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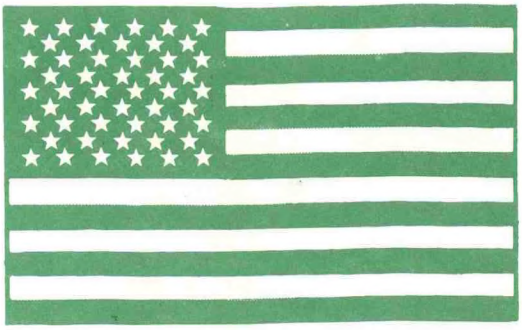

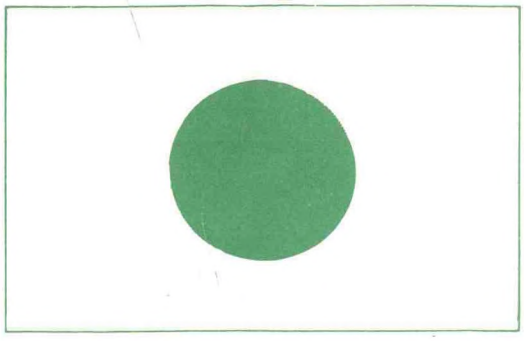

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UJNR

U.S./Japan Cooperative Program in Natural Resources

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17th MEETING of the U.S.-JAPAN MARINE FACILITIES PANEL

May 1991
Conference Record

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

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17th Meeting of the Marine Facilities Panel of the United States-Japan Cooperative Program in Natural Resources (UJNR)

May 1991

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Marine Facilities Panel Charter

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

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

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

Preface

This conference record contains 59 technical papers and special reports presented at the 17th biennial meeting of the Marine Facilities Panel of the United States-Japan Cooperative Program in Natural Resources (UJNR), held May 13-14, 1991, in Tokyo, Japan. From May 15-24, the Joint Panel toured numerous Japanese marine facilities in Tokyo, Okinawa, and Kobe. A final meeting of the Joint Panel was held May 24 at the Mitsubishi Shipyard in Kobe. A complete schedule and a detailed summary of the meeting and study tour are provided in this report.

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

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

Diverse members of private industry and academia have also participated in past meetings. At this meeting, Japan participants included the Japan Marine Machinery Development Association; Shipbuilding Industry Foundation; Japan Foundation for Shipbuilding Advancement; Mitsubishi Heavy Industries Co., Ltd.; Sumimoto Heavy Industries Ltd.; Ishikawajima-Harima Heavy Industries Co. Ltd.; Japan Marine Science and Technology Center; Coastal Development Institute; Nihon University; and Hokkaido Tokai University. U.S. participants included Westinghouse Electric Corporation; Marine Development Associates; Harbor Branch Oceanographic Institution; Science Applications International Corporation; Brown & Root USA Inc.; University of California; University of Hawaii; University of Rhode Island; University of Texas; and Texas A&M University.

Special recognition is accorded to Mr. Richard Krahl, of Offshore Consultative Services, for serving as the U.S. Panel's finance chairman; and to Ms. Mary Leach and Ms. Fatimah Taylor of the International Affairs Branch, National Ocean Service, NOAA, for making the logistical arrangements for the study tour.

Pamela H. Rubin
Editor/Technical Program Coordinator

Dedication

Since the 16th meeting in 1989, four of our members passed away. Words cannot fully express our respect and gratitude for our departed colleagues and good friends. They will be remembered and greatly missed. We dedicate these proceedings in their honor.

Japan Panel

Mr. Tamio Ashino (January 1990) was affiliated with the Japan Marine Machinery Development Association (JAMDA) and served on the panel for more than 10 years. He will be remembered for his warmth and kindness, and for many years of dedicated service in planning, organizing and coordinating the excellent study tours.

Mr. Sadao Ando (January 1991) was affiliated with the Ship Research Institute, Ministry of Transport for many years. His valuable contributions in ocean engineering projects are documented in the last two proceedings of the Marine Facilities Panel. During the last meeting in the U.S., Mr. Ando and his wife Yoshi went on the entire study tour and contributed a great deal of warmth and happiness.

U.S. Panel

Mr. Frank Busby (August 1990) was founder and director of his own company, Busby Associates. He was a world-renowned expert in the technology of deep submergence and a leading authority on undersea vehicles. Several of his papers on undersea vehicles appear in the proceedings of the Marine Facilities Panel.

Mr. Robert Rupp (November 1990) was affiliated with the Sperry Rand Corporation for more than 30 years, and last served as manager of its Ocean Systems Group. Several of his papers on advanced undersea systems were presented at our meetings. In 1983, he hosted the Marine Facilities Panel's visit to the Sperry Rand Corporation in New York.

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Opening Remarks

Eifu Kataoka

Chairman, Japan Panel

Good morning, ladies and gentlemen. It's a pleasure for me to be able to address you on the opening of the 17th Joint Meeting of the UJNR Marine Facilities Panel.

First of all, on behalf of the Japan Panel, I would like to extend my heartiest and warmest welcome to U.S. Chairman Joseph Vadus and the members and advisors of the U.S. Panel who are attending the 17th Joint Panel Meeting.

We are also quite pleased and honored to have with us Mr. R. Wildman, U.S. Chairman of the Marine Resources and Engineering Coordination Committee of the UJNR, as well as Dr. E. Malloy, Counselor for Science and Technology of the U.S. Embassy of Japan, and Mr. R. Tanino, Director of the Technology and Safety Division of the Transport Policy Bureau, Japan Ministry of Transport. We thank you for your attendance.

In addition, I would like to take this opportunity to express my heartiest gratitude to the National Oceanic and Atmospheric Administration of the United States, the Science and Technology Agency of Japan, the Ministry of Transport of Japan, and Mr. R. Sasakawa of the Japan Shipbuilding Industry Foundation for their cooperation and assistance in making this meeting a success.

It's a surprise for me to learn that one year and seven months already have passed since the 16th Joint Panel Meeting was held in the United States. I would like to take the opportunity to thank the U.S. hosts for their warm hospitality at our last meeting. This 17th Joint Meeting could have been jeopardized by the Persian Gulf War, so I'm truly happy to be able to welcome you here today.

In the years since the first Joint Panel Meeting of the MFP was held in 1970 in Tokyo, we have held 17 meetings. I believe this panel is one of the most active panels of the UJNR. The panel's theme has been expanding to cover not only vessels and marine facilities, but environmental issues as well, and its activities are attracting keen attention.

Many outstanding papers will be presented from the U.S. and Japanese participants at this Joint Meeting, and through the presentation and discussion of these papers, I hope that the meeting will further promote technology exchange and cooperative research in ocean development through the 21st Century.

I believe that Chairman Vadus will also express his condolences, but I'm truly sad to have to report that four close members of the U.S.- Japan Joint Panel will not be here with us this time. I would like to express my condolences to their grieving families and pray for their repose.

Last but not least, I would like to express our heartiest gratitude to the secretariat staff of both the U.S. and Japan, who have labored hard to organize this meeting. Thank you very much for your attention.

Opening Remarks

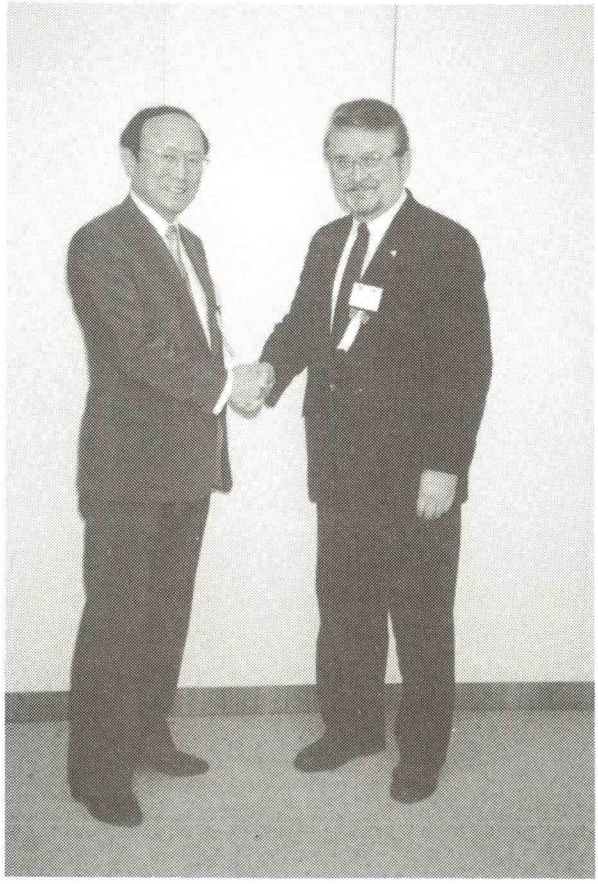
Joseph R. Vadus

Chairman, U.S. Panel

On behalf of the U.S. Marine Facilities Panel, it is a distinct honor and pleasure for me to extend warm greetings to Mr. Eifu Kataoka, Chairman of the Japan Panel, and to each of the members and advisors of the Japan Panel. We are very pleased to return to Japan to meet with our many Japanese colleagues.

The success of the Marine Facilities Panel can be attributed to the excellent professional and personal relationships that have developed over the years. These meetings bring together some of the leading experts in ocean and coastal engineering, naval architecture and oceanography, and result in a high-quality, equitable technology exchange.

In the years ahead, I hope we can continue to maintain the high standards and close bonds of friendship that all of you and our predecessors have established. Sadly, some of our colleagues are no longer with us. I would like to take a moment to remember four colleagues who passed away since our last meeting.



MFP Chairmen Eifu Kataoka and Joseph Vadus.

Mr. Tamio Ashino of JAMDA passed away in January 1990. He will be remembered for his warmth and kindness, and for many years of dedicated service in planning, organizing and coordinating the excellent study tours. He was a dear friend.

In January 1991, Mr. Sadao Ando of the Ship Research Institute passed away. His valuable contributions in ocean engineering projects are documented in our last two proceedings. In the last meeting in the U.S., Mr. Ando and his wife Yoshi participated in the entire study tour and added a great deal of warmth and happiness.

The U.S. side also lost two good friends and colleagues. In August 1990, Mr. Frank Busby of Busby Associates passed away. He was internationally known for his expertise in undersea vehicles. He was a good friend for 20 years, and we published several ROV/AUV papers together. He has left a legacy of reference publications.

In November 1990, Mr. Robert Rupp, formerly of Sperry Rand Corporation, passed away. In 1983, he hosted a visit to Sperry Rand in New York, and he contributed papers on advanced undersea systems at several meetings. He was a good friend and colleague of mine for 30 years.

Words cannot fully express our respect and gratitude for our departed colleagues. They will be missed. Let us dedicate this meeting in their honor and share in a moment of silence in remembrance. Thank you.

On behalf of the U.S. Panel, I thank Chairman Kataoka and the Japan Panel for preparing an excellent program and study tour. In particular, I would like to recognize Mr. Yamauchi and Mr. Chiaki of the SRI Planning Office; Mr. Narita of JAMDA; and Ms. Pam Rubin, Ms. Mary Leach and Ms. Fatimah Taylor of NOAA for their cooperative efforts.

Since its first meeting in 1970, the Marine Facilities Panel has maintained a fine record of achievement thanks to all of you and all who have preceded us. Let's continue the fine tradition. Thank you.



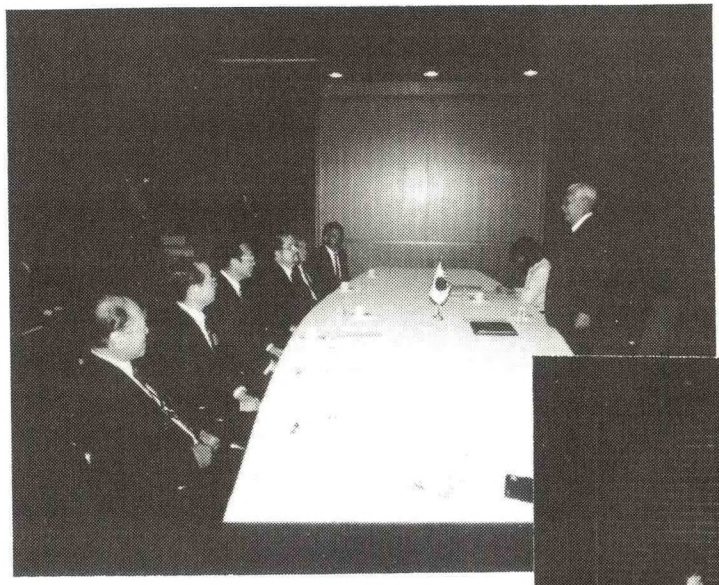
The Marine Facilities Panel at the New Sanno Hotel, Tokyo, Japan.

Special Recognition

On May 13, 1991, several members of the Marine Facilities Panel met with Mr. Ryoichi Sasakawa at Sasakawa Hall. Mr. Sasakawa extended his warm and cordial greetings to the Panel and expressed his continued interest in its joint activities. In closing, he wished for the Panel to have a productive and enjoyable meeting and study tour.

Mr. Sasakawa is known throughout the world for his leadership and philanthropic endeavors to improve the welfare of mankind. In addition to being chairman of the Japan Shipbuilding Industry Foundation, he chairs more than 50 organizations concerned with public health, social welfare, international understanding, culture, and sports. Mr. Sasakawa is interested in marine activities and has been a long-time supporter of the objectives and progress of the Marine Facilities Panel.

The U.S. Panel presented him with a plaque for his continued support of Marine Facilities Panel activities through the years. Mr. Sasakawa indicated that this plaque would be placed in his Ship Museum in Tokyo.



Mr. Ryoichi Sasakawa addresses several members of the Marine Facilities Panel.



On behalf of the U.S. Panel, Mr. Vadus presents a plaque to Mr. Sasakawa.

Marine Facilities Panel Awards

On May 13, 1991 at Sasakawa Hall, Mr. Eifu Kataoka presented awards of special recognition to U.S. participants Mr. J. Dan Hightower and Dr. Kilho Park. On May 14 at the U.S. reception in the New Sanno Hotel, Mr. Joseph Vadus presented awards to Japan participants Prof. Naonosuke Takarada, Mr. Ikuo Mutoh and Mr. Yasuo Hisada. The citations on the plaques recognized the participants' "many years of dedicated service and valuable contributions to the Marine Facilities Panel of the U.S.-Japan Cooperative Program in Natural Resources."









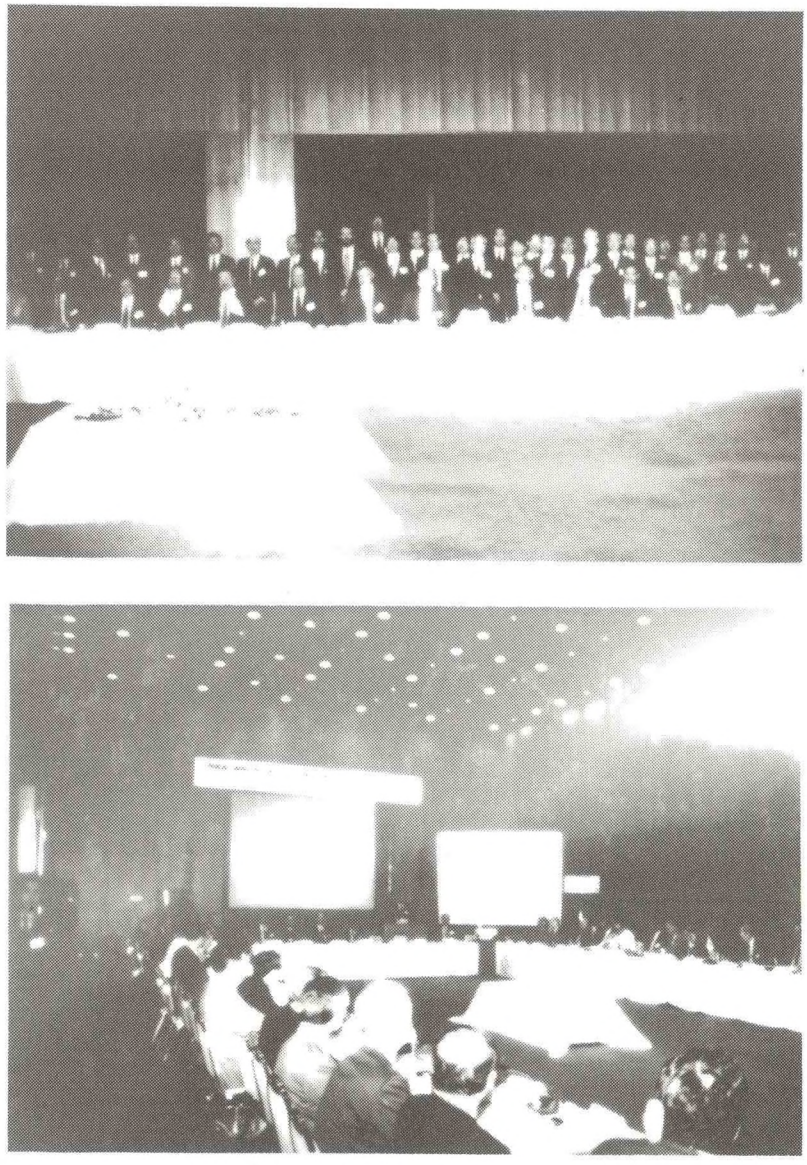


Top photos, left to right: Mr. E. Kataoka presents plaques to Dr. K. Park and Mr. J. Dan Hightower. Bottom photos: Mr. J. Vadus presents plaques to Prof. N. Takarada, Mr. Y. Hisada and Mr. I. Mutoh.

Plenary Session

The Plenary Session was held May 13 and 14, 1991, at Sasakawa Hall in the New Sanno Hotel, Tokyo, Japan.

Following opening remarks by U.S. Chairman Joseph R. Vadus and Japan Chairman Eifu Kataoka, the meeting began with opening remarks from Y. Miki, Japan Chairman, MRECC; R. Wildman, U.S. Chairman, MRECC; E. Malloy, Counselor for Science and Technology, U.S. Embassy; and R. Tanino, Director, Technology and Safety Division, Transport Policy Bureau, MOT.



The Marine Facilities Panel at the Plenary Session in Sasakawa Hall.

Itinerary: 17th Meeting of the UJNR MFP

Date	Time	Activities
May 11 (Sat.)		U.S. Panel arrives in Tokyo New Sanno Hotel/Ginza Daiichi Hotel
May 12 (Sun.)	9:30-12:00	Meeting of the U.S. Panel at New Sanno Hotel. Japan coordinators explain logistics. Rest of day free; jet lag recovery
May 13 (Mon.)	8:45 9:00-17:00 19:00-21:00	Arrive at Sasakawa Hall (by bus) Plenary Session Japan Reception (Sasakawa Hall)
May 14 (Tues.)	8:45 9:00-17:00 18:30-21:00	Arrive at Sasakawa Hall (by bus) Plenary Session U.S. Reception (New Sanno Hotel)
May 15 (Wed.)	8:00 11:00-12:00 14:10-15:10 15:30-16:30 18:30	Leave Ginza Daiichi Hotel Tokyo Wan Traffic Advisory Service Center JAMSTEC (SHINKAI 6500 et al.) Sumimoto Shipyard, Oppama VLCC double-hull development and other marine programs Arrive at Ginza Daiichi Hotel
May 16 (Thurs.)	8:20 9:45 10:00-12:30 14:30-16:00 18:00	Leave Ginza Daiichi Hotel Arrive at Hamarikyu Pier Cruise of harbor facilities (Hamarikyu —> Tokyo Bay Bridge —> Tokyo International Airport —> Kawasaki Artificial Island —> Navigation Safety Center —> Yokohama Bay Osanbashi Pier) IHI Research Institute Arrive at Ginza Daiichi Hotel

Date	Time	Activities
May 17 (Fri.)	9:00	Leave New Sanno Hotel
	8:40	Leave Ginza Daiichi Hotel
	10:55-13:25	Fly to Okinawa (JAL 903)
	14:15	Arrive at the prefectural office of Okinawa
	14:20-14:30	Meeting with Governor Ota of Okinawa Prefecture
	14:30-15:20	Summary of some developing plans on marine facilities in Okinawa
	16:20-17:20	JAMSTEC marine activities including artificial reef project
	18:30	Arrive at Miyako Hotel
May 18 (Sat.)	9:00	Leave Miyako Hotel
	10:00-10:10	Meeting with the president of Ryukyu University (at Ryukyu University)
	10:10-11:30	Tour facilities in the University
	14:00-15:00	Summary of the tourist submersible "Moglyn"
	15:00-16:30	Board "Moglyn" for undersea exploration
	17:00	Arrive at Onna Marine View Palace Hotel
May 19 (Sun.)	10:00-15:00	Tour of Okinawa
May 20 (Mon.)	8:30	Leave Onna Marine View Palace Hotel
	9:30-12:00	Okinawa floating city (AQUAPOLIS) and marine recreation parks
	13:30-14:30	Okinawa Prefectural Sea Farming Center
	17:35-19:30	Fly to Osaka (JAL 918)
	21:00	Arrive at Osaka Terminal Hotel
May 21 (Tues.)	9:00	Leave Osaka Terminal Hotel
	10:00	Arrive at Sakaisenboku Pier
	10:10-11:40	"Kaiyono-Utsuro" & Kansai International Airport (cruise around site; briefing on construction progress and environmental monitoring)
	11:40	Arrive at Tannowa Pier
	14:10-14:40	Environmental Research Center for the projects of Kansai International Airport
	14:40-15:30	"Taruino-Utsuro" (sedimentation and purification of water quality by tide in the water course with marine basins)
	15:30-17:30	Arrive at Osaka Terminal Hotel

Date	Time	Activities
May 22 (Wed.)	9:00	Leave Osaka Terminal hotel
	9:40-11:30	Floating facility for waste-water treatment
	13:30-15:50	Furuno Electric Co. Marine Instrumentation activities
	16:50	Arrive at Osaka Terminal Hotel
May 23 (Thurs.)	8:30	Leave Osaka Terminal Hotel
	10:00-11:30	Port and harbor facilities on Rokko Island
	11:50-12:20	Kobe Port Island Kinenkan
	14:00-15:30	Rokko Island New Energy Center (A center for experimental energy-generating systems)
	16:10	Arrive at New Kobe Oriental Hotel
	1900-21:00	Reception with the participants in Kobe and Osaka area
May 24 (Fri.)	8:30	Leave New Kobe Oriental Hotel
	8:50-11:20	Mitsubishi Heavy Industries marine programs, including visit to MHD-propelled ship YAMATO-1
	11:30-12:30	Final meeting of MFP
	12:40-14:00	Lunch and farewell reception
	14:40	Arrive at New Kobe Oriental Hotel
May 25 (Sat.)	8:30	Leave New Kobe Oriental Hotel
	9:15-12:32	Bullet Train to Tokyo (Hikari 104) (Shinkobe station—>Tokyo terminal)
	14:00	Arrive at New Sanno Hotel
	14:20	Arrive at Ginza Daiichi Hotel
	13:01-13:54	"Narita" express train for Narita Airport (Some members of U.S. Panel)
	16:00	Departure of U.S. Panel begins



Six past and present chairmen of the Marine Facilities Panel. Seated around the table from left to right: N. Hamada, K. Sugai, J. Vadus, S. Motora, E. Kataoka, N. Nagasawa.

U.S. Marine Facilities Panel

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Mr. Joseph Vadus

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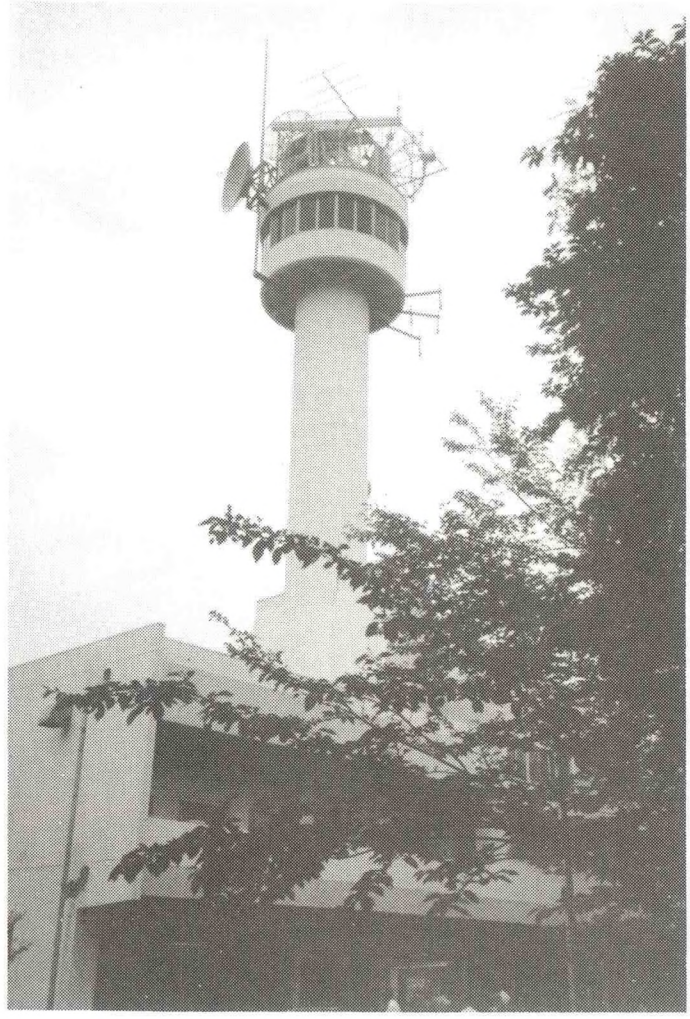
17th UJNR/Marine Facilities Panel Study Tour

Following the plenary sessions, held May 13 and 14 at the New Sanno Hotel in Tokyo, the 17th MFP study tour commenced on May 15 in the Tokyo area. It then proceeded to Okinawa, Osaka, and Kobe. A brief description of the facilities visited and the programs being conducted at them follows.

Wednesday, May 15

Tokyo Wan Traffic Advisory Service Center

This Center was established in 1977 and is located in the Yokosuka area south of Tokyo near the mouth of Tokyo Bay. It provides local mariners with navigational information on the movement of vessels, weather conditions, marine notices and other pertinent information through the use of three shore-based radar installations and an integrated communication system. The bay is approximately seven miles wide at this location, where some 700 vessels pass through each day. The Center controls the movement of 15 percent of these vessels — those in excess of 2,000 meters in length, having a gross tonnage over 10,000 tons, or carrying dangerous cargo. Operators monitor radar screens that display a vessel's current location and its expected location one minute later. The vessel's actual location is updated every six seconds, and the expected location can be extended to 99 minutes. The system has been responsible for reducing a high percentage of vessel collisions.

