and stop the diesels and prevents carbon deposits from developing in the diesels. In order to save diesel fuel and thus reduce costs, it became evident that a means of cycling the diesel must be examined. Furthermore, if the number of hours of diesel operation per year could be significantly reduced, then the periods between routine maintenance visits could be increased. This would be of great benefit to the Coast Guard as it could reduce personnel requirements for maintaining lighthouses. The study then examined the use of diesels with battery storage as well as wind/PV arrays with battery storage and diesel back-up. A very elaborate model of a diesel generator was developed that included all life cycle cost considerations and various control laws for operating the diesel in conjunction with battery storage.

The computer model was used extensively in the study to simulate the technical performance of different power source configurations as the parameters were varied. The following results were calculated for each system:

A. The total number of hours that the diesel runs each year.
B. The number of diesel starts required during the year.
C. The number of gallons of diesel fuel used each year.
D. The battery life in years.
E. Battery charging losses.

Based on the results obtained above for technical performance, the computer model then considered different sizes of the storage battery array, wind machine and PV array. Also considered was the electrical load required and the generic climatic location. Using this information the computer model performed an economic analysis which could systematically determine life cycle costs for any alternate power source configuration. In performing this analysis, the computer model considered important economic factors such as the discount rate, fuel escalation rate and year of installation to compute the annualized cost of operating a specific power source.

Due to the large number of parameters that could be varied, an exhaustive analysis would have required an exorbitant amount of computer time and costs. Fortunately, it was possible to intelligently omit many of the cases and a clever method of sampling a small number of days per year, rather than simulating hourly performance for an entire year, greatly reduced the amount of computer time required. The results of the Phase I study are summarized in Table 3. The top four rows correspond to the most cost effective combinations found of wind machines, PV arrays and battery storage with a six kilowatt diesel back-up. The two rows at the bottom of the table correspond to the best size of battery storage used in conjunction with only a diesel-electric generator. This special case is obtained in the computer model by setting the size of the wind machine and PV array to zero. The values for annualized cost and fuel used per year are also given as a percentage of the current diesel systems used in lighthouses, that is, with the diesel running continuously.

Several general conclusions were drawn from the results obtained:

- Wind systems are more economical than solar systems everywhere except in Southern coastal sites.

- Only Northern and Alaskan offshore sites are dramatically more economical than the simple diesel and battery storage systems when wind systems are used.

- The cost savings from reduced fuel usage is greater for the medium power sites than for the high power sites. The six kilowatt diesel, which is the standard power source now used at lighthouses, is actually oversized if adequate battery storage is available. This size diesel is needed to meet peak power demands in the present lighthouses, but the average power at a lighthouse is typically around one kilowatt. Simulation of the low power class was deferred so that more appropriately sized diesels can be considered.

TABLE 3
SUMMARY OF MOST ECONOMICAL SYSTEMS

System			SOUTHERN SITE	NORTHERN SITE	ALASKAN SITE
DIESEL + BATTERY + ALTERNATE ENERGY HYBRID	HIGH POWER	COASTAL	Cost ($/yr) 20.0K (77%) Fuel (gallon) 2568 (59%) Bat. (ampere-hour) 500 Sun (nominal kW) 1 Wind (peak kW) 0	Cost ($/yr) 6.4K (24%) Fuel (gallon) ≈0 Bat (ampere-hour) 6000 Sun (nominal kW) 0 Wind (peak kW) 12	Cost ($/yr) 6.4K (25%) Fuel (gallon) ≈0 Bat. (ampere-hour) 8000 Sun (nominal kW) 0 Wind (peak kW) 8
		OFFSHORE	Cost ($/yr) 6.1K (23%) Fuel (gallon) ≈0 Bat. (ampere-hour) 6000 Sun (nominal kW) 0 Wind (peak kW) 12	Cost ($/yr) 4.2K (16%) Fuel (gallon) ~ 0 Bat. (ampere-hour) 1500 Sun (nominal kW) 0 Wind (peak kW) 6	Cost ($/yr) 4.0K (≤16%) Fuel (gallon) ~ 0 Bat. (ampere-hour) 2000 Sun (nominal kW) 0 Wind (peak kW) 5
	MEDIUM POWER	COASTAL	Cost ($/yr) 17.1K (65%) Fuel (gallon) 1825 (42%) Bat. (ampere-hour) 1500 Sun (nominal kW) 2 Wind (peak kW) 0	Cost ($/yr) 5.1K (20%) Fuel (gallon) ≈0 Bat. (ampere-hour) 4500 Sun (nominal kW) 0 Wind (peak kW) 8	Cost ($/yr) 5.2K (20%) Fuel (gallon) ≈0 Bat. (ampere-hour) 6000 Sun (nominal kW) 0 Wind (peak kW) 8
		OFFSHORE	Cost ($/yr) 15.5K (59%) Fuel (gallon) 2373 (56%) Bat. (ampere-hour) 1500 Sun (nominal kW) 0 Wind (peak kW) 4	Cost ($/yr) 3.7K (14%) Fuel (gallon) ~ 0 Bat. (ampere-hour) 1000 Sun (nominal kW) 0 Wind (peak kW) 4	Cost ($/yr) 3.6K (14%) Fuel (gallon) ~ 0 Bat. (ampere-hour) 2000 Sun (nominal kW) 0 Wind (peak kW) 3
DIESEL + BATTERY ONLY	HIGH POWER		Cost ($/yr) 20.8K (80%) Fuel (gallon) 2836 (65%) Bat. (ampere-hour) 2000 Battery Life (yr) 8.24 Diesel Use (hours/yr) 5323	Cost ($/yr) 20.8K (80%) Fuel (gallon) 2842 (65%) Bat. (ampere-hour) 2000 Battery Life (yr) 8.30 Diesel Use (hours/yr) 5353	Cost ($/yr) 21.0K (80%) Fuel (gallon) 2879 (66%) Bat. (ampere-hour) 2000 Battery Life (yr) 7.73 Diesel Use (hours/yr) 5414
	MEDIUM POWER		Cost ($/yr) ≤18.7K (71%) Fuel (gallon) ≤2420 (56%) Bat. (ampere-hour) ≥1500 Battery Life (yr) ≥4.20 Diesel Use (hours/yr) ≤4350	Cost ($/yr) 18.4K (70%) Fuel (gallon) 2309 (53%) Bat. (ampere-hour) 2000 Battery Life (yr) 5.26 Diesel Use (hours/yr) 4198	Cost ($/yr) 18.4K (70%) Fuel (gallon) 2290 (53%) Bat. (ampere-hour) 2000 Battery Life (yr) 5.31 Diesel Use (hours/yr) 4167

Cost and fuel useage as percent of current diesel only system are given in parenthesis.

Ampere-hours are for 12 volt batteries.

- The optimum battery size differs greatly for each locale. Large batteries cost more initially but last longer and reduce the number of diesel starts. The model assumes a 12 volt battery array and gives ratings in ampere-hours. This provided a convenient technique for varying the energy storage required in the computer model, however, in practice a 120 volt battery array would be more practical.

The final report[1] from Phase I also recommended two conceptual designs for the use of alternate power sources at lighthouses. The two designs differed primarily in the degree of DC vs AC power that the load was configured to use.

Phase II of the project was initiated on 1 May 1981. The objective of this work was to develop, fabricate and test the conceptual designs proposed in Phase I. In so doing, Phase II would confirm the overall system designs and determine an optimum design scheme based on experimental results.

On 15 October 1981, a wind machine was installed at the Cape Henry Lighthouse in Virginia Beach, Virginia. The machine is mounted on a 60 foot (18.3 meter) tower and can generate approximately 2.5 kilowatts in a 30 miles per hour (48.3 kilometers per hour) wind. The rotor diameter is 16.4 feet (5 meters) in diameter. The machine cost approximately $10,000 and was developed especially for remote site applications by the North Wind Power Company under a U.S. Department of Energy contract. The completed experimental system, which is expected to be operating in early 1983, will consist of the wind machine, diesel generator, storage battery array and a microprocessor controller. The system will be fully instrumented for data collection purposes. The Cape Henry Lighthouse is not a remote lighthouse and it is presently operated by commercial power. It will be reconfigured in an experimental arrangement to run solely off power supplied by the wind machine and the diesel generator. Should a failure occur in this alternate power source, the lighthouse will revert back to commercial power.

Future Plans

Upon final installation of the experimental system at Cape Henry, a test and evaluation effort will begin. The general purpose of this testing is to explore various system designs with the intention of finding an optimum mode for economical operation; identify any problems associated with the components that make up the alternate power source; and insure that solutions to any problems are in hand. This will complete Phase II of the project. Phase III of the project will begin in 1983 and will involve the installation of an alternate power source at an actual remote site, particularly a cold weather environment where a good test of the reliability involved with starting and stopping diesel generators in subfreezing temperatures can be carried out. Maintenance and other reliability improvements will also be studied along with the use of Coast Guard field personnel to maintain the system. The final result of this project will be a fully engineered system specification that can be used to procure operational systems. A sophisticated computer model, based on the present model used in Phase I, will provide Coast Guard engineering personnel with a design tool for use in the planning and installing of alternate power sources at remote lighthouses.

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