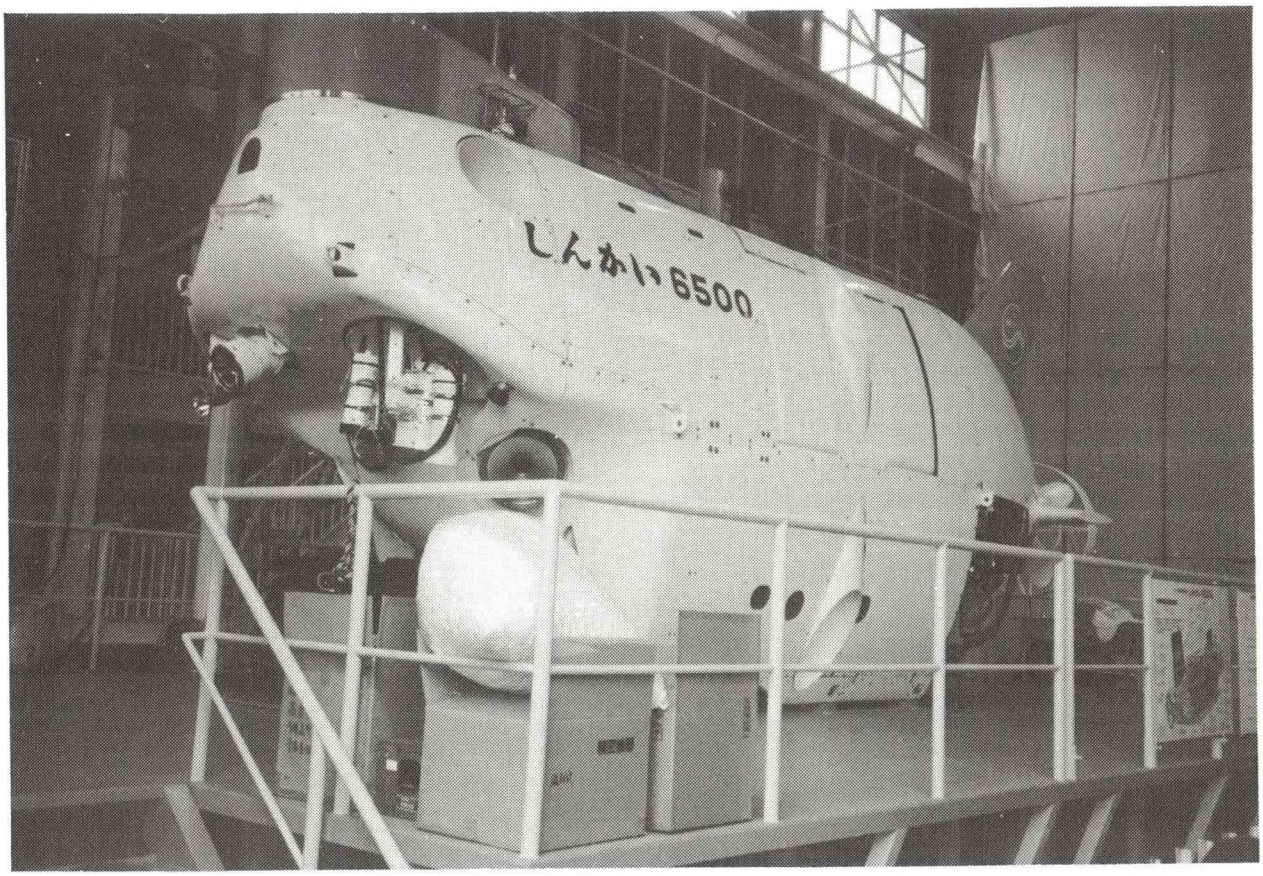


Control tower for Tokyo Wan Traffic Advisory Center.

Wednesday, May 15 (continued)

Japan Marine Science & Technology Center (JAMSTEC)

JAMSTEC's mission is to promote research and development in Japan's marine sciences and technologies through the cooperation of government, academia and the private sector. The main facility is located in Yokosuka, with Mr. Hiroyuki Nakota as the Executive Director. It is the home port of the SHINKAI 6500 research submersible designed at JAMSTEC and built by Kawasaki Heavy Industries, Ltd. The SHINKAI 6500 was designed for deep-sea research and resources development in the areas of geology, geophysics, earthquake prediction, and ocean floor resources surveys. The name reflects its maximum depth capability of 6500 meters. The system consists of the manned submersible SHINKAI 6500, its support vessel YOKOSUKA, and a dive-support system for navigation and telecommunication. On August 11, 1989, the submersible succeeded in a test dive to a depth of 6,527 meters in the Japan Trench off Sanriku — the greatest depth attained by any manned submersible presently in service.



SHINKAI 6500 at JAMSTEC in Yokosuka.

Wednesday, May 15 (continued)

JAMSTEC's Research Vessel KAIYO

The KAIYO is a twin-hull, semisubmersible vessel that provides high on-the-sea stability, a wide deck, minimal underwater noise, a precision navigation system, and a dynamic positioning system. The vessel was designed by JAMSTEC and completed in 1985. For undersea work it contains a submersible decompression chamber and deck decompression chamber system capable of working to a depth of 300 meters. For surveying the ocean bottom topography, KAIYO is equipped with a Multi-Narrow Beam Echo Sounder capable of producing real-time contour plots of the ocean bottom utilizing precise depth information. The vessel itself is 53 meters in length, 28 meters in width, with a maximum draft of 6.3 meters. It can operate at a service speed of 13 knots and has a complement of 29 crew and 40 research personnel.



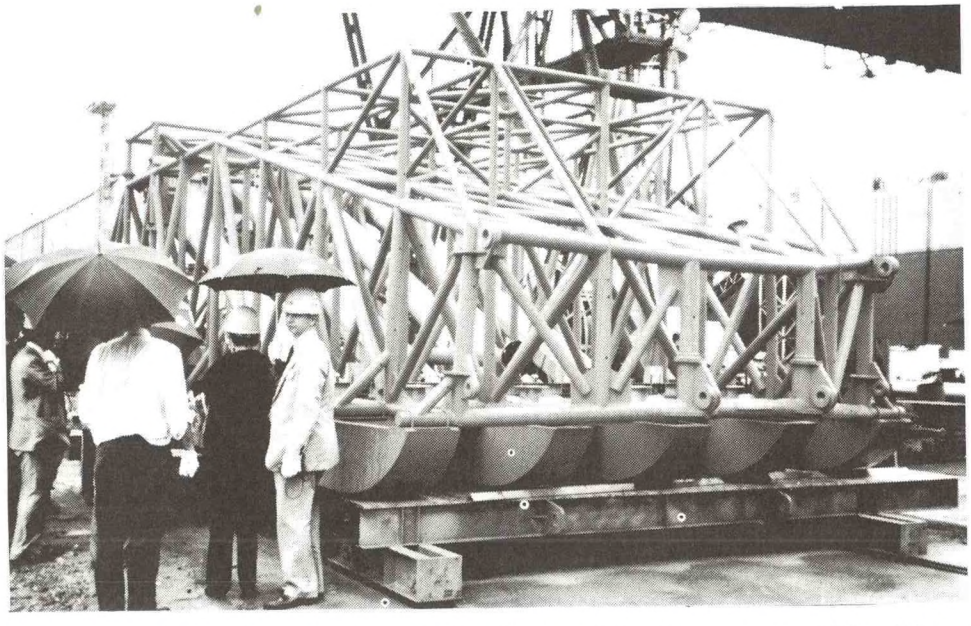
KAIYO, the research vessel and support ship for the SHINKAI 6500.

Wednesday, May 15 (continued)

Sumimoto Heavy Industries, Ltd.
Oppama Shipyard

The Oppama Shipyard was established in 1971 and is the center of Japan's VLCC double hull development and other shipbuilding research. The General Manager is Mr. Shuichi Nagamatsu. The shipyard launched the first double-hull, double-bottom tanker after passage of the Oil Pollution Act of 1990. Another double- hull tanker is currently under construction. The shipyard employs a computer-aided design system as well as computer-aided manufacturing. Automation is used extensively in the fabrication yards. One research project is a manganese module mining system designed for towing at a depth capability of 5,000 meters. The system will be able to recover manganese nodules using a hydraulic lift system with four suction heads. A surface vessel and supporting system is not available at this time.





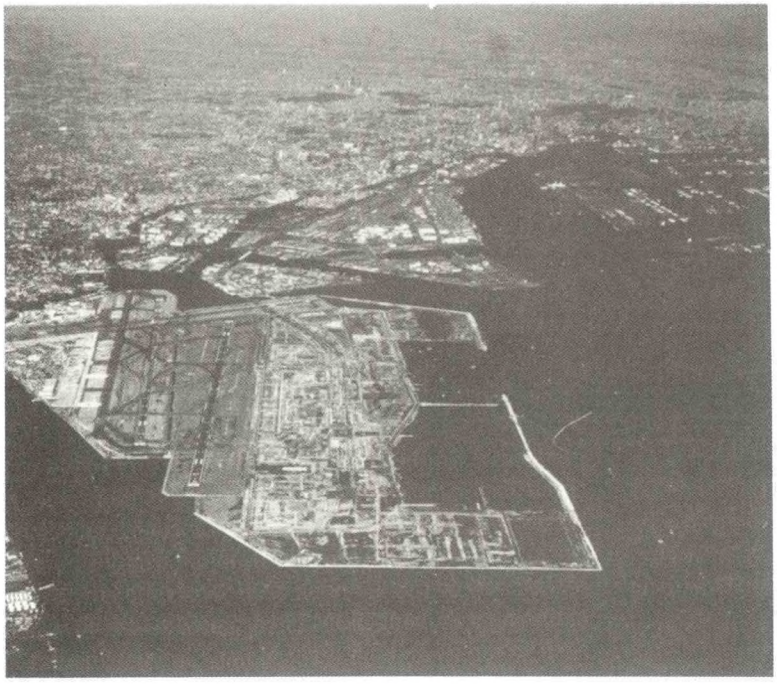
Top photo: Double hull tanker under construction. Bottom photo: Manganese module mining system.

Thursday, May 16

The Port of Tokyo and Tokyo Bay Facilities

The Port of Tokyo is in the innermost part of Tokyo Bay. Over 58,200 ships call at this port every year, loading and unloading over 70 million tons of cargo. Incoming cargo accounts for 50 million tons and outgoing cargo 20 million tons. To accommodate this commerce, an extensive reclamation program has been in effect for many years. As much as 3,730 hectares have been reclaimed — 2,371 since 1961. Currently, construction is continuing on a bridge that will link the city of Tokyo to Tokyo Teleport Town, an urban sub-center to be created in the middle of Tokyo Bay, 6 kilometers south of Tokyo's Central Business District. Another ongoing project is reclaiming land for expansion of the Tokyo International Airport (Haneda). Upon completion of the expansion, the current airport will be abandoned and the lands used for other purposes. The disposal of urban wastes contributes significantly to the materials used in the reclamation process.

The development of offshore man-made islands is one of Japan's high priorities, and it is estimated that the country will have reclaimed nearly 150,000 hectares by the year 2000. In Tokyo Bay, not only the Port of Tokyo but also the Ports of Kawasaki and Yokohama are actively involved in reclamation activities.



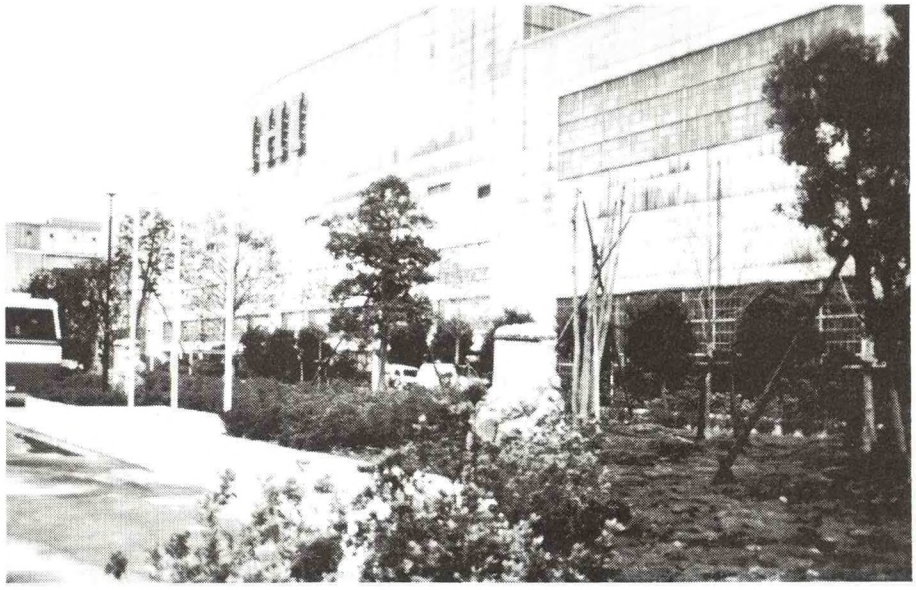


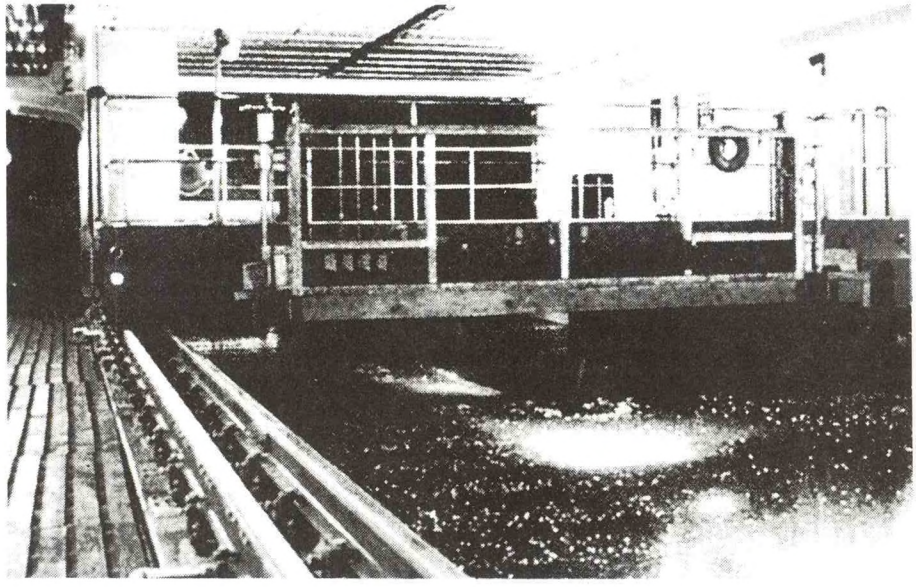
Top photo: Aerial view of Tokyo Bay. Bottom photo: The Marine Facilities Panel is briefed aboard the City of Tokyo's launch during its tour of Tokyo Bay .

Thursday, May 16 (continued)

IHI Research Institute

Located in the Tokyo and Yokohama areas, the Research Institute of Ishikawajima-Harima Heavy Industries Co. Ltd. is engaged in basic research and development ranging from biotechnology to floating factories and production systems. The Research Institute in Yokohama is equipped with various testing basins for ship and marine structures, as well as testing and research facilities for plants and machinery from other industrial areas. Projects involve research in many high technological fields, as well as a better understanding of existing technologies.





Top photo: IHI's Osaka area facility. Bottom photo: IHI towing tank facility.

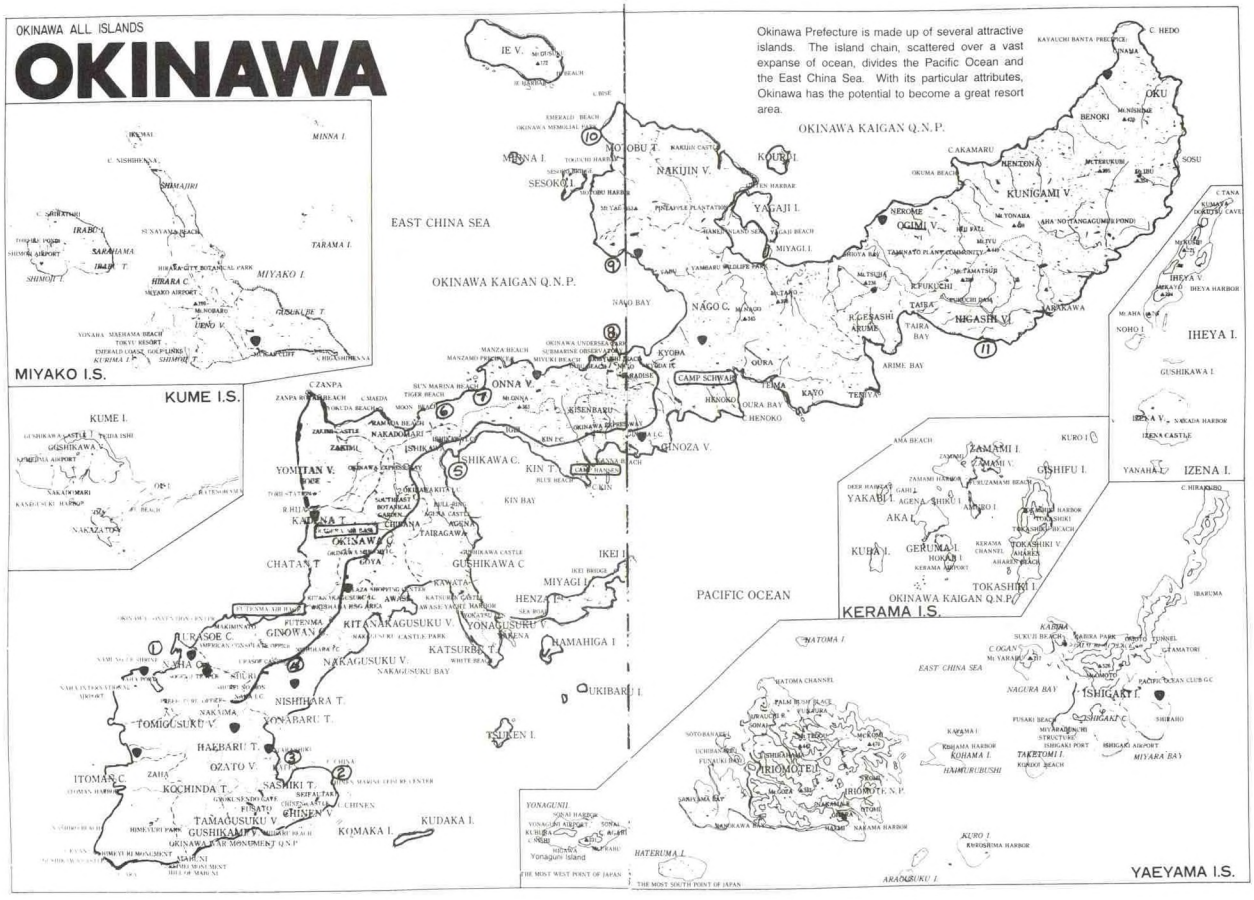
Friday, May 17

Okinawa

The southwest archipelago of Japan extends from the island of Kyushu to Taiwan, of which the islands of Okinawa comprise the southwesternmost group. The islands are on the same latitude as Miami and the Bahamas and, in fact, tourism is becoming a major industry. Although Okinawa was returned to Japan in 1972, 75 percent of the U.S. military in Japan is located on Okinawa.

Okinawa Prefecture is trying to catch up to the rest of Japan economically, but remains the poorest prefecture in the country. A master plan has been developed with the object of creating an international tourist resort in the Pan-Pacific area.

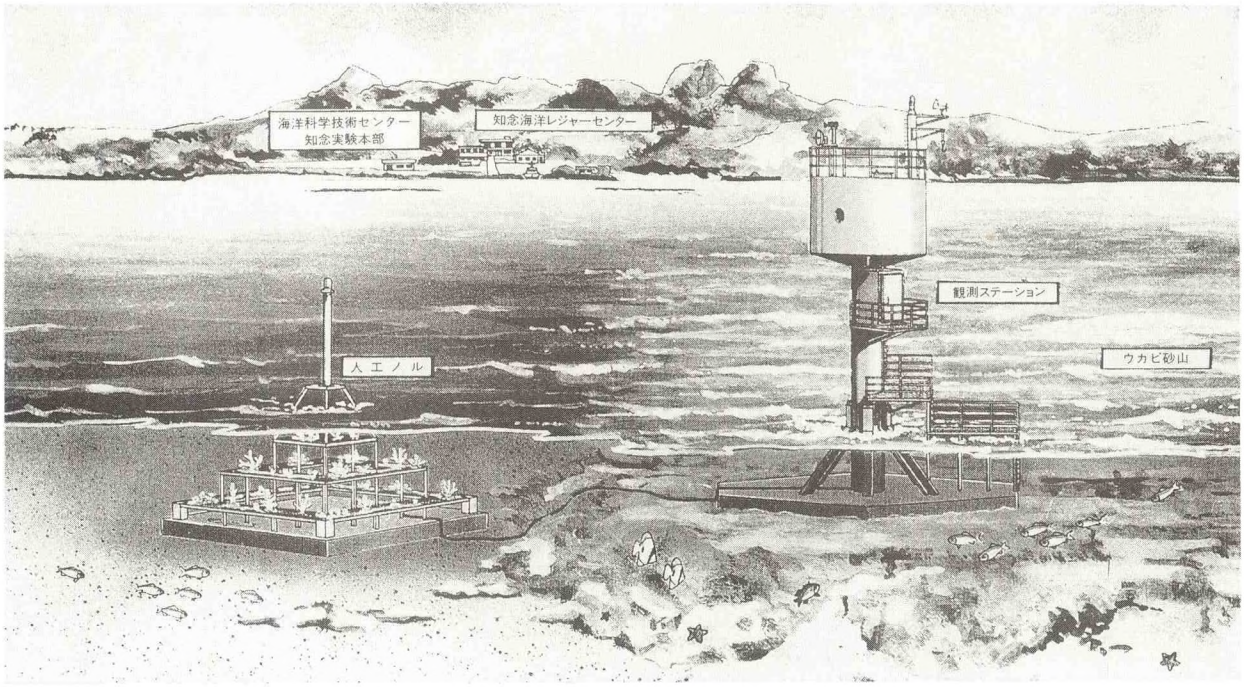
One project under way to revitalize Okinawa is the Marine Town Project. It purpose is to develop a new waterfront, construct an artificial beach and marina, and develop local industries. The project will involve reclamation of some offshore lands and will take approximately 10 years to complete.


OKINAWA ALL ISLANDS
OKINAWA
Okinawa Prefecture is made up of several attractive islands. The island chain, scattered over a vast expanse of ocean, divides the Pacific Ocean and the East China Sea. With its particular attributes, Okinawa has the potential to become a great resort area.
MIYAKO I.S.
KUME I.S.
KERAMA I.S.
YAEYAMA I.S.
IHEYA I.
IZENA I.
EAST CHINA SEA
PACIFIC OCEAN
OKINAWA KAIGAN Q.N.P.
NAHA C.
NAHA
NAGO C.
NAGO BAY
KIN BAY
KIN T.
ONNA V.
ONOZA V.
YOMITAN V.
KADENA T.
CHATAN T.
OKINAWA C.
GUSHIKAWA C.
IKEI I.
MIYAGI I.
HENZA I.
KITANAKAGUSUKU V.
NAKAGUSUKU V.
NAKAGUSUKU BAY
KATSUREN T.
YONAGUSUKU V.
HAMAHIGA I.
OUKIBARU I.
TSUKEN I.
NISHIHARA T.
TOMIGUSUKU V.
YONABARU T.
HARUBARU T.
OZATO V.
SASHIKI T.
KOCHINDA T.
ITOMAN C.
TAMAGUSUKU V.
GUSHIKAMI V.
CHINEN V.
KOMAKA I.
KUDAKA I.
MINNA I.
IE V.
MOTOBU T.
NAKIJIN V.
SESOKO I.
YAGAJI I.
KOURI I.
MIYAGI I.
OKUMA BEACH
CAMP SCHWAB
HENOKO
OURA BAY
KYOWA
KUBA
TERUYA
ARIMI BAY
KAWATA
KUBA I.
GERUMA I.
AKA I.
ZAMAMI I.
GISHIFU I.
TOKASHIKI I.
TOKASHIKI V.
YAKABU I.
AGENA
SHIKU I.
ARURO I.
KUBA I.
HOKAN I.
KERAMA CHANNEL
KERAMA AIRPORT
AHASEN BEACH
NATOMA I.
NATOMA CHANNEL
EAST CHINA SEA
NAGURA BAY
ISHIGAKI I.
ISHIGAKI C.
ISHIGAKI AIRPORT
MIYARA BAY
TAKETOMI I.
KOHAMA I.
KOHAMA HARBOR
HAMURUBUSHI
IRIOMOTE I.
IRIOMOTE N.P.
NARAHA HARBOR
HATERUMA I.
ARAOSUKU I.
KURO I.
KHOSHIMA HARBOR
YONAGUNI
YONAGUNI AIRPORT
SONAI
KUBURA
SHIRAHO
Yonaguni Island
THE MOST WEST POINT OF JAPAN
THE MOST SOUTH POINT OF JAPAN
OKINAWA WAR MONUMENT Q.N.P.
HIMEYURI PARK
HILL OF MABUNI
KOMESU
SHUZEDAI
SHUZEDAI CASTLE
NAKAZATO
KUME I.
GUSHIKAWA
NAKADOMARI
NAKAZATO
KASHIMA AIRPORT
KASHIMA
KASHIMA HARBOR
TSUKASAN PARK
TSUKASAN TUNNEL
KAMIMORI
SUKUJI BEACH
KAMIMORI
KAMIMORI
KAMIMORI

Friday, May 17 (continued)

JAMSTEC Aquamarine Project on Okinawa

The major objective of this project is to estimate the feasibility of restoring the growth of damaged coral reefs and to colonize new grounds. Coral reefs form a living breakwater necessary to protect the coastal zones from erosion; however, pollution from onshore construction and the Crown of Thorns starfish infestation has damaged the reefs to the point where they are essentially dead in many areas. The JAMSTEC project involved designing an artificial reef and transplanting many pieces of living coral onto this base. An observation tower was installed to monitor the oceanographic and atmospheric conditions. The results to date indicate that the transplantation was successful and that the artificial knoll is a feasible means of recovering damaged corals.





Top photo: Illustration depicting JAMSTEC"s Artificial Coral Reef Project, including the observation tower. Bottom photo: Panel members observing the Coral Reef Project from aboard a glass-bottom boat.

Saturday, May 18

University of the Ryukus

As the first public institution for higher education established on Okinawa, the University of the Ryukyus was formally opened on the site of the ancient Shuri castle on May 22, 1950, by the United States Civil Administration of the Ryukyus. When Okinawa was returned to Japan, it became a National University in May 1972. Its president is Keishin Sunagawa. The University is a well-rounded academic facility containing six colleges, a graduate school, special education courses, a junior college and a library. Because its subtropical location lends itself to becoming a center for studies on subtropical marine biology, the university has established a research institute on tropical agriculture, a marine science center, an agricultural experiment station and an experimental forest. The university aspires to be an international center of higher learning open to Southeast Asia and the entire Pan-Pacific region.

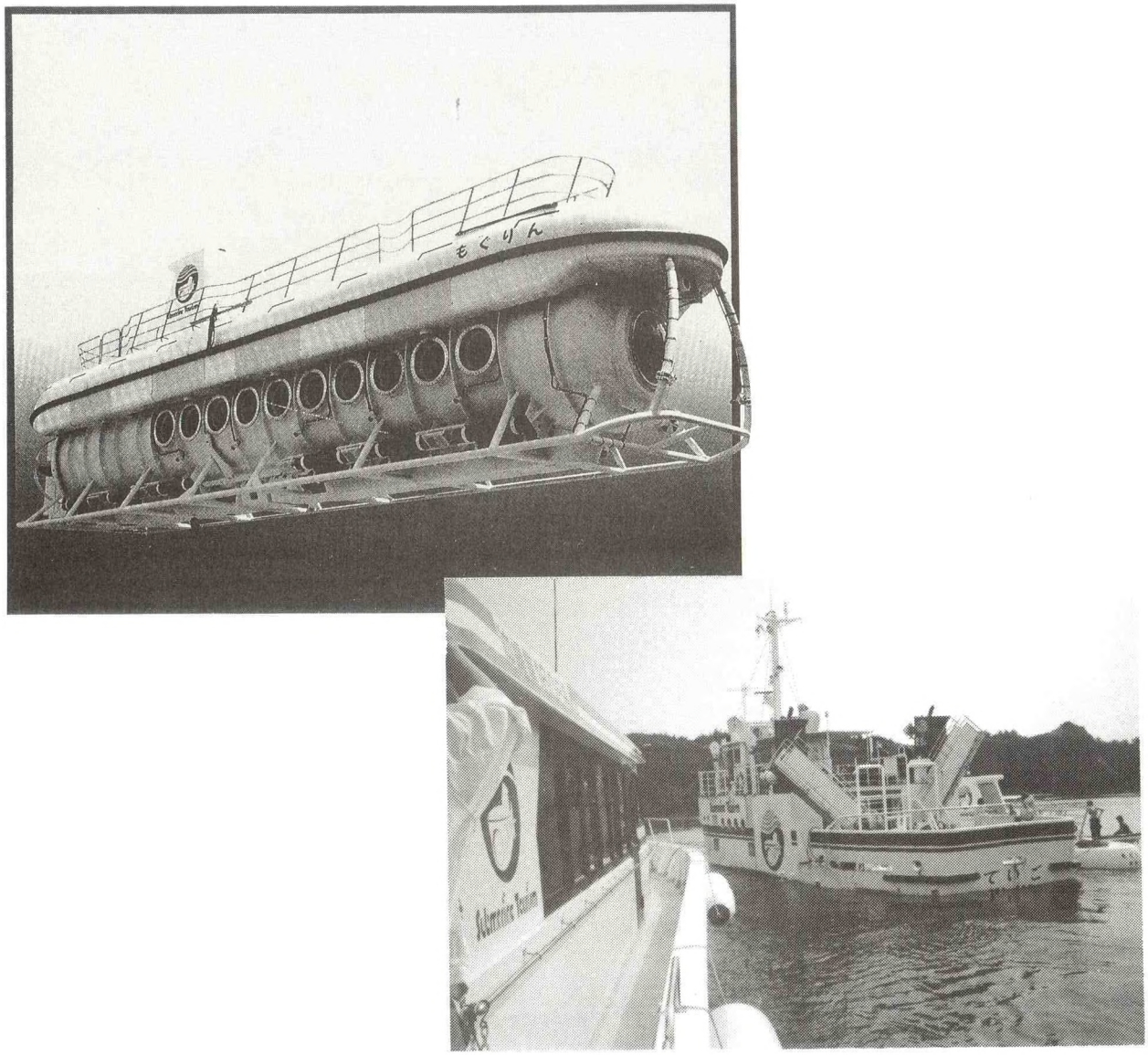


Top photo: Panel members visit the control station of the model basin shown below. Bottom photo: At the University of the Ryukus, a scale modell of the inlet and channel area of the Marine Town Project.

Saturday, May 18 (continued)

The Tourist Submersible MOGLYN

This passenger submersible operates off the west coast of Okinawa allowing 40 passengers the opportunity to view the marine environment through 20 side view ports at depths up to 50 meters. The 30-meter-long vessel was built for Japan Submarine Tourism, Ltd. by Mitsubishi. MOGLYN has been operating every day for 17 months, making seven dives a day in winter and eight a day during summer months. Power is provided by lead acid batteries which are charged each night and are expected to last for 600 hours. The submersible requires a tender for towing to and from its berth each day and for loading passengers, and a shuttle boat to transport passengers to and from shore. A diving boat and two scuba divers accompany the submersible to identify marine life and coral reef features. So far, tourist participation has not been sufficient to make the project successful economically. However, the project is being subsidized by several large Japanese corporations, including Mitsubishi and Japan Airlines, and they project that increased tourist trade will make MOGLYN a self-sustaining project.

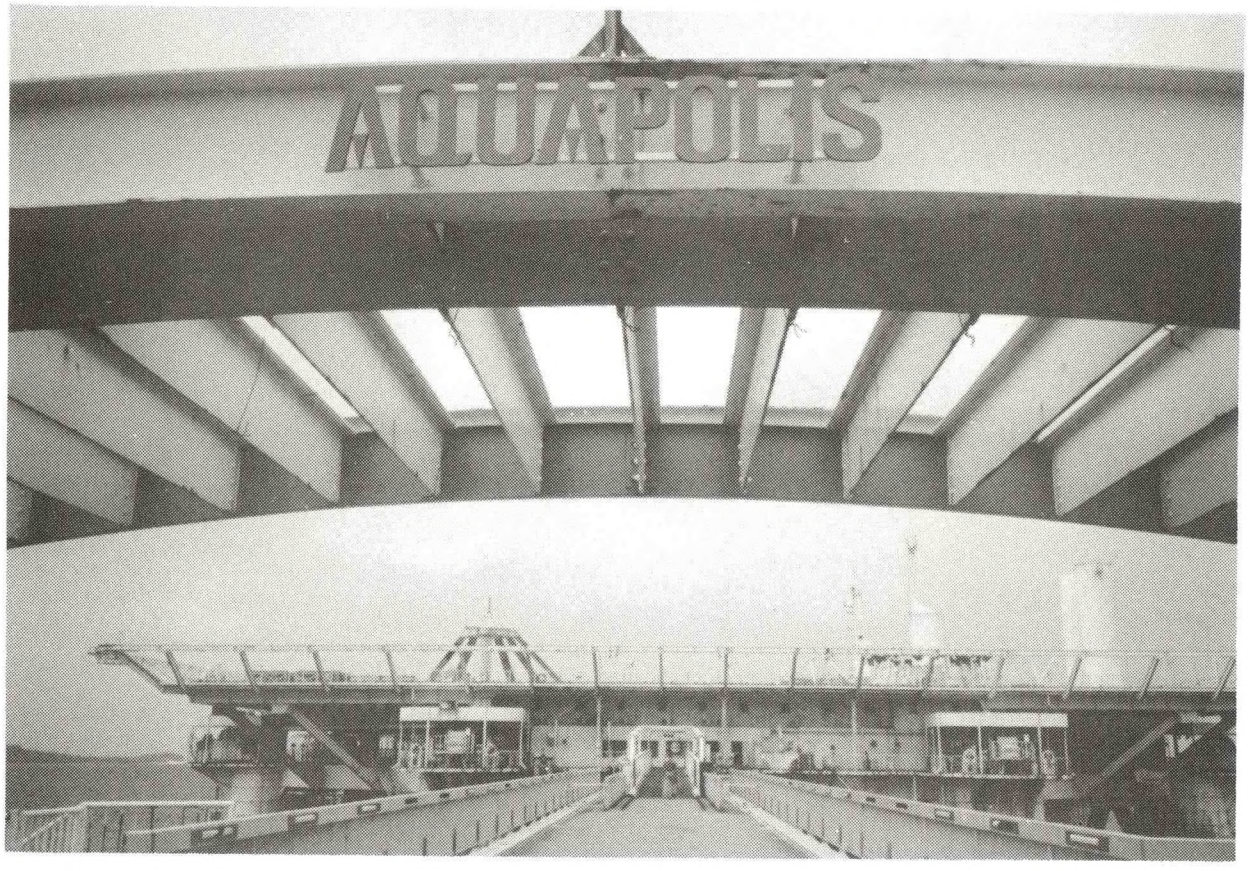


Top photo: The tourist submersible MOGLYN. Bottom: Photo taken from passenger shuttle launch approaching MOGLYN support ship.

Monday, May 20

Okinawa's Floating City AQUAPOLIS

The AQUAPOLIS is a semisubmersible structure designed in 1973 to be a self-contained floating city compatible with its environment and installed as a symbol of Okinawa's International Ocean Exposition. The structure was constructed by Mitsubishi and consists of three decks with an overall length of 104 meters and a width of 100 meters. Supported by 16 columns, its total weight is 28 tons. The mooring system was developed by Mitsui Ocean Development Engineering Company using a four-point system with 16 chains attached to permanent anchors cemented in holes drilled through the coral encrusted sea floor. The three decks contain numerous displays including a Marinorama, various stages and assembly areas, residence areas and eating facilities. The structure has been in place for more than 15 years, and the lack of painting and presence of rust are evident on the external elements. A lack of funding has prevented proper upkeep; however, there is hope for refurbishing as part of the overall Prefectural Plan.



The floating city AQUAPOLIS.

Monday, May 20 (continued)

Okinawa Prefectural Sea Farming Center

The Center's primary purpose is to promote the growth of harvestable species of fish, invertebrates and seaweeds. Research activities are determined by the immediate economic interests of the fishing industries. One of the unique organisms being propagated is the giant clam, which is valued both for its shell and as a food. Other invertebrates, such as the swimming crab, prawns, snails, and sea urchins, are also being propagated. There is also an attempt to replenish fish populations, such as the rabbit fish and the flat fish. Another area of study is the establishment of productive shrimp farms. The station is also engaged in ecological data collection on the coral reefs and the creation of artificial reefs in conjunction with JAMSTEC.



Mr. Chalres Bookman inspects the holding tanks at the Okinawa Prefectural Sea Farming Center.

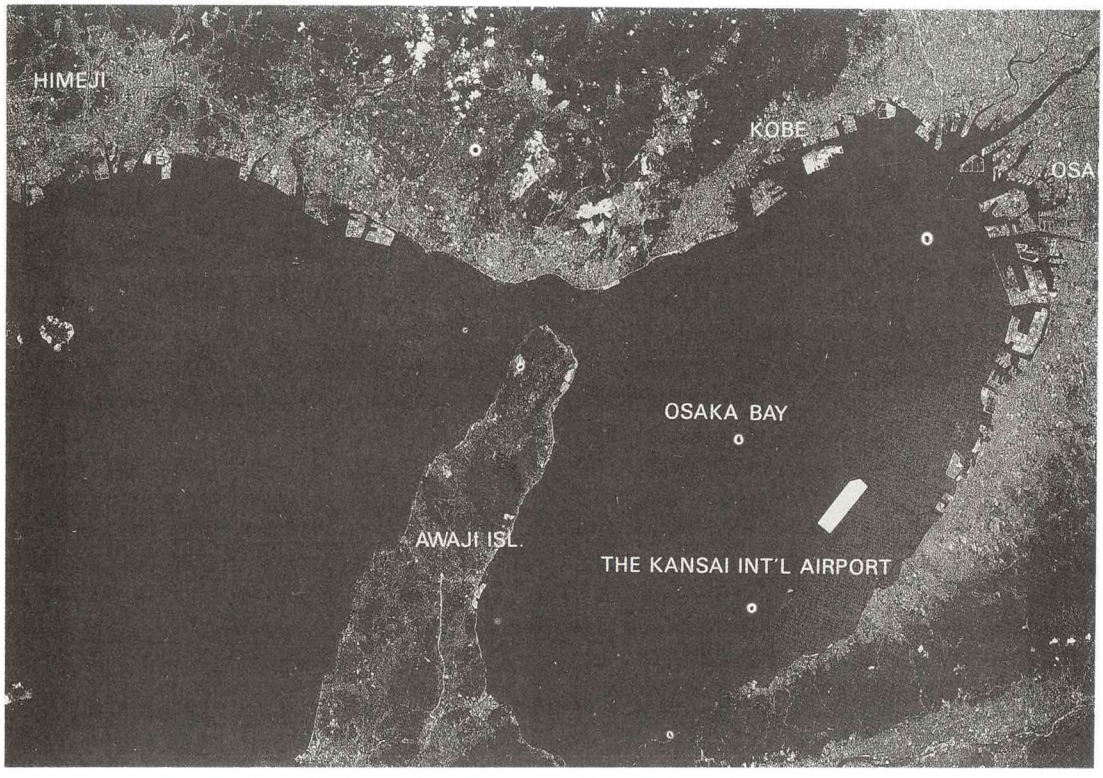
Tuesday, May 21

Kansai International Airport

In 1994 the first fully developed offshore airport will be completed in the southeastern part of Osaka Bay, some 300 miles south of Tokyo. The existing Osaka International Airport is seriously restricted in operation as to the number of aircraft and number of hours of operation as a result of aircraft-generated noise pollution. To resolve the noise pollution issues and to cope with the ever-increasing demand for greater airport capacity, the idea was conceived to build the Kansai airport, the first round-the-clock airport in Japan, five kilometers offshore from the southern area of Osaka Prefecture.

Construction, which began about four years ago, involves four phases: foundation improvement, seawall construction, reclamation, and airport facility construction. The third phase is nearing completion. Concurrently, an airport access bridge to link the airport with the mainland is under construction.

The greatest problem encountered to date has been in the foundation improvement. The seabed soil in the construction area has an average depth of 18 meters and consists of a 20-meter-thick layer of soft alluvial clay on top of a 400-meter-thick layer of diluvial clay. For this reason, the entire foundation of the proposed island was stabilized using the sand drain method. This involves driving sand piles into the clay layer, allowing the weight to be discharged due to the weight from above and thus consolidating the foundation. A total of one million sand piles were driven into the sea bed during this step. For the reclamation phase it was projected that 164 million cubic meters of soil would be dumped into the main island area which was created by the seawall. This allowed for the anticipated eight-meter compaction of the sea floor. However, the actual compaction was 11 meters, which required dumping an additional 19 million cubic meters of soil. This has resulted in a 15-month delay in the airport's projected completion date, and a six-month delay in the commencement of construction of the airport facilities. Ground breaking for these facilities occurred shortly after the MFP's visit. The soil used in the reclamation process is being obtained from an unusable mountainous site onshore, which will be developed as a housing project after reclamation is completed and the mountainous terrain flattened. Eighty barge loads of soil are transported to the construction site each day. Although the physical construction of the airport began in 1987, plans for the project had been in progress since the early 1960s.



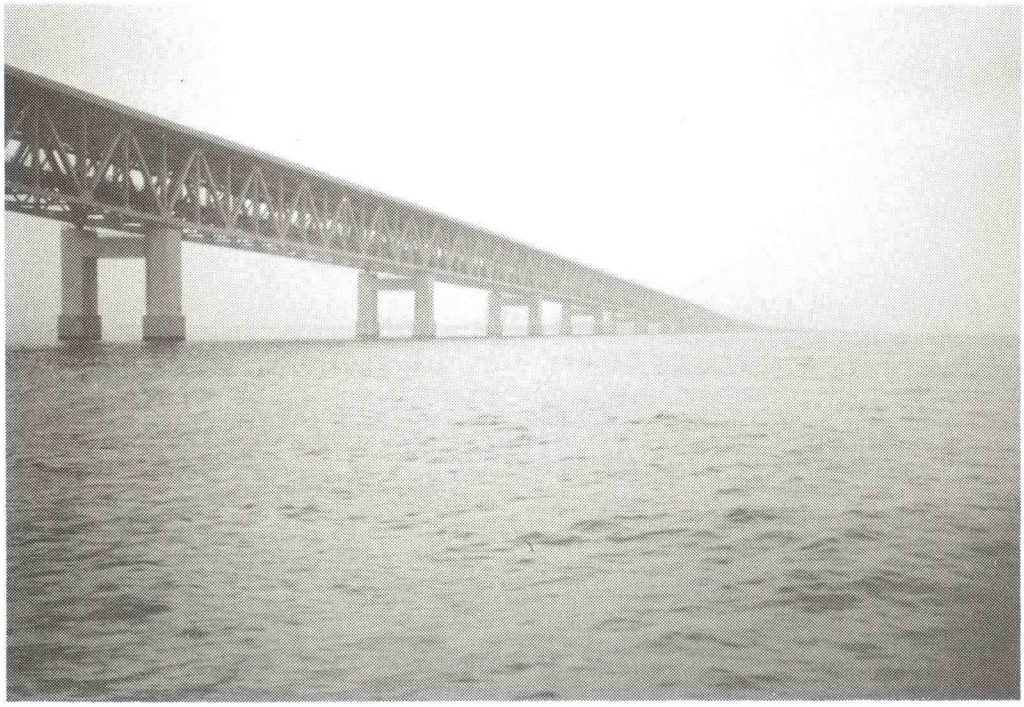
Aerial view of the Osaka Bay area.

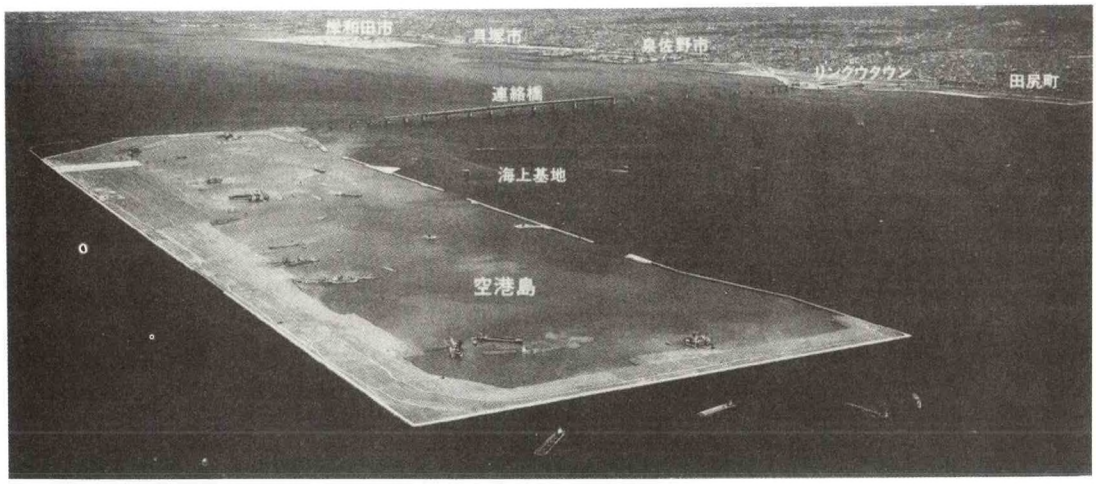
Kansai International Airport

(Description continued from previous page)

Two other projects are under construction in support of the Kansai airport. The Rinku Town Development is immediately onshore from the airport and will be the terminus of the airport access bridge. The soil being used for reclamation is taken from an area that is earmarked for housing development once the reclamation is complete.

As these three projects are being carried out in close proximity, an environmental monitoring system is operated to ensure protection of the local environment. Such items as ambient air quality, water quality and noise are monitored automatically 24 hours a day so that countermeasures can be taken immediately if a compromising condition occurs.





Top photo: The bridge from Osaka to Kansai airport spans approximately five kilometers. Bottom photo: Kansai International Airport under construction in Osaka Bay.

Tuesday, May 21 (continued)

Sea Purification Project (Taruino-Utsuro)

An experimental water purification program is also in effect at Kansai International Airport. This research is being conducted to determine the feasibility of purifying water in an enclosed basin. Tidal action creates a hydrostatic head on the trapped water, which, in turn, forces the water through the rubble pile that creates the enclosure. This provides a filtering effect and also allows the microorganisms in the rubble to react on the polluted water, thus further purifying it. Favorable results have been reported from this project.

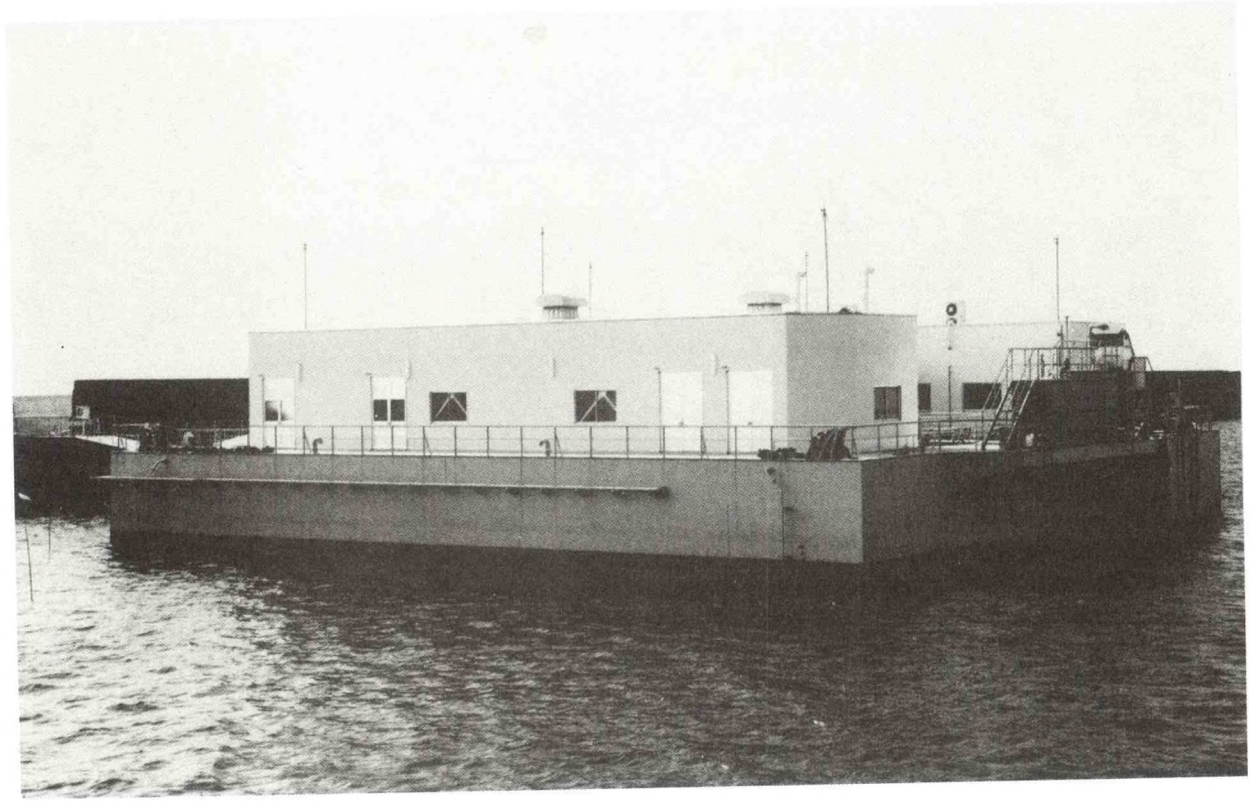


The Sea Purification Project utilizes tidal flow.

Wednesday, May 22

Floating Facility for Waste-Water Treatment

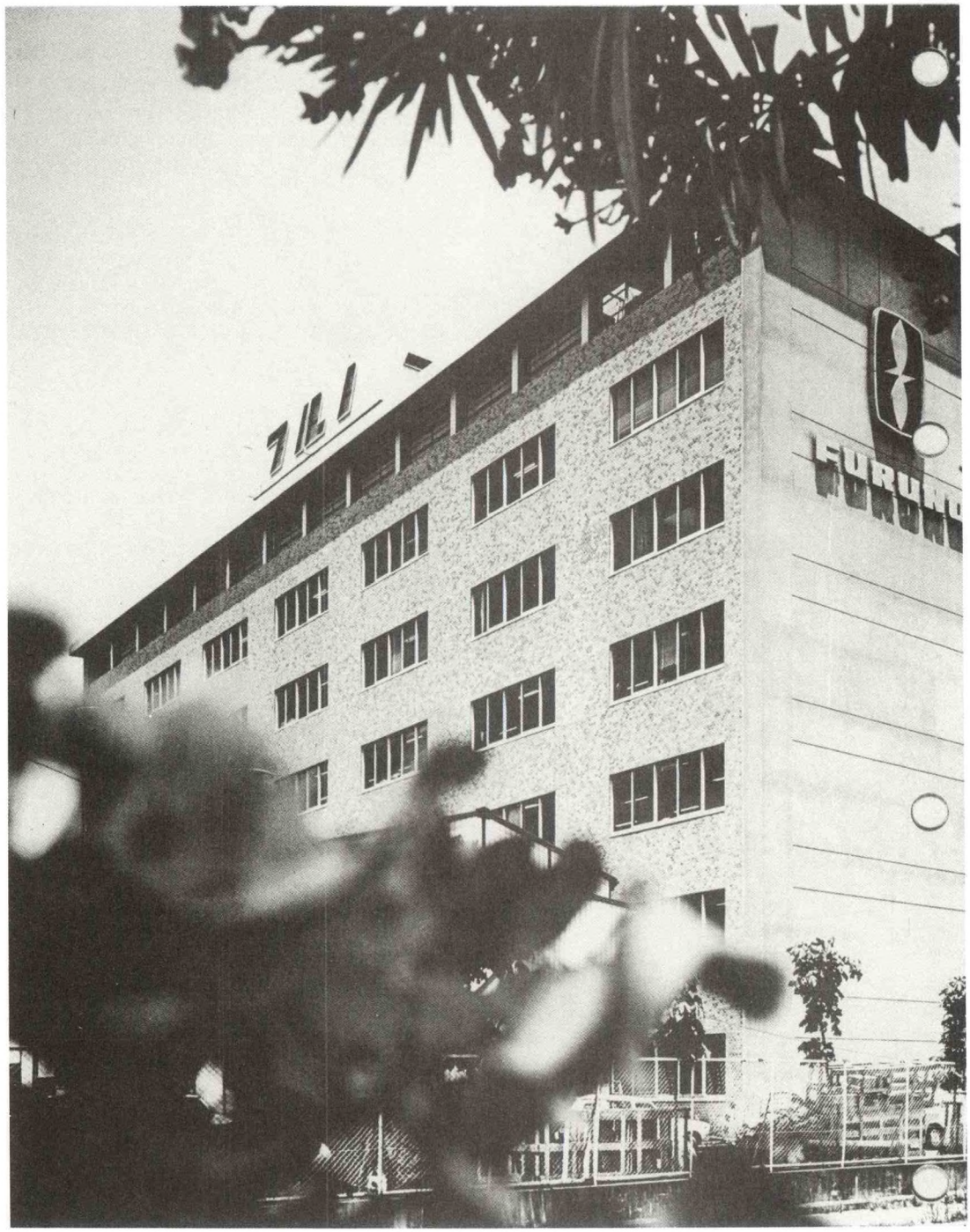
The floating facility is located in the coastal waters off of Osaka, adjacent to coastal reclamation projects which are developing new residential/recreational space using urban and pre-processed industrial waste products. The water is transported in barges to the reclamation area and the waste treatment facilities. It takes about six years to complete this type of reclamation project.



Osaka's floating facility for waste-water treatment.

Furuno Electric Company, Ltd.

Founded in 1946, Furuno Electric Company, LTD. has grown to be the world's leading manufacturer of a wide array of marine electronic equipment. Furuno includes among its hundreds of ocean research products such items as scientific sounders for fish-stock assessment; side-looking sonar for bottom mapping covering a 120-degree swath with one degree resolution; and survey sounders for accurate sub-bottom profiling. In 1971, Furuno developed the first Japan-made Doppler navigation sonar to meet the safety requirements of the shipping companies that operate VLCCs and ULCCs.



Furuno Electric Company, Ltd.

Thursday, May 23

Rokko Island Port and Harbor Facilities

The Port of Kobe, with its natural harbor and strategic location of industrial centers, has been in operation since 1886. Today, the Port of Kobe is Japan's leading liner port and the world's leading container port. The port is linked to 122 nations and over 500 ports by 26 liner routes.

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

East of Port Island, the man-made Rokko Island is reaching the final stages of completion. The island covers an area of 5.8 million square meters and will be equipped with the latest in wharf facilities.

As with the construction involved in the Kansai airport and associated projects, an environmental monitoring program has been established. Additionally, a temporary traffic control center has been established to monitor the extra vessel traffic in the area due to the construction.

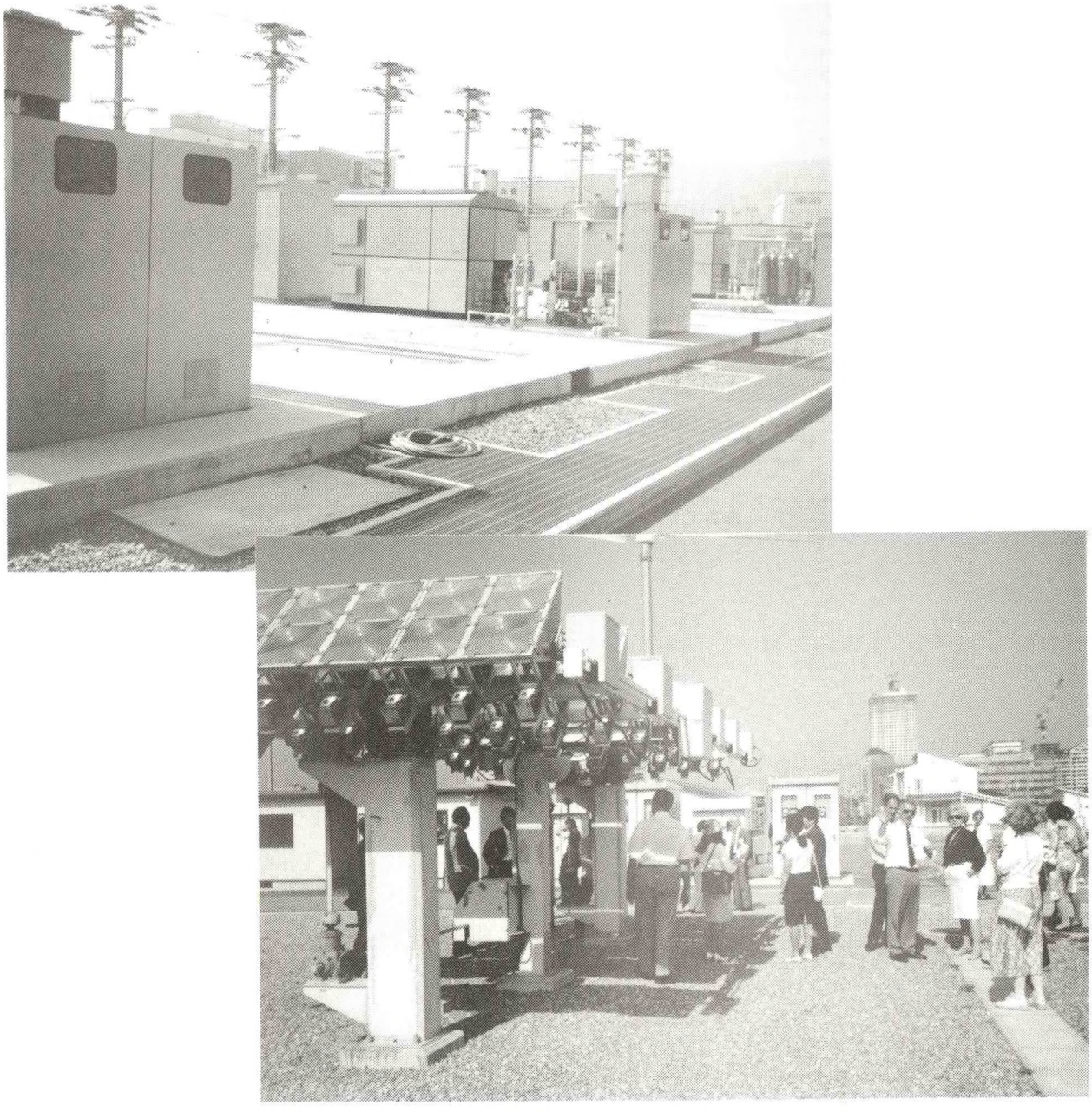


Construction of facilities at Rokko Island.

Thursday, May 23 (continued)

Rokko Island New Energy Center

The Kansai Electric Power Co., Inc. and the Central Research Institute of Electric Power Industry, have established a test center for advanced energy systems on Rokko Island. The objectives of the project are to investigate and evaluate utility interface with a large number of dispersed residential/commercial-scale advanced power generation systems; provide an understanding of the effects of such power generation systems on the utility distribution grid; and establish reliable interconnection and control technologies. The project operates with a 200 kw photovoltaic power generating system; a 33 kw wind power system; and a 300 kw fuel cell system. The test program is to assess the effects of the dispersed power generation systems on the utility grid from the aspects of power quality, protection reliability, and safety.



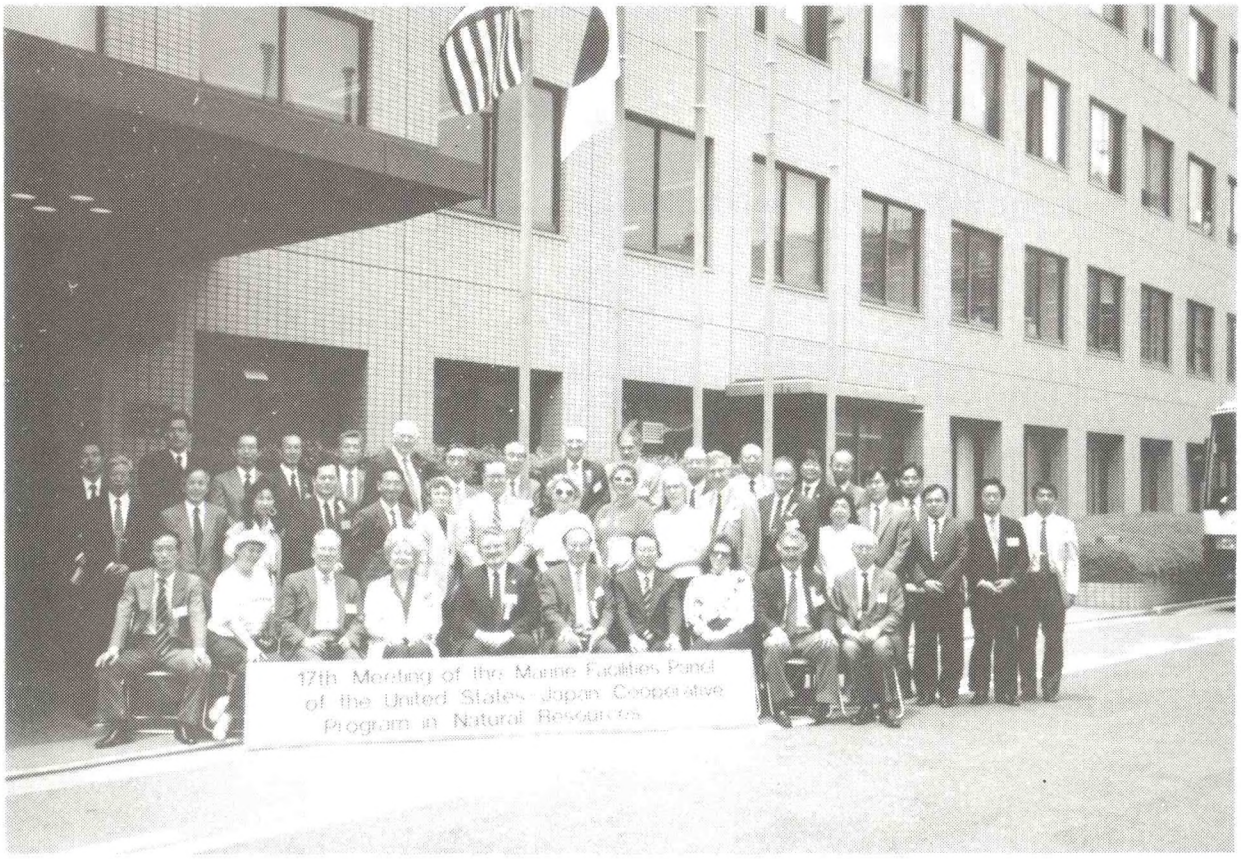
Top photo: Fuel cell units at the test center for advanced energy on Rokko Island. Bottom photo: Also at the center, photovoltaic power-generating arrays.

Friday, May 24

Mitsubishi Heavy Industries Ltd.

Mitsubishi Heavy Industries' Kobe Shipyard is involved in a wide variety of major research and development projects including advanced ship development, 1,000-megawatt nuclear reactors, space projects, traffic control and automated toll stations, and undersea tunneling, to name a few. Of these, two projects are described on the following pages: the world's first MHD-propelled ship, YAMATO-1; and a very large underwater tunneling system.

Following a tour of the above-mentioned R&D projects, Mitsubishi hosted the final MFP meeting. The 17th Meeting concluded with a farewell reception and luncheon.



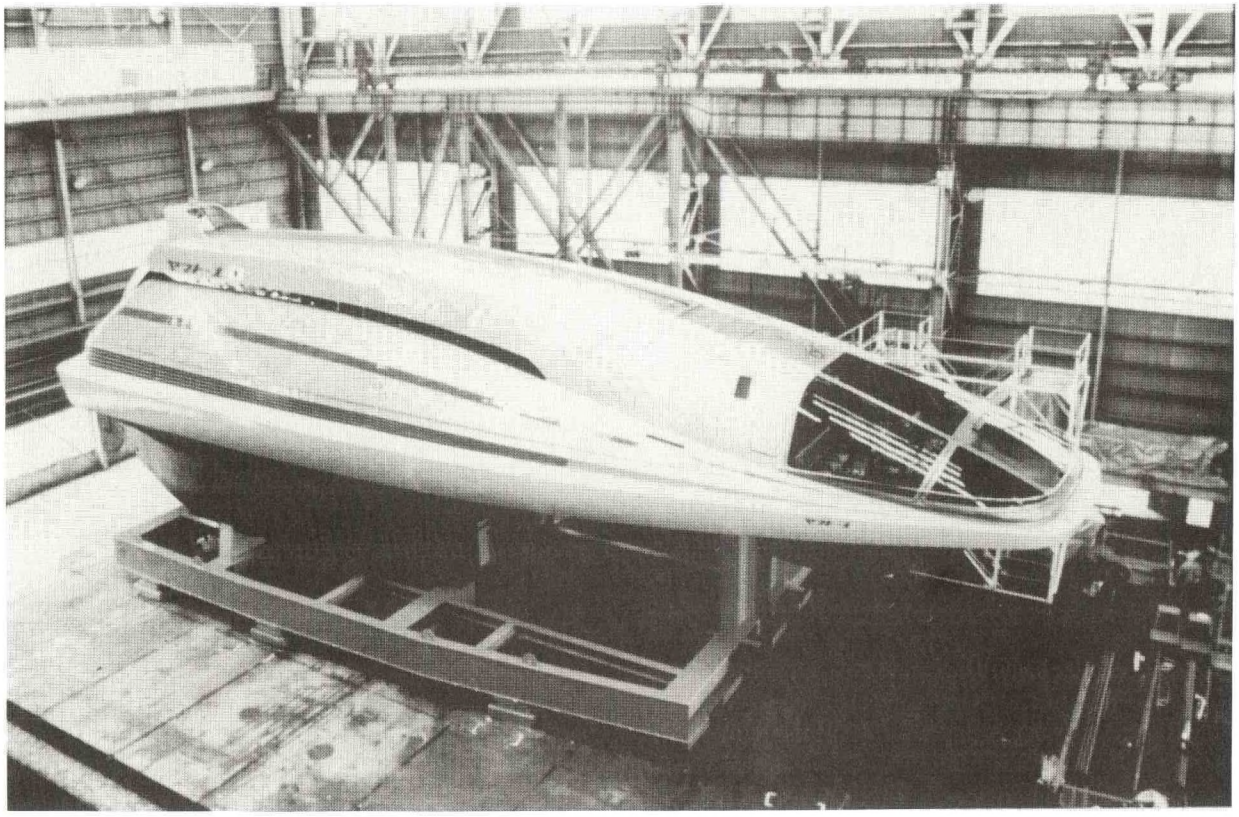
The Marine Facilities Panel at Mitsubishi Heavy Industries on the final day of the 17th study tour.

Friday, May 24 (continued)

Magnetohydrodynamic (MHD) Ship YAMATO-1
Mitsubishi Heavy Industries, Ltd.

Since 1985, the Japan's Ship and Ocean Foundation has conducted an extensive research and development project in magnetohydrodynamic (MHD) ship propulsion, resulting in the design and construction of a prototype experimental ship, YAMATO-1. To accommodate two large MHD thrusters under the waterline, a special ship form (which could be called a semi-catamaran) was adopted. The ship's hull consists of a three-dimensional, complex curvature. The ship displaces 185 tons, with an overall length of 30 m and design speed of 8 knots. Subsytem testing is under way.

The experimental ship was constructed at the Kobe Shipyard of Mitsubishi Heavy Industries, Ltd. The equipment is in the final stages of fitting and adjustment. Specifically, MHD thruster No. 2 for starboard was constructed and successfully tested at Toshiba Corporation, then installed in the ship. MHD thruster No. 1 for portside was completed and is being tested at the Kobe Shipyard.

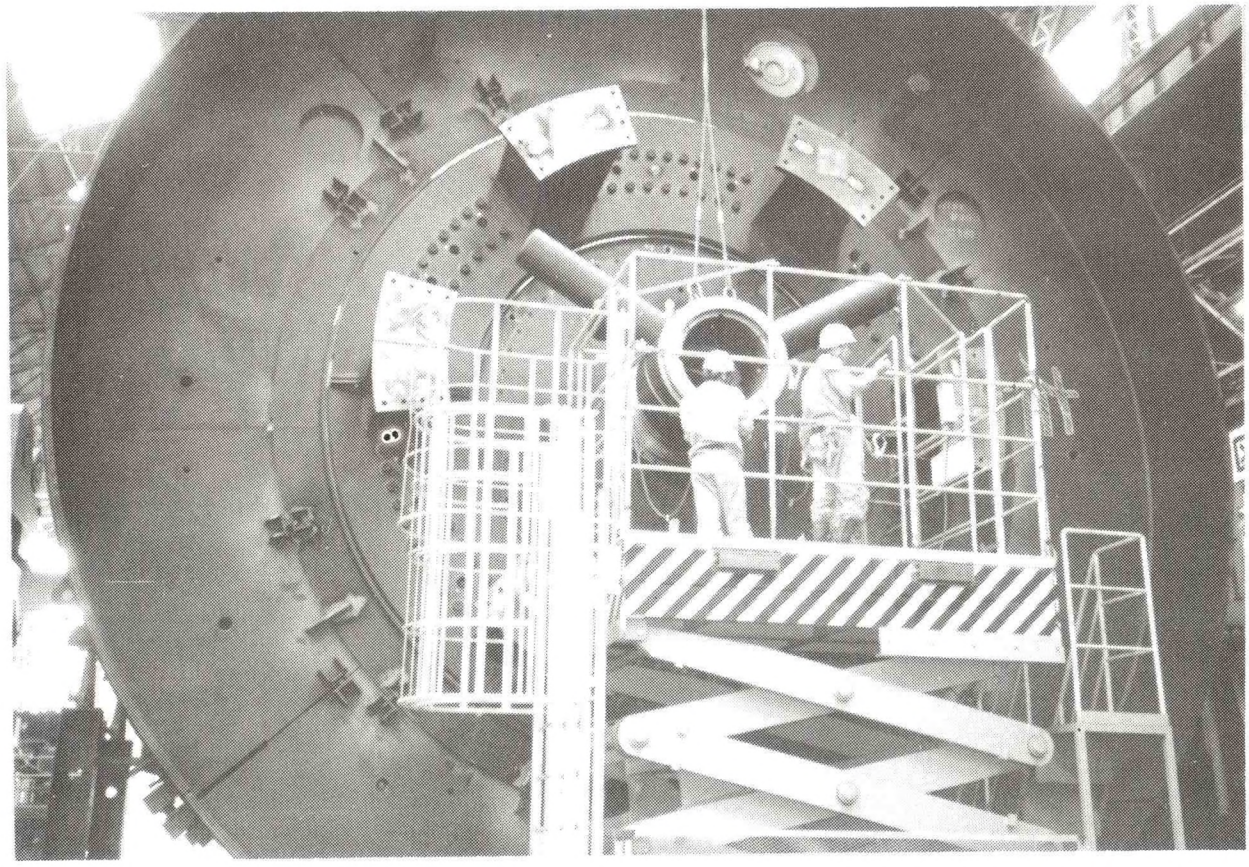


The MHD ship YAMATO-1.

Friday, May 24 (continued)

Underwater Tunneling

Mitsubishi has developed underwater tunneling systems of different sizes and using different cutting and boring techniques. A system similar to the one shown in the photo below was successfully used in tunneling approximately 40 km under the English Channel to connect England and France. This tunneling system is approximately 11 meters in diameter and employs peripheral cutting devices.



An underwater tunneling system developed at Mitsubishi and similar to the one used to tunnel under the English Channel.

Summary of the 17th Meeting

Chairmen Joseph Vadus and Eifu Kataoka presented this summary of the 17th Meeting of the UJNR Marine Facilities Panel at the final meeting, held May 21 at Mitsubishi Heavy Industries Ltd., Kobe Shipyard.

1. Overview

On May 13-14, the plenary sessions were held at the Sasakawa Memorial Hall in Tokyo. Total MFP attendance was 94; 75 from Japan (18 members, 27 advisors, 1 member of the Executive Secretariat, and 29 observers), and 19 from the U.S. (8 members, 10 advisors, 1 observer). Other attendees included special guests Mr. Robert Wildman, Chairman, U.S. UJNR/MRECC; Mr. Rene Eppi, Executive Secretary, U.S. UJNR/MRECC; Dr. Edward Malloy, Counselor for Scientific and Technological Affairs, U.S. Embassy; Mr. Ryuichiro Tanino, Director, Technology and Safety Division, Transport Policy Bureau, Ministry of Transport. Prof. Naonosuke Takarada, Mr. Ikuo Muto, and Mr. Yasuo Hisada were honored to receive testimonial plaques from the U.S. Panel; as were Dr. Kilho Park and Mr. Dan Hightower, who received them from the Japan Panel.

From May 15-24, the study tour proceeded from Tokyo to Yokosuka and Yokohama, Kanagawa; Naha, Okinawa; Osaka, and Kobe, Hyogo. The Panel visited about 20 marine facilities operated by government, industry, and academia, including laboratories, research centers, shipyards, port and harbor facilities, and coastal development sites.

The 17th UJNR/MFP Joint Meeting was highly informative and successful. While valuable technical information was exchanged at the plenary session and during the study tour, perhaps equally valuable were the many informal meetings and information exchanges that took place during luncheons, receptions, breaks, and while the-members and advisors were en route to various site visits.

2. Plenary Session

The U.S. and Japan Panels each presented one keynote address. Keynote speaker for the U.S. Panel was Dr. William Hooke, whose paper was entitled "Marine Facilities in Harmony with the Environment." Keynote speaker for the Japan Panel was Prof. Y. Takaishi, whose paper was entitled "Fundamental Conception on Ocean Exploitation in Japan and Contribution of Shipbuilding Technology." The broad range of themes explored in these keynote addresses set the tone for the technical presentations that followed. A total of 61 papers were prepared for the meeting, 17 of which were reference papers because of the limited time. In addition to the two keynote addresses, 42 papers were presented (U.S., 19 and Japan, 23).

The 61 papers were divided into the following categories for presentation:

- Marine Facilities and Systems for Resource Development and Environmental Conservation
- Advanced Ship Technology Development
- Offshore and Undersea Technology Systems
- Coastal Ocean Space Utilization
- Ocean Measurement, Assessment and Environmental Protection.

Since the papers were distributed and reviewed several weeks before the meeting, each presenter was allowed 10 minutes for a summary report and two minutes for discussion. All of the papers were well prepared and the presentations, usually accompanied by excellent visual materials, were professionally delivered. Discussions following the papers were interesting and, at times, lively.

The proceedings of the 17th UJNR/MFP Meeting and study tour will be published separately by both sides, and copies will be exchanged and-distributed by the Editor of the U.S. Panel and the Secretary of the Japan Panel.

3. Proposal for the Next Joint Meeting

Regarding the 18th UJNR/MFP meeting to be held in the United States, U.S. Chairman Joseph R. Vadus proposed the following tentative plan and options for consideration by Japan Chairman Eifu Kataoka and the Japan Panel. The meeting will be conducted October 15-30, 1992. The opening plenary session will be held in Washington, D.C., followed by participation in the Marine Technology '92 Conference, which could include several sessions chaired by the Japan and U.S. chairmen on "Advanced Technology for Ocean Development and Conservation in Japan and the U.S." The MFP meeting and MTS '92 will be followed by a study tour which will include visits to the southeastern coast, the Gulf of Mexico and the West Coast or Hawaii. Preliminary plans will be discussed at a planning meeting which will be held in Hawaii on October 4, 1991, following the OCEANS 91 Conference, which includes many sessions of interest to the MFP. Topics for the technical program for the 18th meeting will also be discussed on October 4. Editor's note: Since this final meeting it was noted that Japan's Techno-Ocean 92 Conference, scheduled for the third week in October, would present a conflict. Therefore, the tentative plans were shifted to the last week in October and the first two weeks of November. The specific locations to be visited will be determined at the October 4 meeting in Hawaii.

On behalf of the U.S. Panel, Chairman Vadus proposes this tentative plan for review and recommendations by Chairman Kataoka and the Japan PaneI. The U.S. Panel appreciates close cooperation with the Japan Panel for the 18th meeting and study tour.

4. Future Activities

The joint MFP Program will continue cooperative activities, as follows:

A. The joint meetings will continue to be held alternately in the U.S. and Japan approximately every 1.5 years to:

- present technical papers, exchange information and engage in discussion of topics of mutual interest.

- continue to promote and encourage cooperation on projects of mutual interest between the U.S. and Japan.

B. In addition to regular meetings, both chairmen will endeavor to provide appropriate data and information through the UJNR/MFP channels, as requested.

The joint MFP recognizes the importance of ocean technology and marine facilities for ocean development, resource utilization, conservation, environmental protection, and safety in operation. As a result, the following cooperative research projects and technical information exchanges are now under way or planned:

A. *Cooperation in wave data research for ship navigation in the North Pacific.* In 1990, NOAA supplied meteorological data in the North Pacific to Japan's Ship Research Institute (SRI), Ministry of Transport. SRI is developing a wave data base in the North Pacific for improved safety in navigation.

B. *Research on the impact of floating ice floes on ships and offshore structures.* Based on arrangements proposed by Mr. R. Krahl, Mr. C. Smith of the Minerals Management Service, U.S. Dept. of the Interior, and Dr. H. Kitagawa of SRI agreed to pursue cooperative research activities on the impact of floating ice floes on ships and offshore structures. A research plan of mutual interest is now being developed by both sides.

C. *Cooperative research on intelligent ship systems.* Cooperative research on Intelligent Ship Systems, proposed by Mr. P. Mentz at the 16th meeting of UJNR/MFP, has been negotiated between Mr. P. Mentz and Mr. Murayama, who will be the contact persons for both sides.

Mr. F. Kaneko, an SRI researcher, visited Mr. Mentz in Washington in January 1991 for a workshop to determine the scope of the cooperation. The cooperative research project will be conducted in accordance with the plan which is currently being developed by MARAD and MOT.

D. *Cooperative research on an oil-absorbent polymer.* Mr. R. Shamp, Engineering Services Assoc., Inc., introduced an oil absorbent polymer at this meeting. Cooperative research with this material will be considered by both sides.

E. *Facilitation of an information request.* Mr. C. Bookman, Marine Board, National Research Council, requested information on seamen's education systems, pilot systems, etc. in Japan. Chairman Kataoka agreed to contact the Seafarers Department, MOT and Marine Safety Agency to facilitate Mr. Bookman's request.

F. *Cooperative undersea research projects.* Mr. H. Nakato, Japan Marine Science and Technology Center, proposed using SHINKAI 2000 and SHINKAI 6500, developed by JAMSTEC, for cooperative undersea research projects near Japan and elsewhere in the future.

G. *Information exchanges*. Mr. R. Shamp, ESA, Dr. K. Sugai, TSL, and Prof. S. Motora, S&O Foundation, presented papers on advanced ship technology using new concepts; and Mr. J.D. Hightower, SAIC, Mr. W. Webster, Univ. of California, Dr. S. Ueda, PHRI and Mr. Y. Ohkawa, SRI, presented papers on floating offshore platforms. Both chairmen, recognizing the useful contributions that can be made by the above-mentioned technology, agreed to continue information exchange in the future.

H. *Safe operational guidelines for tourist submersibles*. Mr. John Pritzlaff, Westinghouse Electric Co., as chairman of the Society of Naval Architects and Marine Engineers' (SNAME) Panel on Submersibles, is leading the project for the preparation of a new SNAME book on Tourist Submersible Operational Safety Guidelines, and is coordinating and reviewing the inputs from the Japanese including: Mr. Kiyoshi Hirata, President, Japan Submarine Tourism Co.; Mr. E. Miwa, Mitsubishi Heavy Industries (MHI) Ltd., Tokyo; and Mr. H. Morihana and K. Sadakuni of MHI, Kobe.

5. Acknowledgments

Both chairmen extended appreciation to: the Ship Research Institute, Ministry of Transport and the National Oceanic and Atmospheric Administration, the organizations that supported the planning and arrangements for the 17th meeting; the Ship and Ocean Foundation, which supported this meeting; and Mitsubishi Heavy Industries in Kobe, which hosted the final meeting.





Top photo: The 17th U.S.-Japan Marine Facilities Panel held its final meeting at Mitsubishi Heavy Industries Ltd., Kobe Shipyard. Bottom photo: A farewell reception followed the final meeting.

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Keynote Address

FUNDAMENTAL CONCEPTION ON OCEAN EXPLOITATION IN JAPAN AND CONTRIBUTION OF SHIPBUILDING TECHNOLOGY

Yoshifumi Takaishi

1. INTRODUCTION

The Oceans has been giving mankind welfare an incalculable benefit as the fields of rich food supply, borderless transportation and traffic, various recreation, and so on. Recently, the resources existing in the Oceans as mineral resources, natural oil and gas, various energy potentials, 'productivity of living resources and ocean space itself have became new subjects of utilization of ocean, and their exploitation has been actively promoted for these decades of 1970's and 1980's. Further development of ocean resources is still considered as promising in 21st century.

On the other hand, however, a rapid change of environment in the world is also recognized as the results of human activities.

Since oceans play a great role of conservation and improvement of the environment, it will be indispensable to use oceans in keeping its original nature not as simple expansion of human activity on land space.

For a guideline of ocean exploitation of Japan in 1990's, the Council of Ocean Development has recently presented its third report in 1990.

The main conceptions of the report are to be summarized as the following chapters,[1] i.e.

(1) Pursue new possibilities of ocean exploitation technology,
(2) Investigate global change and elucidate ocean environment,
(3) Promote ocean exploitation based on the long-term viewpoint,
(4) Preserve the beauty of sea and create pleasant environment,
(5) Promote ocean exploitation under international viewpoint,
(6) Replete the basis supporting ocean development.

In this paper, the governmental plan for ocean development based on this report will be explained, and present activities relevant to shipbuilding technology will be reviewed.

2. REVIEW OF PLAN AND ACTIVITIES

2.1 Utilization of Ocean Resources

(1) Living Resources

The importance of living resources in the oceans as fishes is increasing as foods to support increasing population in the world. Since the amount of the living resources in the ocean is limited but renewable, aquacultural activity will be effective to increase usable living resources by means of advanced management and technologies. The aquacultural activities are now in such tendency that expand to offshore and deeper sea zones. For this purpose, various types of offshore structures have been and are being developed successfully.

In Japan, such offshore aquacultural test pilot-farm have been installed by the project called "Marinoforum 21".[2] The structures are both juck-up type and floating TLP type platforms. The other concept of structure used for corfs[3], artificial seaweed farm plants[4] or floating fish reefs[5] have been also examined. These structures are an application of offshore oil rig construction technology.

(2) Mineral Resources

Mineral resources found on the ocean floor as cobalt, manganese, nickel, etc. are indispensable material for modern high technology development. The presence of these materials is clearly detected earlier but its mining technologies are still under development.

The development project of Manganese Nodule Mining System aiming at commercial production at the early stage of 21st century will be steadily promoted. [6) 7) 8)]

(3) Oil and Gas Production

The exploitation technology of ocean oil and gas seems to be established in 1970's and 1980's for shallow and medium sea depth by use of various rigs such as juck-up type, gravity type, semisubmersible type, surface vessel type, and so on, corresponding to various environmental conditions from Gulf to North Sea or Arctic Sea.

The oil and gas exploitation in the future will be expanded into deeper and marginal offshore oil field. For such a purpose, various concepts of platform as articulated columns, tension leg platforms, guyed towers as well as semisubmersibles are under development[9)]. In Japan, JOIA has conducted for these ten years the researches developing a guyed tower platform for 150～300 m water depth and a tension leg platform for 500 m and deeper regions. The major research subjects of TLP are the mooring system capable of diverless installation and a stable gravity foundation system suitable to the dynamic loads by earth quakes.[10)-13)] The towing and installing techniques of a long riser pipe is also a problem to be investigated.[11)]

As to development of arctic oil field the research works concerning to transportation vessels navigable in ice-covered water are steadily being promoted in Ship Research Institute.

(4) Ocean Energy Utilization

A great endevour has been paid to develop devices and structures for wave energy utilization in the past. However, any large scale power plant utilizing wave energy is not realized yet but some small scale devices for local use. Instead, the offshore structures for ocean wave control to create calm sea areas attract attention for the purpose of wider utilization of ocean spaces.[14) 15)] Wave focusing by submerged plate is now investigated by JAMSTEC and the at-sea experiment of a proto-type is planned.[14)]

A unique floating wave power absorber "Mighty Whale" is an example of wave power utilization researches in Japan which are still continuing.[16) 17)] For achieving practical use, a long-term investigation together with researches on the compound system with other functions as wave field control or deep sea water utilization would be necessary.

2.2 Ocean Space Utilization

Vast space of oceans could be utilized for various pouposes, i.e.

a. living space in water-front area,
b. industry use,
c. fishery,
d. storage,
e. recreational space,
f. trsffic and transportation,
g. waste disposal or processing,

and so on.

In the past few decades, reclamation of the foreshore for industrial use has been the major activities of ocean space utilization.

In future, the compound utilization of ocean space by combining floating structures, man-made islands, and other facilities should be pursued.

In such circumstances, the development of economical and safe offshore structures is indispensable, and the

assessment technology should be developed and applied for safety and protection of environment.

The development of floating offshore structures to be used for ocean space utilization is one of the core themes. The main problems to be investigated are the optimum mooring system corresponding to water depths, functional test as well as endurance test which are to be accomplished by use of prototype structure at sea, and establishment of safety assessment techniques.

Various concepts of such offshore structures are proposed, for example, a floating hotel[18], a semisubmersible type ring-like structure[19], a floating air port of single point mooring[20], and so on.

A latest example of large scale offshore structure for ocean space utilization is the oil storage facility at Kami-Goto, Kyushu.

The "POSEIDON project" is a proto-type experiment for establishing a concept of huge scale semisubmersible offshore platform for ocean space utilization[21].

(2) Marine Recreation

Corresponding to increasing tendency of recreational boats and yachts in Japan, the expansion and preparation of marina and related facilities are becoming an urgent problem, and several projects are now promoted by related ministries, for example, Port Renaissance 21 project, Coastal Resort project, Marine Town project, Coastal Community-zone project[22]. The Ministry of Transport presented "Marine'99 Project" in 1988, containing repletion of berthing and storage facilities of recreational boats, generation of more attractive water-front, increase of safety, establishment of information service system and counter plan to recreational cruising demands[23]. "Hello My Boat" project is one of realized policy among them. Inproving safety at sea is one of the major policy of this project.

2.3 Countermeasure to Global Environmental Problems and Conservation of Natural Environment

This problem is devided into four directions, i.e.

a. Observation for clarifying ocean environment,
b. Prevention of pollution in oceans,
c. Preservation of natural environment and creation of better conditions,
d. Care on environment in case of ocean development.

Concerning to the shipbuilding technology, reduction of ship-originated loads of pollution is the main subject of environmental problems. The reduction of CO_2 contained in the exhaust gas should be achieved by developing new type marine engine. The improvement of hull construction to minimize the leakage of crude oil from wrecked ships is urgent subject of shipbuilding technology[24].

The other subjects concerning to the environmental problem are as follows; development of pollutionless paints, effective use of disused FRP vessel disposal technology, etc..

The investigation concerning to the diffusion and purification mechanism of ocean should be promoted, either for monitoring of pollution or for active utilization of ocean space to improve the global environmental change, for example, the disposal of CO_2 in deep sea[25].

2.4 Ocean Survey

The scientific knowledge about ocean is not only basis of all activities in ocean but also of vital importance to establishing prevention of disaster caused by earth itself. To this aim, steady, long-term and well-planned

observation of ocean, smoothy utilization of obtained data, as well as high quality control system should be conducted.

For rational design and safe operation of ships and offshore structures, wind and wave data on the ocean are indispensable. The development of ship-borne instruments is still wanted for onboard wave measurement, together with development of satellite-borne instrument as well as efficient buoy observation system.

Sea ice observation technique should be developed by use of remote sensing.

2.5 Common Technology Development

(1) Ocean Observation Techniques

The observation systems combining various methods on ships, air-planes, buoys, satellites, sea floor stations are necessary for effective and comprehensive measurement of ocean. An offshore observation platform could serve to test such systems. As to the elemental technology, improvement of ocean meteorological observation ship, ship-borne automatic observation instruments, development of multi-purpose buoys, under-water robotic vehicles for measurement are to be developed.

(2) Diving Technology

Automation of under-sea works as pipe line laying, installation and maintenance of offshore structures will become necessary for deep sea exploitation. Manned and unmanned under-water tethered vehicles for deeper sea are under development.

Researches on untethered autonomous under-watere vehicles are also being performed[26].

(3) Development of Special Ships

The development of design and construction technology of a new-type high speed ship is situated as the most noticeable research project of shipbuilding field.

In relation with this project, development of surrounding fields such as navigation assisting system for high speed ships is atracting attention.

The simulation system which has been developed in the research project on high intelligent ships will be used also for high speed ship development[27].

(4) Design and Installation Technique of Offshore Structures

Advanced technology for design and installation of offshore structures should be introduced. The detecting technique of deterioration of offshore structures should be established, and simple and reliable methods for inspection and repair of the structure should be developed.

To achieve these technology, tests by proto-type structures at actual sea are necessary.

(5) Material Engineering

Improvement of durability, decrease in cost and free from pollution should be pursued by application of new materials and compound materials to offshore structures and development of anti-fouling means.

(6) Under-water Power Sources

The fuel cell, Stirling engine, CCDE, oxihydrogen engine are considered as promising power source in deep sea operation. For this end, development of elemental technology such as storage system of hydrogen fuel, oxy-hydrogen burning in high-pressure water, power system of solid oxide fuel cell are inevitable.

The nuclear power source for deep-sea use will be developed by stages, in harmonizing with development of marine

reactors[28].

(7) Data Base of Marine Meteorological Data and Data Service System

To improve the data service system, automation of onboard observation and and extension of ships equipped with such instrumentation are of fundamental procedure. Marine data collection by the voluntary ships should be continued. The standardization of data base should be promoted internationally with rational quality control procedures[29].

3. DEVELOPMENT OF SOCIAL BASIS

To promote the above-mentioned policy of ocean development, improvement of internal structure of R & D for ocean engineering and more active international cooperation will be proceeded. It is recommended that more international open-door policy for exchange of researchers and more cooperation between academy, industry and government should be promoted.

The importance of fund and education is also emphasized.

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abbr.; SNAJ: The Society of Naval Architects of Japan

Marine Facilities and Systems for Resource Development and Environmental Conservation

Advanced Ocean Resource Application

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Introduction

Hawaii is rapidly advancing as the international site for ocean resource research and development. Already in place are:

- the Natural Energy Laboratory of Hawaii and Hawaii Ocean Science and Technology Park complex, an R&D and commercialization facility of 900 acres utilizing deep, nutrient-rich and pathogen free coldwater to stimulate new marine industries;

- a new School of Ocean and Earth Science and Technology, which is home to the U.S. Department of Interior sponsored Marine Minerals Technology Center, the national site for ocean basin seabed mining and processing research;

- the Pacific International Center for High Technology Research, which has become the premier engineering office for integrated ocean thermal energy conversion (OTEC) development; and

- a wide spectrum of supporting organizations, ranging from the Naval Ocean Systems Center to the Hawaii Undersea Research Laboratory, and next generation facilities such as an operating SWATH vessel and Project DUMAND.

Much of the above was previously reported in prior UJNR meetings. This paper will focus on four relatively unexpected areas:

- ocean resource meetings in Hawaii;

- technology systems for ocean ranching;

- renewable fuels from the sea; and

- Blue Revolution 2000.

Ocean Resource Application Meetings In Hawaii

Hawaii hosted the National Science Foundation sponsored Very Large Floating Structures workshop last month (April 1991). The keynote speech was provided by Hawaii State Senator Richard Matsuura on Blue Revolution 2000. A special section will later report on the details.

Senator Matsuura worked on the Green Revolution as a researcher in India.

In the Fall of this year, three important meetings will occur in Honolulu:

- September 25-27: National Science Foundation sponsored workshop on Stockpile 2000 (strategic metals from the sea), hosted by the Marine Minerals Technology Center of the University of Hawaii;

- September 26-29: National Science Foundation sponsored workshop on open ocean mariculture, hosted by the Center for Ocean Resources Technology of the University of Hawaii; and

- October 1-3: Oceans '91.

Technology Systems For Ocean Ranching

It has long been Man's dream to farm the oceans in much the same manner as we now cultivate the lands. As the open ocean is largely an aquatic desert, the controlled upwelling of nutrient-rich deep ocean waters offers immense promise for creating man-made fisheries and marine biomass plantations. The engineering challenge, however, for economically bringing this fluid from depths greater than 500 feet, containing the mixture within the euphotic zone, stimulating the biological growth chain, and harvesting desired seafood products and feedstock for transportation fuel and other high value chemicals, is great, and only now being explored.

Marine fish stocks are declining from over-fishing and environmental influences. However, the demand for seafood is rising, and the U.S. per capita fish consumption, now at 17 pounds per person, could double by the beginning of the 21st Century, primarily due to changes in dietary habits. Also, as the world population continues to increase, the ensuing global demand for edible protein will greatly exceed the supply. Thus, the opportunities for innovative means to expand the availability of new fisheries will become quite attractive, as marine protein is, in fact, "healthier" than most of the terrestrial options.

The National Science Foundation (NSF) has sponsored a series of workshops on various aspects of ocean resource technology. The first meeting was held in October of 1986 in Hawaii, which was reported as "Results of a Conference on Engineering Solutions for the Utilization of the Exclusive Economic Zone Resources". The deliberations established research priorities, which were published in the June 1987 issue of SEA TECHNOLOGY. A set of workshops was subsequently held in Hawaii, Japan and Taiwan, dealing with deep sea instrumentation, ocean robotics, artificial upwelling and very large stable platforms.

The March 1991 workshop at Kailua-Kona on artificial upwelling stimulated detailed discussions between Japan and United States researchers. There was, however, a recognition that expertise in upwelling was limited and field data generally lacking. An agreement was reached between the Japan Marine Science and Technology Center (JAMSTEC) and the Center for Ocean Resources Technology (CORT) of the University of Hawaii to develop cooperative projects in this area. Dr. Kelton McKinley of CORT was sponsored by JAMSTEC to undertake this mission. In addition to JAMSTEC and CORT, the Electrotechnical Laboratory of the Japan Ministry of International Trade and Industry (MITI), OTEC Association of Japan and the Pacific International Center for High Technology Research (PICHTR) will begin to work together on sharing information and personnel. Several exchanges have already been consummated.

The next NSF workshop will be held in Honolulu from September 26 to 29 later this year on

"Engineering Research Needs for Off-Shore Mariculture Systems," just before the Oceans '91 conference scheduled for October 1 to 3, also in Hawaii. This will be the first international gathering of scientists and technologists from around the world to meet in a comprehensive workshop to set research and technology transfer priorities. The uniqueness of this conference is that the concept of induced upwelling will be suggested as a new dimension to enhance productivity.

In our discussions, we have proposed Hawaii as the international laboratory for open ocean experiments. The Natural Energy Laboratory of Hawaii with companion Hawaii Ocean Science and Technology Park, new School of Ocean and Earth Science and Technology in the soon to be constructed Pacific Ocean Science and Technology structure, and national deep ocean Marine Mineral Technology Center of the Department of Interior—all are already in operation. When then President Ronald Reagan in 1983 pronounced the national Exclusive Economic Zone, he doubled the jurisdictional area of the nation, and, in land-sea domain, made Hawaii the second largest state in the Union. The ocean is our next realistic frontier to create new industries and augment international productivity, and Hawaii is ready to work with organizations from around the world to bring about the Blue Revolution.

An important early step for Project Blue Revolution 2000 will be cooperative projects at the Deep Sea Water Laboratory of JAMSTEC located in Kochi Prefecture and Natural Energy Laboratory of Hawaii. Among the projects proposed for land and sea testing include:

- development of system models to evaluate the technical and economic performance of alternative designs for bringing deep ocean water to the surface, optimizing effluent discharge, maintaining the fluid in a biologically productive zone relative to ambient currents, maximizing biological productivity, and examining the socio-economic factors associated with open ocean fisheries, and

- design, construction and operation of a stable platform capable of supporting at-sea scientific and engineering research to test the pumping, dispersal and life support systems for artificially-upwelled open ocean mariculture.

The development and commercialization of open ocean ranching can be facilitated if Japan and the USA cooperate in a manner that can establish mutual benefits. The program being planned and implemented will depend on teamwork and synergy.

Renewable Fuels From The Sea

While a considerable amount of energy is stored within the tropical and semi-tropical belt, this band does not support centers of major industrial development, nor is it a site for significant energy markets. Thus, for offshore power production of ocean thermal energy conversion (OTEC) to prove useful and competitive, it is necessary to formulate efficient and economical means to redistribute the energy generated to areas of high energy consumption. This need has sparked interest in the development of transportable fuels and other products which take advantage of power produced by ocean energy conversion systems in manufacturing processes. A U.S. Department of Energy review of the concept provides a concise assertion:

> "The greatest potential for OTEC is to supply a significant fraction of the world's fuel needs using large plantships to produce hydrogen, ammonia, or methanol." (*The Potential of Renewable Energy: An Inter laboratory White Paper,* Idaho National Engineering Laboratory, Los Alamos National

Laboratory, Oak Ridge National Laboratory, Sandia National Laboratory, Solar Energy Research Institute, March 1990)

Substantial effort has been expended thus far to improve isolated ocean energy conversion technologies, yet very few have reached the commercial stage. One major reason for their lack of commercial success is that the isolated technologies have not capitalized on ancillary products or on inputs that might synergistically integrate these isolated technologies into complete systems. It is integration that will make the development of ocean resources economically viable in the future. Figure 1 outlines this potential.

If the ocean is ever to develop into a major supplier of energy fuels, system packages will be the primary inducement. Many tens of thousands of ocean energy megawatt equivalents can someday power floating cities and industrial platforms for strategic metals, transportation fuels, chemicals, and other products. The commercial success of these enterprises will almost surely depend on total system integration. For example, a grazing platform which harvests and processes seabed ores, using OTEC electricity, and returning wastes to the ocean floor, could well turn out to be the only acceptable option for strategic metal production. Likewise, a marine biomass plantation encircling a floating methanol production facility in the open ocean, utilizing upwelled deep ocean water, creating new fisheries, while perhaps enhancing the atmosphere by utilizing carbon dioxide, could be much more efficient and economical than non-integrated ocean or land-based enterprises.

During the next decade, much of the research required to advance the science and engineering relating to production of fuels and energy-enhanced products from the sea can be performed at land-based facilities such as at the Natural Energy Laboratory of Hawaii and the Kochi Laboratory of the Japan Marine Science and Technology Center, both of which feature pipes that bring deep, cold water to the surface. However, prototype experiments will also need to be performed on the open ocean to test concepts and gain the confidence of the financial sector.

The National Science Foundation sponsored a workshop in 1989 on "The Ocean Enterprise." The panel on OTEC recommended a series of projects leading to a 500 MW ocean mineral platform combining OTEC and seabed ore processing by the Year 2000, and a 1000 MW Pan American complex featuring multinational cooperation and a full range of co-products at a cost of $10 billion by 2010. If global warming becomes a serious matter, nuclear powerplants continue to face societal acceptance problems, mineral shortages occur, and the commercial equivalent of the National Aerospace Plane—which will be powered by liquid hydrogen—flies, OTEC should be in a prime position to provide fuels from the sea by year 2020.

Blue Revolution 2000

Blue Revolution 2000 is proposed to be very large floating structure of approximately 100,000 square feet, estimated to cost $100 million, to serve as a base of operations for pilot facilities in OTEC, seabed mining/processing, ocean ranching, and scientific experiments, including the possibility of remediating global warming. A target operational date of the Year 2000 has been discussed.

Blue Revolution 2000 would be an ideal focal project for the various ocean resource enterprises because every ultimate commercial-scale application—OTEC, sea ranching, floating cities, strategic metals, storage of toxic wastes—will find use for stable platforms. There is, of course, military interests, as for floating naval bases. The industrial sector will participate by establishing incubator enterprises. The Project will serve to

coordinate and integrate the interdisciplinary development of generic marine technologies common to all EEZ resource needs.

In years one to three, the research focus will be on the use of artificial upwelling for open ocean mariculture, development of marine materials, and the design of the floating test bed, in addition to maintaining progressive programs in OTEC, seabed minerals and ocean science. Actual construction of the platform will not occur until Year Five, and full operations are being planned for the Year 2000.

The Committee for Blue Revolution 2000, composed of representatives from government, industry and academia, began meeting in the Summer of 1990 to assist in the conceptualization. Fund-raising will be a major task and international cooperation will be essential.

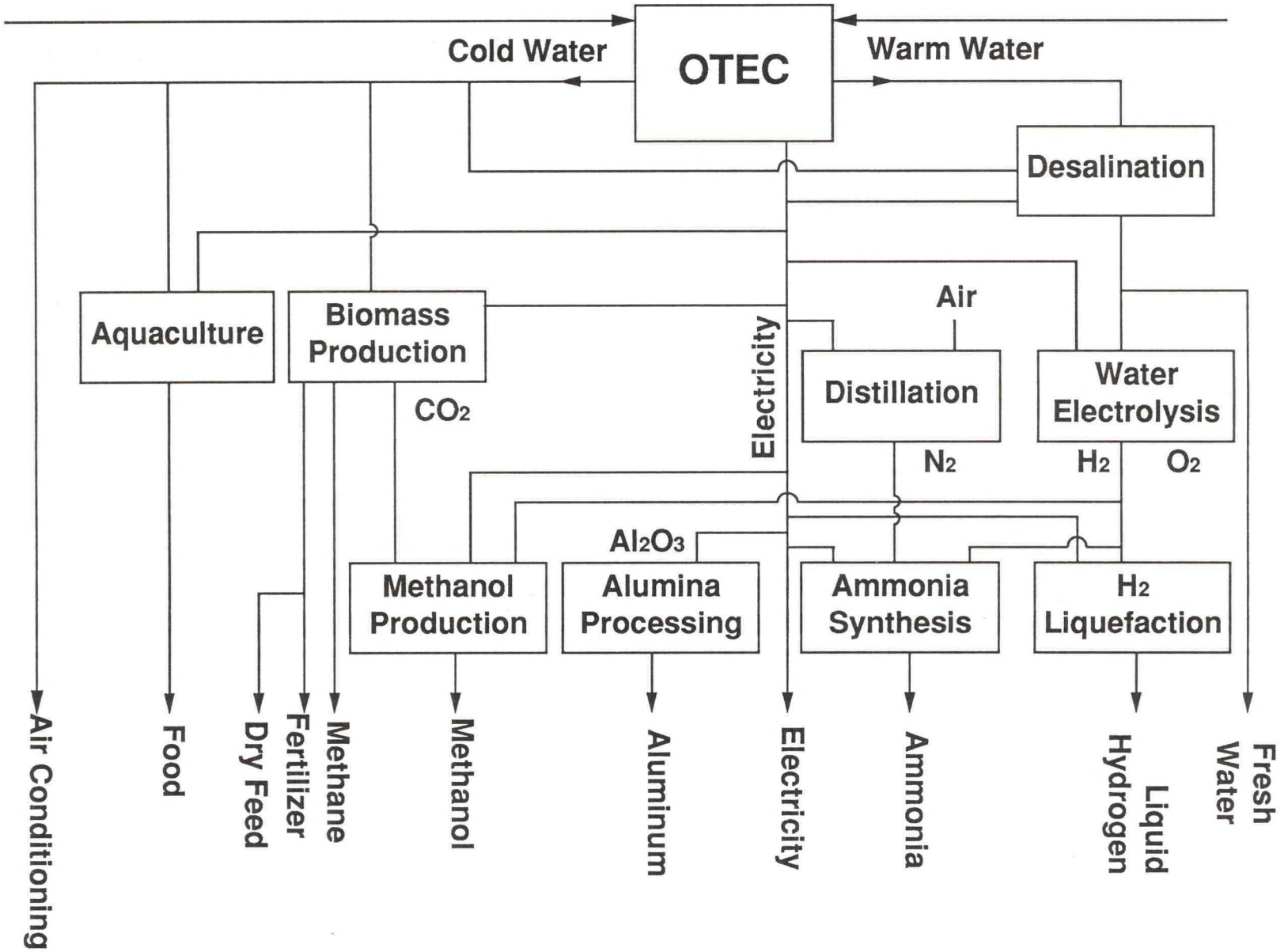

Fig. 1. Integrated, multiple product ocean energy system.

OFFSHORE STRUCTURES FOR DEEP OCEAN OIL AND GAS OPERATIONS

by

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17th Meeting of the U.S.-Japan Committee on Natural Resources
Marine Facilities Panel

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ABSTRACT

As the opportunities for the exploration for oil and gas remain limited on the outer Continental Shelf of the United States, due to Congressional moratoria, and the President's decision to delay offshore drilling in environmentally sensitive areas, the deep waters of the Gulf of Mexico (GOM) continues to provide the most promising areas for exploratory drilling. Prior discoveries are now in the development stage and current drilling activity indicate additional oil and gas reserves worthy of further development. However, environmental conditions related to the deep waters of the GOM, eddy currents and geohazards, present challenges to the design engineers resulting in unique configurations of the more conventional structures to accommodate these conditions.

CURRENT DEEPWATER DEVELOPMENT

As reported in earlier meetings of this Panel, several projects have been undertaken in water depths in excess of 1000 feet in the GOM. Shell Offshore Inc., launched it's Bullwinkle platform on May 31, 1988, the tallest manmade offshore structure in the world set in 1350 feet of water. The project is currently on schedule. Twenty-six production wells have been drilled and production capabilities appear to be better than anticipated. Permanent production facilities are being installed with production of 45,000 barrels (bopd) of oil per day expected during July of this year.

The first Floating Production System (FPS) in the GOM was installed in Green Canyon Block 29 in 1520 feet of water with production commencing on May 5, 1969. This project incorporated the use of a converted drilling rig, the Penrod 72, as a floating drilling/production facility with permanent moorings, a system consisting of a subsea template, subsea Christmas trees, and the deepest water pipeline in the GOM. Unfortunately, the project has since been abandoned due to the poor production Performance of the oil reservoirs.

The first tension leg platform concept to be incorporated in a GOM project is in the Conoco Oil Corporation's Jolliet Field. The design of this facility, technically a Tension Leg Well Platform (TLWP), differs from the first TLP, the Hutton platform, installed in the North Sea, inasmuch as this is a lightweight platform containing only the wellheads, a limited amount of production equipment, and a workover rig. Production wells were drilled with a template on the seafloor and the TLWP installed over the wells. Work is currently centered on well completions, many of which will be dual completions. Complete installation of the platform was delayed for several months as two tendons were lost during tow-out. Each tendon in excess of 1600 feet in length was floated and towed to the installation site. Severe weather during towing operations resulted in the loss of two of the tendons in water deep enough to preclude recovery. The connecting rings were recovered, however. The remaining tendons were installed and limited operations were allowed to proceed on the facility until replacement tendons were manufactured. First production from the field was in December 1989. Peak production is expected to be 30,000 bopd, however, current production is about 9,000 bopd, reduced as a result of sand problems in the wells. This is being corrected and total production should be on the increase.

FUTURE DEVELOPMENT ACTIVITIES

According to reports from the Minerals Management Service there are 56 blocks in the GOM located in water depths in excess of 1000 feet that have hydrocarbon discoveries. There are 32 discoveries in 1000 to 2000 feet of water, 16 in 2001 to 3000 feet of water, and four in water depths greater than 4000 feet. The majority of these discoveries were made in 1987 and design concepts for development of these tracts are now being formulated. Additionally, one-third of all the undrilled leases in the GOM lie beneath at 3,000 feet of water and on many of these their lease expiration dates are nearing.

Conoco has initiated preliminary engineering studies of a second TLWP to be located immediately south of the Jolliet project. This platform could conceivably produce from three adjacent blocks. Drilling is proceeding on these leases in water depths from 1620 feet to 1920 feet. The second TLWP will be very similar to the Jolliet version. Conoco will undoubtedly be able to reduce costs on the second platform as a result of lessons learned from their first TLWP platform. However, the poor results from a recently completed well may cause the postponment of this project.

Shell continues its aggressive program for development of deepwater reservoirs. Tension leg platforms are being proposed for three projects in water depths in excess of 2000 feet. The "Auger" prospect, will require production facilities in the world's deepest water to date, 2800 feet. This is proposed as a 32 slot TLP with a peak production

of 45,000 bopd. Unlike the Conoco Green Canyon TLWP, Auger will support a drilling rig and complete production facilities. The deck weight of 10,000 tons is almost twice that of Conoco's TLWP, but is less than one-half of Conoco's Hutton platform in the North Sea and one-fourth of other proposed North Sea platforms. It should be noted, though, that the production capacity of the proposed North Sea platforms are more than four times that of the GOM facility, and the Hutton platform is located in a water depth one-sixth that of the Auger. This platform will have several unique features. One of the most interesting is that Auger will have a fixed-position drilling rig and will use gantry beams to position wellheads below the rig for drilling/workover operations. Auger will also have a lateral mooring system. The well locations on the seafloor will not be aligned vertically under the deck positions of the wells, resulting in marginally slanted risers. The mooring system will allow the entire hull and drilling rig to be moved over any particular well in order that work on the well can be conducted with the riser in a vertical position. The seafloor well configuration will also allow wells to be completed individually without the need for a conventional subsea well template. However, several wells will be predrilled prior to installation of the facility. Initial drilling of two of these wells has indicated additional deeper productive horizons. Shell will drill an additional 8 wells before the facility is installed in 1993. First production is expected in 1993. lines.

Another potential candidate for a TLP is the Shell-operated Ram/Powell prospect being developed jointly with Amoco and Exxon. The field is in the Viosca Knoll area and has a target depth for the TLP of about 3000 feet. Discussions are being held, between the partners to resolve issues in several areas including the number of wells necessary to produce the drainage area. This, of course, is a necessary parameter for platform design. Originally, the three companies planned to install a facility similar to the Auger with a more conventional integrated drilling/production subsea template.

Shell and its partners have established a special group to determine the optimum way to develop the MARS prospect, also located in about 3,000 feet of water. This prospect contains large, complicated, hydrocarbon reservoirs and the development of the prospect will be approached slowly. Shell is also planning to install their Cognac B platform adjacent to their original Cognac platform which was installed in 1978 in 1025 feet of water. The proposed platform will be in deeper water and unlike the three piece original structure will be a one-piece structure similar to the Bullwinkle facility.

Exxon has elected to develop their Zinc prospect in the Mississippi Canyon area with a 10-slot subsea template in 1,500 feet of water. The flowline and controls for the subsea wells will run six miles back to their Alabaster

platform which will be installed in 486 feet of water.

British Petroleum has plans to install a fixed platform to develop its Mississippi Canyon area prospect located in 1,030 feet of water. This 32-slot one-piece structure is unique in that it will be a four-leg structure rather than the more traditional eight-leg type jacket. Although the fewer number of members will be larger, the total weight of the structure will be minimized thus reducing the overall cost. The design was approved for fabrication March 12, 1990 with construction to be by Gulf Marine Fabricators in Ingleside, Texas.

DEEPWATER DEVELOPMENT CONCERNS

The GOM was the birthplace of the technology to develop offshore hydrocarbon resources. Technologies developed here have been exported to all areas of the world where offshore development has taken place and has become the foundation for the development of more advanced technologies to solve the engineering problems indigenous to each producing area. Such is the case of the deepwater of the GOM where problems caused by the regional environmental conditions continue to face the design engineer. Due to the configuration of the land masses in this area, the thin passageway between Florida and Cuba is considered the driving force for the Gulf Stream which creates high current velocities in this great volume of water. As the Gulf of Mexico loop current portion of the Gulf Stream enters the Gulf of Mexico between the Yucatan Peninsula and Cuba turns and exits into the Atlantic Ocean through the Gulf Straits, eddy currents are formed which drift across the Gulf in a clockwise rotation in a south southwest direction. These currents may have a velocity of several knots and can exert an environmental load on a structure equal to that of a hurricane. In addition, as the current passes around vertical tubular members, small eddies may develop which can cause vortex-induced vibrations resulting in a higher fatigue factor. Other problems are encountered in the deployment of anchors and mooring systems for drilling rigs in these depths of water. Soft sediments referred to as "gumbo", may extend more that 50 feet below the mudline. This has required innovative anchor patterns for the mooring systems. These factors greatly influence the direction that predesign studies must take to provide a proper basis for rig placement and platform design.

CONCLUSION

The deepwater areas offshore the United States continue to present challenges for the development of extensive hydrocarbon reserves both discovered and inferred. The evolution of the technology for the development of these resources is an iterative process due to the individuality of each prospect, but a baseline is being generated that can form a standard for future work and a basis for developing prospects in even deeper waters and more hostile environments.

THE INSTITUTE FOR PACIFIC ASIA
ONE UNIVERSITY'S ANSWER TO THE RISING POWER OF THE PACIFIC

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Introduction

Texas A&M University is one of the ten largest universities in the United States. Founded in 1871 and opened for classes in 1876, it is the State of Texas' oldest institution of higher education.

The University is a land-grant, sea-grant and space-grant university; one of the few to hold all three designations. Its 1990 fall enrollment is 41,171, including 2,475 international students from 107 countries. During the 1989-90 academic year Texas A&M ranked seventh in overall enrollment in the United States. It is part of The Texas A&M University System, as shown in Figure 1. The System has more than 71,000 students.

The University, as shown in Figure 2, (below) consists of 10 academic colleges, Agriculture and Life Sciences, Architecture, Business Administration and Graduate School of Business, Education, Engineering, Geosciences, Liberal Arts, Medicine, Science, Veterinary Medicine and General Studies. The Colleges of Business Administration, Engineering,

TEXAS A&M UNIVERSITY SYSTEM

Texas A&M University
Prairie View A&M University
Tarleton State University
Texas A&M University at Galveston
Texas A&I University
Corpus Christi State University
Laredo State University
West Texas State University
Texas Agricultural Experiment Station
Texas Agricultural Extension Service
Texas Animal Damage Control Service
Texas Engineering Experiment Station
Texas Engineering Extension Service
Texas Transportation Institute
Texas Veterinary Medical Diagnostic Laboratory
Texas Forest Service

Figure 1

TEXAS A&M UNIVERSITY

College of Architecture (1,500)
College of Agriculture and Life Sciences (5,000)
College of Business Administration and Graduate School of Business (6,000)
College of Education (3,400)
College of Engineering (9,800)
College of Geosciences (700)
College of Liberal Arts (6,700)
College of Medicine (200)
Colllege of Science (2,900)
College of Veterinary Medicine (1,600)
General Studies Program (2,700)

Figure 2. Numbers indicate enrollment in each college.

Agriculture and Life Sciences, Architecture and Veterinary Medicine are among the largest such academic units in the nation. The University offers 151 fields of study at the undergraduate level, 148 at the master's level, 105 at the doctoral level and two professional degrees, the M.D. and D.V.M.

More than 180,000 academic degrees have been awarded by the University, including 35,200 graduate and professional degrees. Approximately half of the advanced degrees have been awarded within the past 15 years. Of these degrees, 5,000 have been awarded to international students from 118 countries.

Texas A&M has approximately 2,200 faculty members, more than 80 percent of whom hold doctoral degrees. The faculty includes two Nobel Prize recipients and a Pulitzer Prize-winning playwright.

The research budget for fiscal year 1990 exceeded $272,000,000. This makes the University rank seventh nationally. The 5,200-acre campus is the largest in the nation, and includes a 434-acre high-tech research park. The Offshore Technology Research Center directed by Prof. Jack Flipse is housed in the Texas A&M Research Park. The University operates one of the largest fleets in the nation, with vessels ranging from a 470-foot deep-ocean drilling ship to a converted oceanliner used as a floating classroom. The fleet also includes small craft used for pollution studies along the Texas coast.

International Thrusts

In 1986, the University decided to focus its activities on three areas of the world, Mexico and Latin America, Europe and Pacific Asia. In addition, the decision was made to focus on the following strengths of the University: engineering, agriculture and business.

To support the focus on Pacific Asia, the Board of Regents created the Institute for Pacific Asia. The Institute has both an Internal and External Board of Directors. This allows close coupling to both the academic and international business communities.

The major efforts of IPA have included work leading to the establishment of a branch campus of Texas A&M in Koriyama, Japan, several agreements with Asian educational institutions and the establishment of Mitsui Scholarships in the College of Business Administration and Graduate School of Business.

In early 1990, the international activities of the University were combined and an Assistant Provost for International Programs was appointed. By combining International Student Services, Study Abroad, Institute for Pacific Asia and Mexican and Latin American Programs into one organization located in the organization of the chief academic officer of the University, much better coordination among the international elements and of the academic units represented by the colleges is obtained. This is illustrated in Figure 3 (below).

Current Activities

With the successful opening of the Texas A&M-Koriyama Campus in the spring of 1990, IPA has begun to explore activities involving research projects for the Australian government, multi-

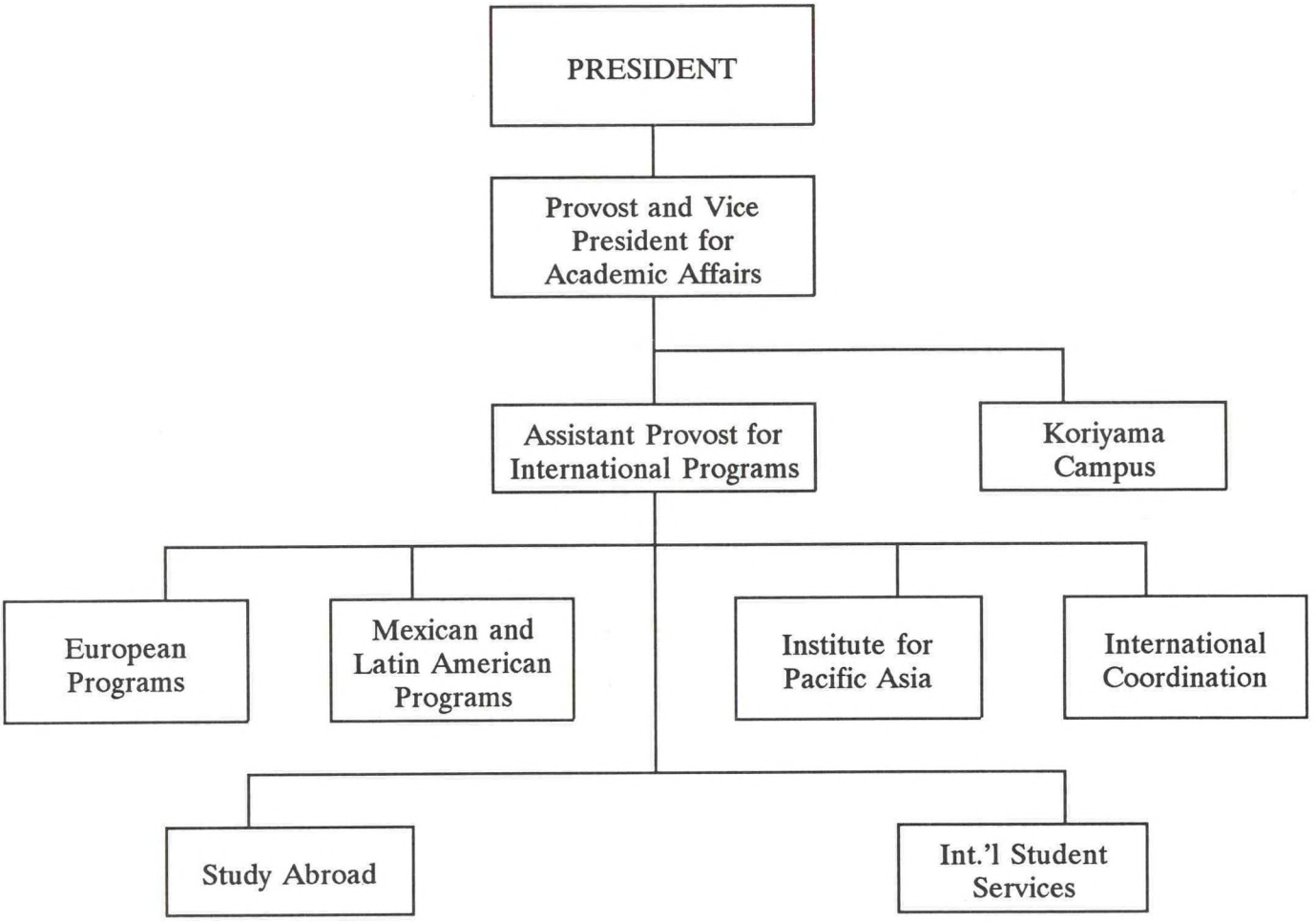


Figure 3

disciplinary projects in agricultural education in the People's Republic of China, expanded University linkages with institutions in the Association of Southeast Asian Nations (ASEAN), and presence in Japan of the Texas Engineering Experiment Station.

Contacts are being made with U.S. subsidiaries of Asian corporations to develop opportunities for research, service and educational cooperation. A program is being pursued with children of Japanese executives in the U.S. to allow them to consider the Koriyama campus for initial study, then finish their degrees at the College Station campus.

Since its inception, IPA has been supported by the University through funds provided by the State of Texas. Efforts are now under way to broaden the support base through grants from U.S. government agencies, as well as through funding by international institutions, including private companies. These funds will allow a much broader range of activities and will provide additional teaching, research and service activities benefitting both the University and the participating Asian institutions.

Future Directions

Working with Texas A&M's Center for International Business Education and Research, the Institute for Pacific Asia is seeking to develop linkages with universities in ASEAN. Funded by the U.S. Agency for International Development, these links will be beneficial to human resource development in ASEAN and will be sustainable over a long period of time. A grant is expected for the first of these efforts in early summer 1991.

A multi-disciplinary training program for agricultural educational and management personnel from Shangxi province of the People's Republic of China is being pursued with the Soil and Crop Sciences Department of the College of Agriculture and Life Sciences including reciprocal visits in mid-1991. Potential World Bank funding is being explored. This program would help improve the infrastructure of the heavily farmed areas of the PRC and would provide research opportunities for Texas A&M.

Exploratory work is in process for a Japanese presence for the Texas Engineering Experiment Station, an agency of the Texas A&M System. This will likely be located in Tsukuba and would involve joint efforts of Texas A&M, Tsukuba University and private industry. The activity will provide opportunities for educational and research interaction among the two Universities, government and private research institutions and private companies. It will broaden the cooperation between Japan and the U.S. and should benefit both countries.

In the marine field, IPA will work with the Geodynamics Research Institute, the Offshore Technology Research Center, additional University entities and institutions in Asia to develop research and service programs. Many of the research centers of the University pursuing activities related to marine interests are shown in Figure 4.

Summary

Texas A&M has achieved a position in the top ten universities in the U.S. in many areas, including total enrollment and research budget. Through formal efforts of the Institute for Pacific Asia, a position of power in Asia will be developed in the next five years. I hope to be able to work with many of you individually and as representatives of your institutions to make this happen.

TEXAS A&M UNIVERSITY
MARINE RELATED INSTITUTES
AND CENTERS

UNIVERSITY

Autonomous Submersible Vehicle Laboratory
Center for Energy and Mineral Resources
Center for Petroleum Reservoir Recovery
Center for Tectonophysics
Department of Oceanography
Geochemical and Environmental Research Center
Geodynamics Research Institute
Institute of Nautical Archaeology
Materials Testing Laboratory
Ocean Drilling Program
Sea Grant College Program
Texas Water Resources Institute

TEXAS ENGINEERING EXPERIMENT STATION

Center for Dredging Studies
Offshore Technology Research Center

Figure 4

SYSTEMS CONSIDERATIONS FOR THE DEEP OCEAN WATER RESOURCE

17th Meeting Marine Facilities Panel
U. S. Japan cooperative Program
in Natural Resources

JOHN P. CRAVEN
President, Common Heritage Corp.
Honolulu, Hi

ABSTRACT

Generic system characteristics are defined for a system dependent on deep ocean water as a resource and designed to demonstrate environmentally sustainable, economically viable, self sufficiency in energy, fuel, fresh water and protein for an oceanic coastal community. The Cape Verde Islands are employed as an illustrative example.

INTRODUCTION

Since 1982 when a 12" deep ocean water pipe was placed in operation at the NELH laboratory at Ke-ahole Point Hawaii, various entrepreneurs have attempted to commercialize a products or services derived from the use of this ocean resource. In each instance 'bottom line profit' was declared to be the motive but the actual behavior of each entrepreneur belied that declaration. Each entrepreneur concentrated his/her efforts on a particular innovation of special interest to them. Little consideration was given to multiple uses of the water in a riparian sense and few of the contractors took a 'systems' approach to deep ocean water as a resource. In spite of these narrow foci, a surprising number of these entrepreneurs have demonstrated economic viability based on their product alone, though burdened with the penalty for amortizing and operating the deep ocean pipe and pump system.

The inability of society to innovate on a systems basis is a generic problem of management which has been overcome in very few instances. The author's good fortune has associated him with some (the Polaris FBM system development, the U. S Navy Deep Submergence System, the National Underwater Research Program, etc). Classical economics was irrelevant for these systems even though "cost effectiveness" measures were rigidly enforced.

Experience has, indeed taught that the effective introduction of innovative systems generally requires the enunciation of a set of objective criteria against which progress can be measured and which will permit potential joint venturers to assess their interest in participating or cooperating in the system development. But it is a characteristic of the human that underlying each set of objective criteria is a subjective human purpose having non-quantifyable economic externalities which, in fact, determine the ultimate acceptability and viability of the system. The early identification of one or more of these societal goals provides the framework on which objective criteria can be built.

THE GENERIC SYSTEM CONCEPT

Although a number of subjective human purposes (military and commercial) have been proposed which require utilization of the deep ocean water resource, this paper will outline the system characteristics associated with the Okamura - Craven challenge. Shortly before he died Kenji Okamura met with John Craven to enlist support in generating the political and fiscal environment for a project which would demonstrate self sufficiency in energy, fuel, fresh water and protein for an oceanic coastal community. The response to this request is a challenge addressed to the ocean development communities of the world. it is based on the assumption that technology has now developed to the point where it is possible that such a community can be built. The challenge calls for each competitor to set forth the specific goals in this regard as they apply to a specific community and the plan and schedule for implementation. A Generic System Concept (GSC) to meet this challenge is based on the assumption that the challenge can be met in Tropical Islands and Tropical Coastal Waters through utilization of Deep Ocean Water as the primary resource. The secondary resource will be solar insolation, Other resources of significance will or could be, wind, rain, salinity and salinity gradients, the pressure of depth etc. Potential candidate that immediately qualify are Okinawa, The Cook Islands, Christmas Island, The Cape Verde Islands, Keahole Point, Taiwan, Bali, Tahiti, Nauru, Okino Torishima, Jamaica, Puerto Rico, Samoa, Bermuda, Western Samoa, Kuaii, Brazil, Mexico, The Maldives. There are many others.

GENERIC SUB-SYSTEMS

In a system of complexity the identification of functional requirements and societal interfaces is the first step in a hierarchal identification process leading to component specification. The second step is sub-system designation. This would appear to be an arbitrary process but is, in fact, the most important "art" in systems development. Sub-divisions should be on the basis of technologies associated with each sub-system development. In general, one engineering team will be involved with each subsystem. No technological unit will have the sophistication to manage qualitatively different technologies.

A second criteria for subsystem development is functional in the sense that "tinker-toy " concepts are employed for the production of systems having very different functional characteristics. Thus a basis for Joint Venture is established, each joint venturer having responsibility for one or more subsystems. The following subsystems are thus identified in the schematic of Figure (1): a) Deep Ocean Water Recovery b) Solar Heat Recovery and Storage c) Water Distribution d) Environmental Adaptation & Waste Disposal e) Electrical Energy Generation f) Transportable Fuel Generation g)Community Power and Automotive Systems h) Mariculture i)Agriculture j) Industrial Cooling and Air Conditioning k) Fresh Water Generation l) Ocean Space Utilization m)Oceanic Transportation.

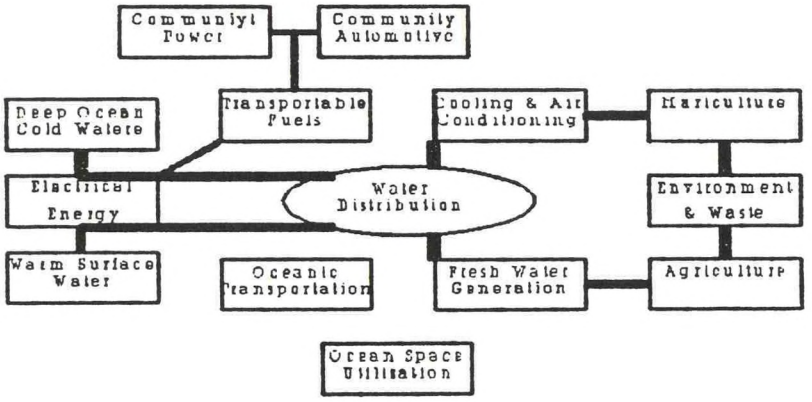


FIG. 1 DEEP OCEAN WATER SUBSYSTEMS

One cannot proceed with the systems process unless it is possible to have a description of subsystems in terms of components which can be built today. This will permit the establishment of envelopes and interfaces within which the subsystem manager must meet his functional requirements. Such boundary conditions permit the subsystem manger to develop solutions which are dramatically different than that postulated but which are functionally equivalent and physically interchangeable. Against these criteria the generic subsystems can now be described.

Deep Ocean Water Recovery

The development of techniques for the transfer of water from the deep ocean to the surface has made significant advance and major new breakthroughs have been designed. Two successful approaches have been employed: the use of positively buoyant polyethylene pipes (40" diameter) deployed in an inverse catenary and vertical (48") deployment from a stable platform. To avoid vapor lock and cavitation the pumps have been submerged at diver

depths. It is clear that pumps located at the deep end of the pipe (say 800 -1000 meters) would be free of cavitation and vacuum problems.

It is also clear that for large diameters (> 8 ft.) in the Marine Development Associates "soft pipe" or cost equivalent will be required. We must conclude therefore that initial and immediate commercial feasibility will obtain through the use of 24 - 30" polyethylene pipes whose pumps are located at the intake end. The pipes should be located at a depth from which the water will be at a temperature in the vicinity of 4^0 Centigrade. Thus immediate commercial viability is associated with systems that consist initially of multiple installations of positively buoyant pipes with high reliability deep ocean pumps. The primary interfaces for this system are at the intake end with the environment. Measures must be taken to insure that major biological organisms are not ingested, that water quality is protected and uniform in terms of temperature, purity and nutrient composition. Ideally the discharge should interface with the water distribution system. An alternative interface would be with the electrical energy generation system. Interface parameters which must be specified and met include water temperature, salinity, nutrient content, pressure, volumetric flow, storage volume, reliability, mean time to failure, mean time for repair, metallic ion content, trace elements, biologics, etc. The technology is such that a single contractor should be able to furnish, install and provide repair and maintenance services for this subsystem. Said contractor should have extensive experience in submarine systems and in particular with submersible pumps and pipes.

Solar Heat Energy Recovery and Storage.

Solar collectors are limited by the low density of solar insolation. Where land costs are high, as in industrialized societies solar collectors are not cost effective as compared with other methods of increasing the heat content of fluids. In special circumstances instances such as the space between runways on an airport, or in a newly developing society land costs will be low. In such instance the solar salt pond has proven most effective in the low cost collection of solar heat. A few locations will be found where geothermal steam 'natural energy' source of heat. Absent these special environmental heat sources reliance must be placed on the warm surface waters. In each case the input interface is environmental and once again the output interface should be with the water distribution system.

The Water Distribution System

The key to cost effectiveness of the entire system is in the water distribution system. Typically the deep ocean water should used at least three times, initially for the generation of electricity. The incoming deep ocean water will be pure, saline,

nutrient rich and cold (ideally 4^0 C.) The water exiting the power plant should be pure, saline, nutrient rich and less cold (generally about 9^0_- C.). Typically the water will then be employed for air conditioning, industrial cooling and Delta T agriculture. The water exiting the cooling systems should be pure, saline, nutrient rich and less cold (generally about 13^0_- C.). This water will, in general, be employed in various forms of mariculture. Water exiting the mariculture systems may be utilized again but should be considered to have entered the "The Waste Water system.

There will be incoming fresh water from some 'municipal water supply system or from the Deep Ocean Water Condensate system It will, in general be fresh water, oligotrophic, aerated, pure and at some ambient temperature. The water distribution system should pass some of this water through heat exchangers to add heat from the warm water system or to induce cold from the cold water system. The available outputs to the various subsystems may therefore include steam, hot water (ideally close to 100^0_- C.) ambient water, and cold water (ideally at the industrial cooling temperature of 9^0_- C., although special circumstances might call for much lower temperatures). In the ideal circumstance this sub-system would include and be integral with the municipal water supply as a public works. It will involve extensive rights of way through the community with parallel networks of insulated pipes. Booster stations which include not only pressure but chilling and heating should be located in the vicinity of each deep ocean pipe (or source of heat). Thus the water delivery system will have output interfaces with most subsystems which are specified in terms of temperature, purity, nutrient content, salinity

Environmental Adaptation and Waste Management System.

Absent a complete balance in subsystem utilization of water there will be substantial quantities of water which will leave each subsystem for return to the environment. In view of the fact that many of these fluids will be discharged in large volumes, at different temperatures, with different nutrient content, bacteriological content, contaminants, etc, the manner of treatment and disposal can range from one which is environmentally and economically beneficial to one which is environmentally destructive and economically burdensome. Depending upon the particular situation this subsystem could include deep ocean return pipes, with diffusers, holding and settling ponds, ponds which sweep up nutrients through algal production, thermal ponds strategically located for microclimate control, various forms of waste water aquaculture, nutrient enrichment of artificial reefs etc. There is a great latitude for local creativity in this subsystem. For example this system can be coupled with disposal of agricultural and human wastes in order to pump carbon into the deep ocean below the photic zone as one measure for reduction of atmospheric CO_2 levels. These risks and benefits make the identification and careful design of this subsystem all the more significant.

Electrical Energy Generation

A number of schemes have been under investigation for electrical energy generation but as of this date there is only one which appears to be commercially viable. That system is the closed cycle system which employs the aluminum heat exchangers developed by Alcan and General Electric of Britain. It is certainly true that alternatives and improvements will be developed but the lead time for these alternatives is at last two years. The size of these closed cycle plants is at the present time primarily limited by the size of OTEC pipes which are presently feasible. They are also limited by the size of the rolls now employed in the roll bonding process for producing the heat exchangers. Immediate feasibility is therefore limited to individual units in the range of from 500 KW to 1 Megawatts with plant sizes employing multiple units being somewhere in the neighborhood of 5 Megawatts. The size required to meet electrical energy requirements for energy self sufficiency for island and coastal communities is, fortunately and immediately in this size range. The output interface for these powerplants is for baseload electricity for pumps and machinery within the immediate vicinity of the generators, or for addition to some sort of power grid. This limitation in range is resolvable through mating with the fuel generation system. Here the primary interface specification is that of the bounds on frequency and voltage level of the electrical output.

Transportable Fuel Generation

Although three fuel generation alternatives are under investigation (methanol, ammonia, and hydrogen) immediate commercial feasibility appears to be limited to ammonia. This is simply because of the ease of modification of gasoline powered equipments to operate on ammonia and because the hydrogen carrier in ammonia is readily available nitrogen. A number of commercial processes are available for electrolysis of water into hydrogen and oxygen and a number of catalytic processes are available for synthesis of ammonia. It is not immediately obvious which process or equipments will be most economical but this is mostly a component review process which requires little if any innovative product development. The output of this subsystem will be of little utility with out modification of the fuel distribution and automotive equipment systems.

Community Power and Automotive Systems

The existence of transportable fuels suggests that the community need not install expensive power grids providing that adequate numbers of motor-generators are available which can burn ammonia. Similarly kits must be provided for modifying the carburation systems of automotive equipments. Initially these modification kits will result in excess amounts of NO_x. The lead time for development of pre-burning separation of the nitrogen and hydrogen is probably in phase with the growth of these systems to the level that the NO_x emissions are significant.

Mariculture

The successful mariculture of a large number of marine species employing deep ocean water has been amply demonstrated. Economic viability has now been demonstrated for a few and is imminent for many others. Since very large volumes of deep ocean water will be available if significant amounts of power are to be generated then the potential for truly large marine protein farms is great. To date the largest successful mariculture ponds are 4 acres in size. The success of these operations suggest that consideration should be given immediately to 1000 acre farms employing atoll lagoons as the location for these semi-artificial ponds. Farms of this size will be required to generate fish in the quantities that justify export over distant waters.

Agriculture

A major result of the research conducted at Ke-ahole was the demonstration that spring crops could be watered from condensate when cold deep ocean water is circulated through pipes shallowly embedded in the ground. The production of plant sugars seems to be related to the use of cold in a manner that is related to thermodynamic processes in the plants which are as yet, poorly understood. The empirical understanding which has been gained suggests that quantity low cost production of mushrooms, strawberries, lettuce, radishes, alpine flowers, and possibly tree ripened fruits is immediately feasible. Where ground costs are large the crops must be produced on a volumetric basis. There has been designed but not yet tested a 'microclimate tower' having a stratified temperature gradient (cold at the bottom warm on top) and a spatial distribution of photons and humidity such that temporal varied microclimates exist is sequential proximity with in the tower. Plants cycled through the tower on a conveyor system will thus undergo diurnal and seasonal variations.

Fresh Water Generation

Fresh water may be generated by condensate systems or more efficiently with high vacuum solar stills. A collateral sub-system could supply fresh water from reverse osmosis driven by deep ocean pressure. Here the deep ocean pipe system has a parallel pipe with a reverse osmotic membrane which will produces a flow of fresh water without the need for a pump.

Ocean Space Utilization

Initially it is expected that installations will be land-based, particularly if aquaculture is a prime subsystem. If the manufacture of fuel is the primary subsystem then the use of stable ocean platforms with vertical pipes may be more cost effective. Depending on the location of these platforms they may be surrounded by various forms of cage mariculture or artificial reefs. A major advantage of these off shore floating platforms

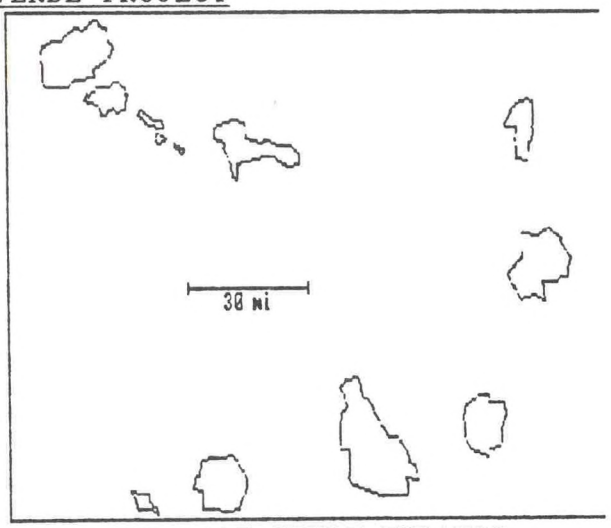
may be that an entire system for fuel generation can be built in one location and deployed or by sea to distant locations.

Oceanic Transportation

The existence of offshore platforms, the export of mariculture product suggests that consideration be given to modern unique forms of oceanic transportation. In particular the swath ship as a basic hull form will meet many interface and system requirements that can not be met with a displacement hull. Indeed the hull for the ocean space platform can be identical with the hull for the swath ship resulting in large reductions in cost from quantity production.

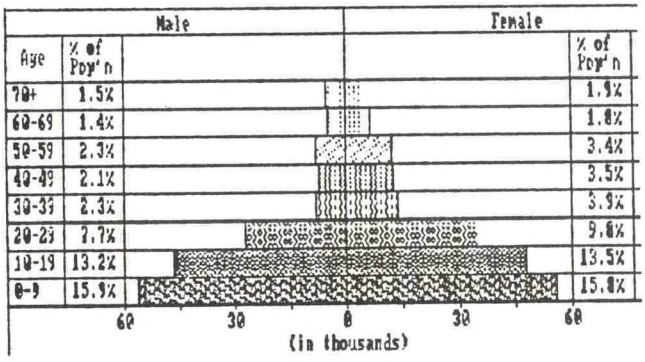
THE CAPE VERDE PROJECT

A review of the tropical ocean reveals the existence of many locales which could benefit from a generic system employing this new resource but only a few locales where this resource appears to be the only mechanism for the avoidance of social catastrophe. One such locale, which appears to be ideal for the demonstration of this concept is the Cape Verde Islands.



THE CAPE VERDE ISLANDS

The Cape Verde Islands are a cluster of sea mount islands located off the West Coast of Africa (approximately 14 degrees North Latitude).



Population Distribution
CAPE VERDE ISLANDS

The climate is similar to that of the Sahara and as a consequence their is a paucity of potable water. The largest island is bigger than Oahu and there are nine other islands which are about the size of Molokai or Lanai and there are five or so islets. Initial examination suggests that the islands are ideally situated with respect to the ocean thermal resource. Surface water temperatures are probably as good or better than Hawaii and deep ocean water is very close to the shores of all of the islands.

The population of the Cape Verde Islands is very young. 76% of the population are under the age of 29, 56% are under the age of 19. The doubling time for the population is 24 years.
Per capita income for the islands is about $400.00 per year and prospects for the future are dim. Except for the deep ocean water, natural resources appear to be very limited. Because of the lack of water there is essentially no tourist activity.

The population is culturally homogenous, ethnically Portuguese-African. The Roman Catholic religion is dominant. There is a healthy democratic society with young and vigorous leadership. This stability augers well for the development process.

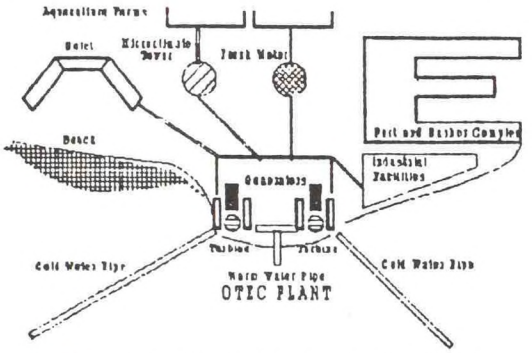
It is therefore proposed that an evolutionary development program for the Cape Verde Islands be initiated employing cold deep ocean water and warm surface waters as the energy resource be initiated.

It is not too early to identify the initial suite of equipments for the project. The initial component should consist of an offshore tension leg platform with two eight foot diameter soft pipes for access to the coldest of water (4^0 C).(Fig 3). The OTEC electrical energy generating plant on the platform will thus be about 3 Megawatts in size. An ammonia generation plant will be located on the platform for the production of ammonia to be stored in bottles for transport to the islands.

Complementary to the offshore plant is a suite of motor generators, automotive vehicles and fuel powered devices which have been modified to operate on ammonia. These will be supplemented by battery powered systems which are recharged by electricity generated by ocean thermal energy. Thus there is no need for a grid except as associated with local networks of motor generator sets or communication devices. Of course lots of rechargeable battery powered small devices will be needed to insure that every aspect of operation in the 'new community' is modern and efficient (although culturally adapted) "high tech". These devices will include satellite receiving and transmission dishes for international communication, networks of personal computers, VCR players and VCR distribution systems vice broadcast Television.

In parallel with off shore plant is construction two 28 inch diameter positively buoyant polyethylene pipes should be located on land. These pipes are primarily for the provision of water for mariculture of cold water of species of plants and animals (algas, seaweeds, salmonids, lobster, shellfish), and for various forms of cooling (air conditioning, industrial cooling, distillation, cold water agriculture of mushrooms, and spring fruits and vegetables). Although not required it would be economic to install an OTEC power plant of about 500 KW in the loop to minimize power consumption by the agricultural, aquacultural, industrial cooling system. Although these figures are far from precise this facility should support the production of between 500,000 and 1,000,000 pounds of high value protein each year.

These developments should be completed in a span of time not greater than two years from the decision to implement the project. The seeming impossibility of this task should be measured against the eighteen months that were required to move from handshake to concept demonstration in the accomplishment of Mini-OTEC. It should be noted that General Electric of Britain and AlCAN now have a production line capable of delivering heat exchangers within nine months of order (These components will probably not have "product guarantees" associated with them since years of testing are required) All other components, including the pipelines, are or were "off the shelf"



CAPE VERDE DEEP OCEAN WATER RECOVERY COMPLEX

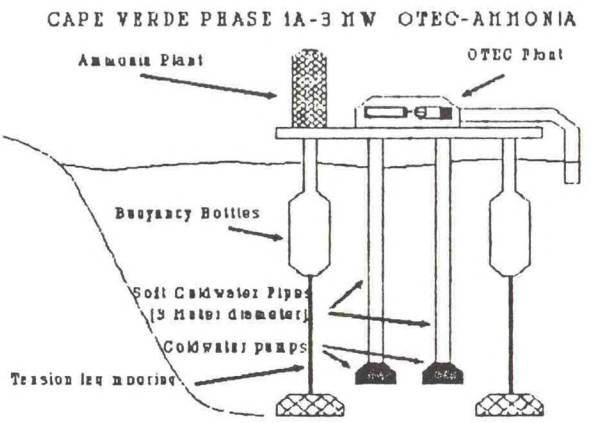


Figure 3. Offshore OTEC Platform

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DEVELOPMENT OF A FLOATING FISHING REEF

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1. ARTIFICIAL CONTINENTAL SHELF

There was a plan of the Artificial Continental Shelf Project.[1] It was to make a photosynthesizing field for production of marine life under the sea surface; that is, to build a 100m wide and 25km long shelf at 10m from the sea surface in the area of 50m depth so as to be used as a seaweed bed (Fig.1).

To realize the plan, an experiment was carried out in 1979 to 1982. A floating structure, artificial seaweed farm plant illustrated in Fig.2, was constructed and biological research was made.

The experiment finished, showing that the formation of the seaweed bed was possible and many fishes swarmed around the cultured seaweed bed. The tested facility itself showed its effectiveness as a floating fishing reef. This experiment was reported in "Experiment of Developing an Artificial Seaweed Farm Plant in the Japan Sea" presented at the UJNR/MFP 14th Meeting in 1986.

Since that time, the plan of the Artificial Continental Shelf Project has been suspended because of the budgetary limitation. Today, however, demands for consolidation and development of fishing grounds in the 200 - nautical - mile waters of Japan are getting stronger and stronger, and the Plan is going to be realized in another form.

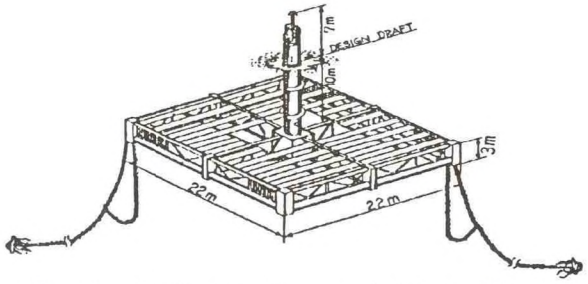

Fig. 2 Artificial Seaweed Farm Plant



Fig. 1 Artificial Continental Shelf

2. FISHING GROUND BY FLOATING FISHING REEF

In 1985, the Fishery Agency, Japan called out to all prefectural governments to make a plan of consolidation and development of fishing grounds, named "MARINOVATION (Marine+Innovation) Plan". In many plans proposed, some were related to the fishing ground by floating fishing reefs.

Fig.3 shows a fishing ground in an offshore field by floating fishing reefs of surface type and subsurface type.[2] This plan, which is based on the Artificial Continental Shelf Plan, aims at creating a spacious shoal by arranging many spots of beds for seaweed and marine life in the field of deep sea where structures are difficult to be constructed so that fishes in migration will inhabit there transiently and the field will become a fishing ground.

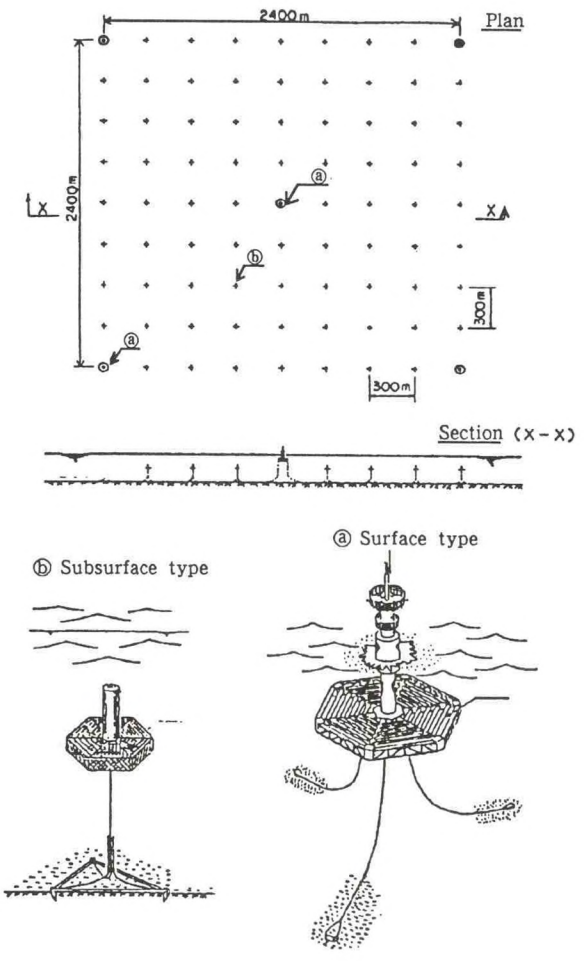

Fig. 3 Offshore Fishing Ground by Floating Fishing Reef

Fig.4 shows a fishing ground in an inshore field by combination of floating fishing reefs and ordinary facilities, which aims at guiding fishes migrating offshore into the field, in addition to multiplying coastal fishes.[2]

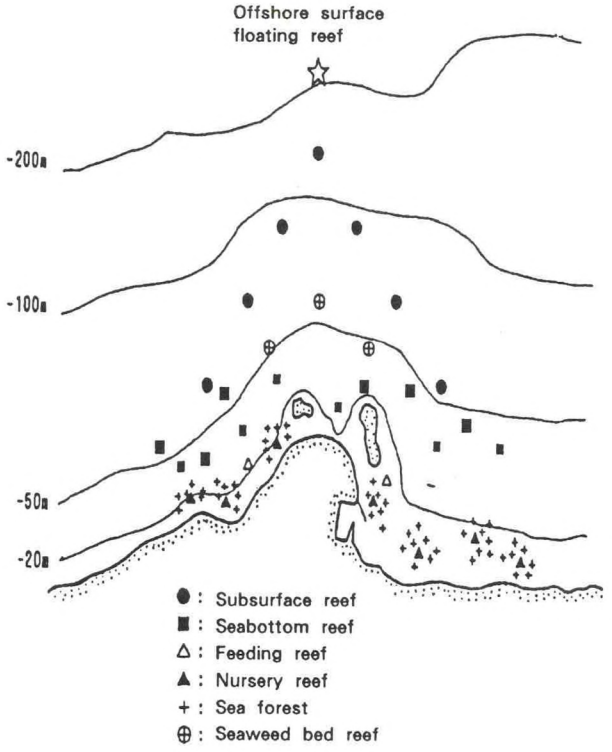

Fig. 4 Inshore Fishing Ground

In Fig.3, the surface type and subsurface type floating fishing reefs are illustrated.

The surface type, which is an improvement of the abovementioned artificial seaweed farm plant, is a fishing ground monitoring station, equipped with echor sounders for fish school and oceanological and meteorological observation apparatuses. Having a bed structure for seaweed, this type is named" Artificial Seaweed Bed Type Surface Floating Fishing Reef".

The subsurface type is set in a middle zone of the water depth so that the sea above the subsurface type reef can be used as a fishing ground without obstacles. Having a bed structure for marine life, it is named "Artificial Seabed Type Subsurface Floating Fishing Reef".

Table 1 Experiment

Condition	Research item	Method	Facility
In current	Current force	Model was fixed in constant current, and drag and moment were measured, changing trim angle.	Circulating water tank
	Static stability	Model was moored by one line in constant current, and induced motion was observed.	
In wave	Dynamic stability	Model was moored by one line in regular wave, and motions were measured.	Seakeeping water tank

For the surface type, an experiment on stability was carried out in a circulating water tank and a seakeeping water tank. For the subsurface type, research on its fish aggregating ability was carried out at sea using actual ones.

3. ARTIFICIAL SEAWEED BED TYPE SURFACE FLOATING FISHING REEF

The artificial seaweed bed type surface floating reef, which had already been proved to have a good effect on fish aggregation, was tank tested to confirm its good stability in the sea, as shown in Table 1.

Fig.5 shows the model used for the test. The model was 1/20 scaled, having a hexagon shelf structure with 66cm sides (16.3m in actual reef). Two kinds of net, 8mm and 4mm wide elements, were prepared for the upper and side surfaces of the shelf to simulate the condition of marine growth; 8mm for thick growing condition and 4mm for half growing condition. The mooring system applied was one point mooring at the shelf center.

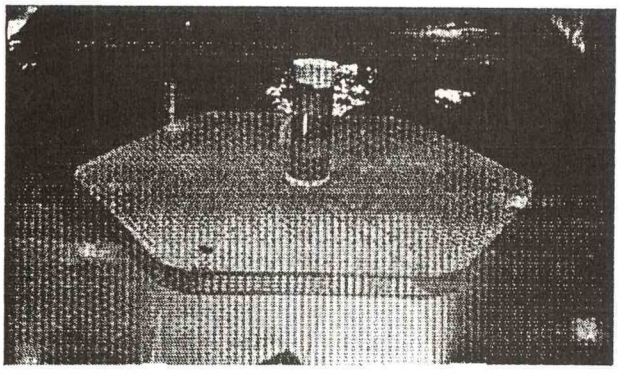

Fig. 5 Model in Current

The test results are outlined below:

① Current force

Fig.6 shows the drag and moment by trim angle. The coefficient of drag is nearly constant, about 1.5, at trim angle $\leqq$ 5 degrees. When the trim angle is positive, the moment works to reduce the trim, which shows occurrence of stability moment.

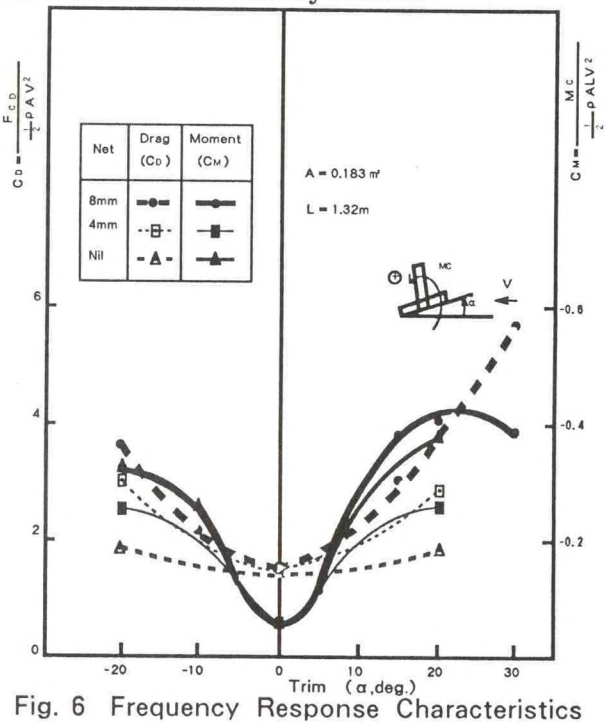

Fig. 6 Frequency Response Characteristics

② Static stability

In the current of less than 3 knots, this floating reef is stable, without generating the selfexcited oscillation. The trim is below 5 degrees (Fig.5).

③ Dynamic stability

Fig.7 shows the frequency response charac - teristics in the one point catenary mooring condition. The dotted lines are for the test results, and the solid line, for the motion amplitude of wave particle at the

same water depth as the shelf depth. From these, the following become clear:

1)Heaving and surging of the reef are the same as the wave particle motion at the shelf depth.

2)Pitching of the reef is small.

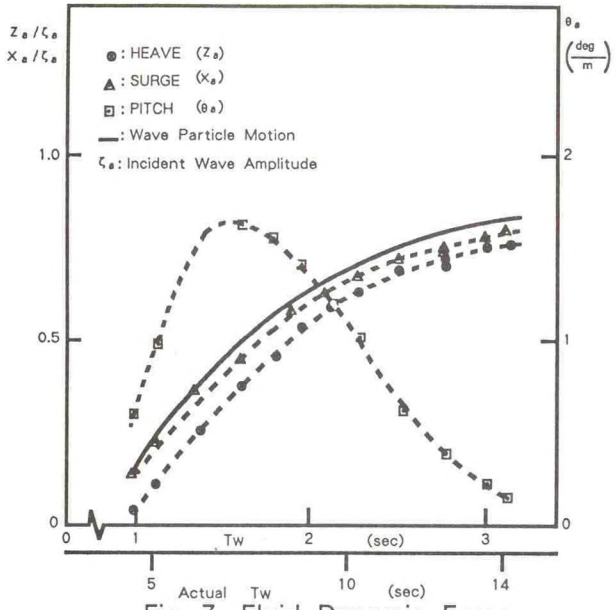

Fig. 7 Fluid Dynamic Force

4. ARTIFICIAL SEABED TYPE SUBSURFACE FLOATING FISHING REEF

The subsurface type was developed so that even when many are set in the fishing ground, they might not interfere with fishing operations. The subsurface type is middle sized or small, while the surface type is large.

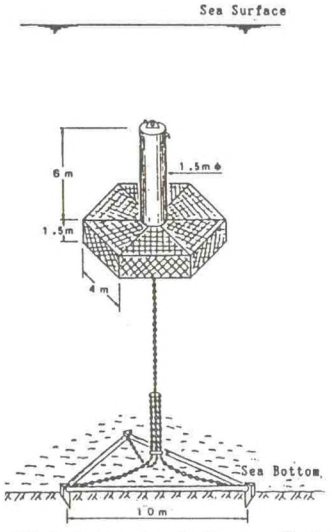

Fig. 8 Artificial Seabed Type Subsurface Floating Fishing Reef

The subsurface type is composed of a steel cylindrical floating tank with 1.5m diameter and 6m height and a shelf (artificial seabed) of steel hexagonal framework with 4m side length and 1.5m height covered with a fishing net for acceleration of marine growth (Fig.8 and Fig.9). For its mooring, a unique one point mooring system is applied. The line is composed of an upper light chain, three lower heavy chains and a triangle anchor (Fig.8 and Fig.10). This system keeps the position of the reef in a strong current, answering a strong demand from many fishermen.

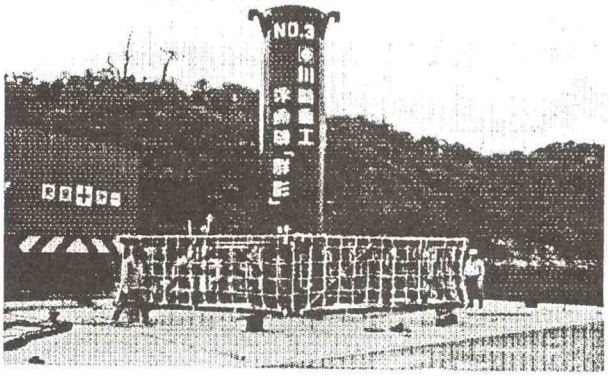

Fig. 9 Subsurface Reef

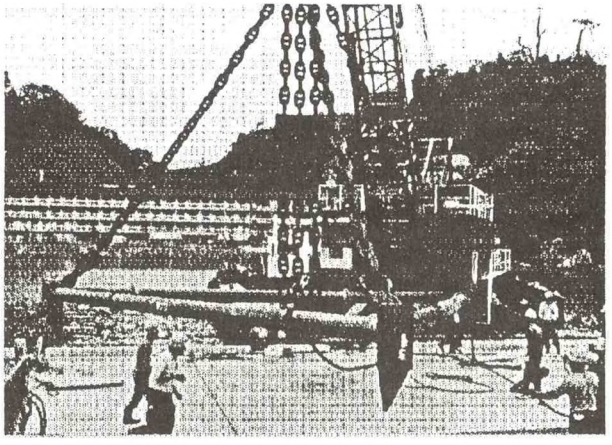

Fig. 10 Anchor

5. FIELD TEST OF SUBSURFACE FLOATING FISHING REEF

To investigate the effect of the subsurface floating fishing reef on the surrounding fishing ground, three such reefs were manufactured and set in May 1987 in the 4.5km offshore area of 80~90m depth in the

Japan Sea off Tajima of Hyogo Prefecture. Fig.11 shows the the test site and Fig.12, the condition of the reefs set down. The three were arranged at 300m spacings in line from shore to offshore, with their top being kept at 50m below the sea surface. The site is a fishing ground of squid, and the depth of 50m is a safety depth in operating the sea anchor (parachute anchor) of a squid fishing boat.

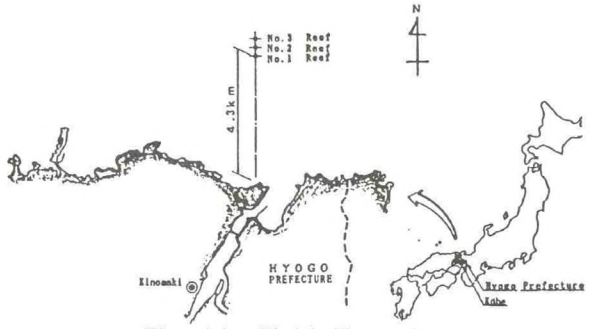

Fig. 11 Field Test Area

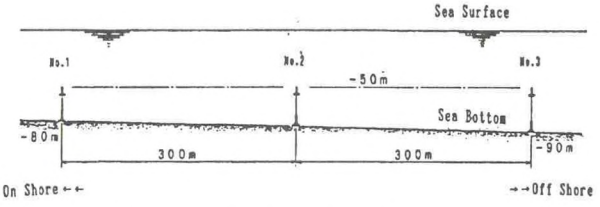

Fig. 12 Setting Condition

The aggregating fish condition was investigated over 3 years, and in May 1990, one of the three reefs was lifted up on a barge and investigated in sessile organisms, corrosion, etc. The whole test was completed with this. The test results are outlined below:

1) Method

The fishing reefs were observed five times mainly using an echo sounder (fish finder) and an ROV (remotely operated vehicle), as shown in Table 2. In addition, the sea water temperature and current velocity were measured, and fish catch was investigated.

In the research by echo sounder, a radial cruising was conducted, with No.2 reef beeing as a center. The east-west sounding line was about 2km and the south-north line was about 3km, as shown in Fig.13. This was

Table 2 Observation Program

No.	Date	ROV Operat.		Echo Sound.	
		No.	Hours	Days	Lines
1	16 – 19 May '88	7	11	3	11
2	17 – 19 Aug.'88	4	7	3	10
3	15 – 19 May '89	5	9	4	16
4	18 – 22 Sep. '89	4	7	4	12
5	21 – 24 May '90	3	3	2	8
	Σ	23	37	16	57

to cover a 1km radius from each reef. Four lines were sounded in one cruise by towing SIMRAD EY - M scientific echo sounder. The ship speed was as slow as about 4 knots to obtain many and clear data, which were recorded by tape recorder.

The ROV was provided with a TV camera and a still camera.

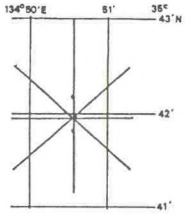

Fig. 13 Cruising Course for Echo Sounding

2) Data by ROV and echo sounder

Photographs by ROV are given in Figs.14 and 15. Fig.14, taken in the first observation, shows a part of the anchor. The flange touches the sea bottom and a gap is found between the pipe and the sea bottom. No scouring is observed. Fig.15, taken in the second observation, shows a part of the shelf. Fish was seen only around the floating reef, and several hundred of *Navodon modestus* were observed. The distribution

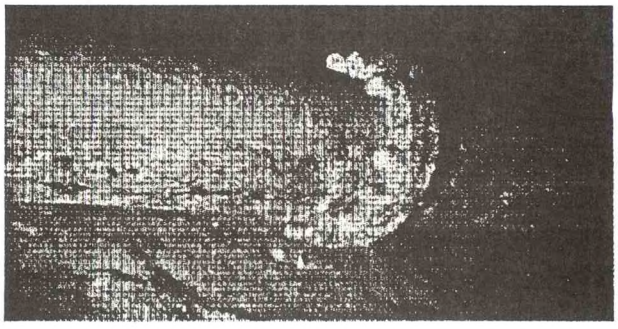

Fig. 14 Anchor

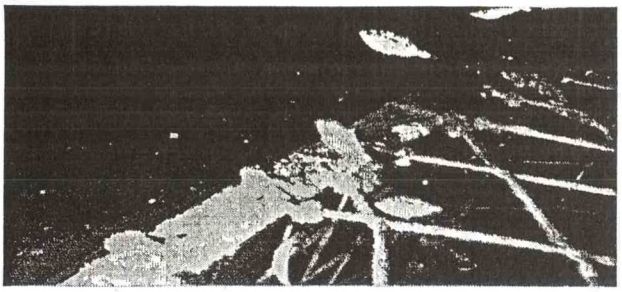

Fig. 15 Shelf

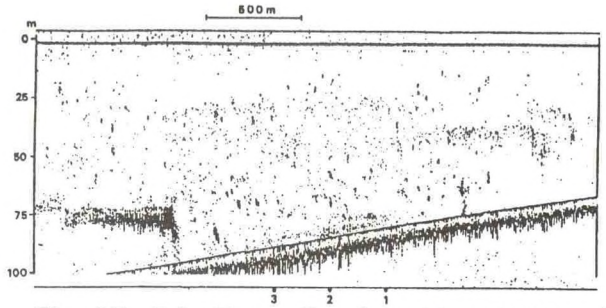

Fig. 16 EchoTrace, Daytime, May 1988

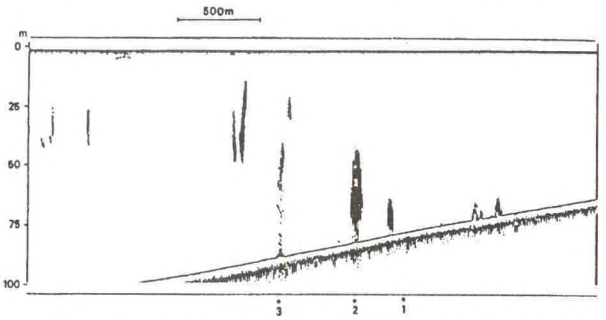

Fig. 17 Echo Trace, Daytime, Sept. 1989

range of this fish was observed in a narrow sphere within 10m from the floating reef.

Figs.16 and 17 show examples of the record by echo sounder. Fig.16 gives the record in the first observation. Nos.1, 2 and 3 in the figure show the location of the three floating fishing reefs. The dense group distribution layer at about 75m depth of offshore water coincides with the thermocline. This group is assumed to be squid. At the bottom layer around No.2 reef, a sparse group was seen staying in 10m thickness and 500m diameter. By the ROV survey of this group, small floating Crustacea was frequently found in suspended solid, and small squid as well. Fig.17 gives the record in the fourth observation. Big fish schools were seen in the surface and middle layers around the floating reefs. These schools are assumed to be young *Trachurus japonicus.*

3) Fish schools around research area

From the cruising research by echo sounder, an outline of the fish school distribution in the area could be known. Characteristics of the fish schools are summarized in Table 3, and schematic diagrams of the fish schools during daytime and nighttime are shown in Fig.18. "A" to "D" in the figure show types of the fish schools in Table 3.

Type "A" is a dense fish school distributed in the bottom layer in the area deeper than 90m (northern part of the research area). In many cases, type "A" was found in sparse type "B". Squid, mainly *Todarodes pacificus*, is assumed to be a species of type "A". This school scattered in the middle and bottom layers during nighttime.

Type "B" is a sparse fish school distributed widely in the middle and bottom layers and in the same deep area as type "A". This school is formed by

Table 3 Types of Fish Schools in Research Area

	Shape of fish school	Distributed area	Species
A	Big and dense	Bottom layer in deep area	Todarodes pacificus, Loligo edulis
B	Wide and Scattering	Whole area, mainly middle or bottom layer in deep area	Crustacea, Squid, Todarodes pacificus, Loligo edulis
C	Small or big school	Middle layer, around floating reef and sunken ship	Trachurus japonicus, Scomber japonicus, Etrumeus teres, Coryphaena hippurus, Othre fishes
D	Small school or solitary	Close to floating reef and sunken ship	Navodon modestus

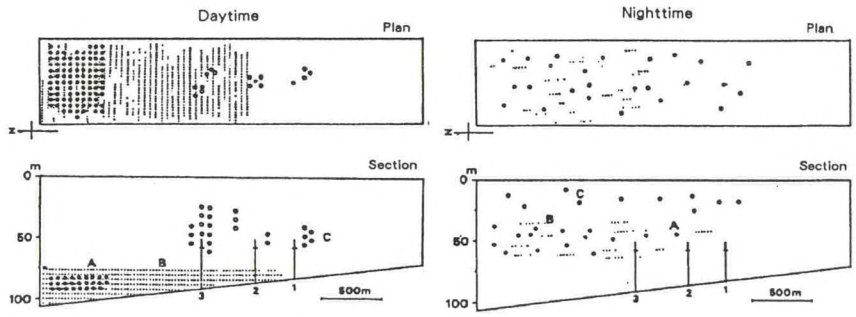

Fig. 18 Fish Schools in Research Area

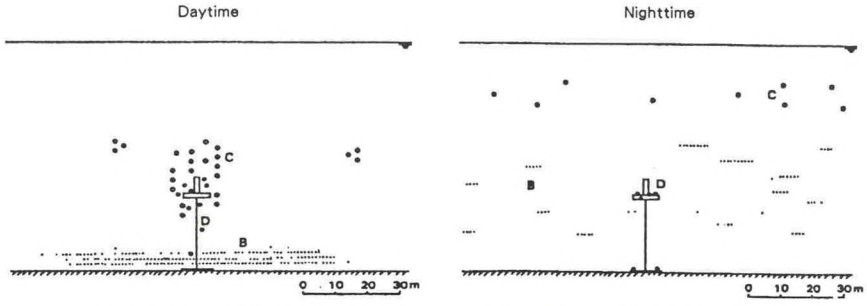

Fig. 19 Fish Schools around Floating Fishing Reef

Etrumeus teres made a short stay and seemed to transit.

Type "D" is a small fish school distributed near the floating reefs. This school was seen to be a solitary in many cases, and the species was *Navodon modestus*. It was considered to stay on the floating reef and/or sea bottom during nighttime, and assumed to inhabit at the floating reefs for a long period.

4) Fishes around floating reefs

The fish school distribution around the floating fishing reefs reflected the fish school condition in the whole research area. It is understood that of the four types mentioned above, "B" to "D" were distributed having something to do with the floating reefs. Table 4 shows the types of fish schools around the floating reefs, and Fig.19, schematic diagrams of the fish distribution during daytime and nighttime.

Todarodes pacificus, Loligo edulis, small Squid and floating small Crustacea mixed in suspended solid.

Type "C" is a fish school distributed in the surface and middle layers. It was seen all over the sea area forming a big school, and in many cases, around the floating reef either in a big school or in a small school. Species of type "C", which changed according to season, are assumed to be migratory fishes such as *Trachurus japonicus, Scomber japonicus, Etrumeus teres, Coryphaena hippurus*, etc. During nighttime, this fish school scattered. As regards the staying period in the research area, *Trachurus japonicus* settling around the floating reefs during daytime was seen staying for several days or more, but *Scomber japonicus* and

Type "B" was sometimes seen to settle in the bottom layer around the floating fishing reefs during daytime (Fig.16). These reefs seam to work on squid to settle transiently.

For type "C", fish schools of *Trachurus japonicus* were sometimes seen only around the floating reefs (Fig.17). It means that all *Trachurus japonicus* aggregated around the reefs. From the observation results, the effective zone of the reefs on *Trachurus*

Table 4 Types of Fish Schools around Floating Fish Reef

	Shape of fish school	Distributed area	Species
B	Wide and scattering	Whole area, mainly bottom layer around floating reef (within 200 − 300m)	Crustacea, Squid
C	Small or big school	Around floating reef (within 200m)	Trachurus japonicus, Coryphaena hippurus, Other fishes
D	Small school or solitary	Close to floating reef (within 5 − 10m)	Navodon modestus

japonicus is judged to be about 1km radius from the reefs. Therefore, by setting many floating fishing reefs at suitable spacings, it is considered possible to make migratory fish settle in the intended sea area for a long period.

5) Sessile organisms and corrosion

At the last stage of the field test, one subsurface floating fishing reef was lifted up on a barge, and sessile organisms and corrosion conditions were surveyed (Fig.20).

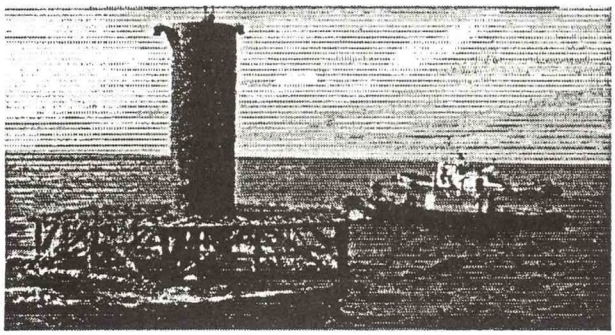

Fig. 20 Lifted up Reef

Table 5 shows the sessile organisms on the floating tank. A lot of *Neopycnodonte musashiana* attached to the top, and the anchor as well, and *Balanus trigonus* and *Salmacina dysteri* attached mainly to the sides. Compared with the sessile organisms on the artificial seaweed farm plant (Fig.2) tested at the same sea area, *Mytilus corsucus* and *Ecklonia kurome* which were main species of the seaweed farm plant, were not observed on the floating reef, while *Neopycnodonte musashiana* and *Saccostrea chemnitzi* were observed only on the floating reef. This is considered to be caused by the difference in water depth where these facilities were set; at 50m depth for the subsurface floating reef and at 10m depth for the seaweed farm plant. On the fishing net covering the shelf structure, a lot of ghost shrimp inhabited, but there were few other organisms.

The outer surface of the floating tank was observed to heavily corroded. The corrosion depth reached about 3mm in some parts. Although no corrosion protection means were provided considering acceleration of attachment of marine life, it seems better to apply some corrosion protection means. The anchor of steel pipe structure corroded little, and the mooring chain corroded partly, but the maximum corrosion depth was about 0.5mm. The chain links on which wire ropes used for installation work 3 years ago were left, had as serious as 3mm deep corrosion partly.

Table 5 Sessile Organisms on Floating Tank

Lo – cat.	Weight (kg/m2)		Sessile Organism	
	In sea	In air		
Top	8	26	Neopycnodonte musashiana	+++
			Balanus trigonus	±
			Balanus roseus	±
			Hydroides ezoensis	±
			Pomatoleios kraussii	±
			Salmacina dysteri	±
			Galathea pusilla	±
Side	1	5	Balanus trigonus	+++
			Balanus roseus	+
			Hydroides ezoensis	+
			Pomatoleios kraussii	±
			Salmacina dysteri	++

Mark	Rate of covering (%)
+++	50 ~
++	10 ~ 50
+	~ 10
±	rare

CONCLUSION

The floating fishing reef is an effective facility to create a new fishing ground. But, going back to the staring point of the idea of Artificial Continental Shelf, it is expected to work also for creating a nursery ground to reproduce fishes.

REFERENCES

[1] Hyogo Prefecture, "Report on the Development of an Artificial Seaweed Farm Plant off Tajima", March 1984.

[2] Hyogo Prefecture, "Repot on the Tajima MARINO – VATION Plan", March 1988.

Offshore Aquaculture Pilot Farm Project

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Ship & Steel Structure Administration and
Business Diversification Hq.
Mitsui Engineering & Shipbuilding Co., Ltd.

With the regulatory zone of two hundred miles now established internationally, coastal fishing in Japan is expected to grow significantly.

Japan's yearly output of cultured marine products including laver and other seaweeds now totals some one million tons, worth ¥500 billion. The raising of yellowtail, sea bream, sole and other varieties is well underway.

Since Japanese aquaculture operations, however, are too densely concentrated in tranquil bays, a number of problems have arisen including the degradation of culture grounds, marine pollution, consumer dissatisfaction with the quality of cultured fish and safety concerns. As a result, aquaculture productivity itself is falling off.

Development of offshore aquaculture is being encouraged to solve these problems. Fish as delicious as those breeding in natural environments can be raised in cleaner offshore waters, winning back the trust of consumers. This could also improve the financial performance of aquaculture and at the same time prevent the pollution of fishing grounds.

Marino-forum 21, the organization established recently to promote research and development of new technology in fisheries in Japan is conducting a feasibility study on offshore aquaculture system.

The offshore aquaculture pilot farms were installed in two places-one offshore Mishoh-machi, Ehime Prefecture and the other in Shiranui Sea, Kumamoto Pref. in Fig 1.

This project was started in 1988 and scheduled to complete in 1990.

Although both of these two systems are designed to handle young yellowtails and sea breams of Southern-Region origin, they differ in designing conditions, with the Kumamoto pilot farm being of a water depth of 40m and a maximum wave height of 5.2m while the Ehime pilot farm of depth of 65m and a maximum wave height of 10m is more of an open sea type than it's Kumamoto counter part.

Considering such differences in designing conditions as mentioned above, the Ehime pilot farm has adopted a tension leg platform(TLP) type constructed by Mitsui Eng. & Shipbuild. Co.,Ltd. and the Kumamoto pilot farm a jack up (JU) type constructed by Hitachi Zosen Co. owing to the shallower water depth and lower wave height.

Both platforms are based on a central service station serving a fleet of floating cages. These constituent units are connected by feed supply hoses and monitor cables. The comparison of both projects is shown in Table 1.

Table 1

OFFSHORE AQUACULTURE PILOT FARM PROJECT

	Ehime Project	Kumamoto Project
Water Depth	65m	40m
Max. Wave Height	10m	5.2m
Max. Wind Velocity	44m/s	38.6m/s
Estimated Fish Production	160 ton/year	300 ton/year
Product	Yellow tail	Yellow tail Sea bream Striped jack
Offshore Station	TLP Type 20mL.x20mB.x21mH Square in Shape	Jack up Type 27mL.x31mB.x3mH Triangular in Shape
Wave-resistant Cages	9,000cub.mx3sets	6,000cub.mx4sets 3,000cub.mx2sets
Feeding System	Automatioc Control, Water Flow Pressure Feeding systems	
Monitoring	Fish Movement Monitoring, Environmental Monitoring, Theft and Cage Net Broken Detection Alarm System	

The yellowtail reared in cages in more exposed sites is really a different and superior product.

Their fish is a better-looking, more natural product with firmer flesh than the same species grown in more congested inshore locations.

The farmers have tried to boost the prices by advertising as a higher-grade product.

1. Ehime Offshore Aquaculture Pilot Farm
(Fig 1, Photo 1)

The flexible rubber cages, 16 metre hexagonal units each enclosing 9000 cubic metres, are moored with ten concrete blocks weighing from 35 to 62 tons each.

Ehime service platfom is a tension leg platform.

Typhoons are frequent in this area, and the water is deep (up to 65 meters). In view of this adverse natural environment, it was decided to use a tension leg platform (TLP). The TLP structure has proved its reliability on oil drilling facilities working in the harsh weather and sea conditions of the North Sea and elsewhere.

It consists of four 4.5 metre diameter columns supporting a superstructure with deckhouse.

Steel cables connect firmly the columns to concrete sinkers, which total 1000 tons in weight. The cables are duplicated for safety, and chafing against the insides of the columns is prevented by special rubber bushing.

The distance from the underside of the platform to the sea surface is 10.7 metres at low water and 8.5 metres at high water. Even the highest waves should therefore pass between the columns.

A small boat landing stage is provided on one of the columns at sea level, and there is a spiral staircase from there giving access to the top of the platform.

The 20 metre square deckhouse includes a control room and mess/meeting room, both of which are air conditioned. Also in the deckhouse there are the feeding room, a generator room, storage space, galley and toilet.

The dry feed pellets are stored in eight silos. Total 20 ton capacity is more than adequate for the three cages currently at the site, and there is plenty of space to add extra silos as more cages are commissioned.

The feed is delivered from each silo to a hopper by a belt conveyor. In the hopper, the pellets are mixed with sea water and conveyed by ejector pump through 4 inch diameter rubber hoses to the individual fish cages nearby.

The feed is delivered to the platform by boat in 500 kg PVC bags. These are hoisted to the storage silos by a crane mounted on top of the deckhouse. The crane has a lifting capacity of 2 tons and a reach of 15 metres.

Supply of the pelleted feed to the fish cages is computer controlled from a main console in the control room. This sophisticated system shows for each cage the type of fish, number of fish, average body weight, average length, total weight, survival rates, etc.

There is another program for feeding procedures which includes the amount of feed held, feed used and quantity left, etc. The program also enables the amount of money spent on feed to date to be calculated.

For the monitoring systems, one of these monitors the activity of the fish in the cages by sonar and underwater video camera.

The sonar system enables the controller to see how the net stands in the water and the behaviour of fish within it.

This information can be used in judging how much to feed the fish.

The video system, which includes an underwater camera in each cage and a camera on the platform looking down on the cages are also supplied. The package includes two monitor screens and camera joystick controls.

A video camera in each cage is suspended from a float.

The other monitoring system keeps a check on environmental conditions such as water temperature, salinity, dissolved oxygen level, wave height, current direction and velocity, wind direction and velocity, air temperature, temperature inside the feed silos, and so on.

The operator can also check the history of water temperatures, wave heights, etc., as well as produce daily or monthly averages, and so on. The data can be presented in a number of ways including tables and graphs, and print-outs can be obtained at the press of a button.

One of last summer's violent typhoon winds blew at up to 40 metres a second. It generated waves up to 10 metres high, but the service platform and the cages took it all in their stride and survived undamaged.

In rough weather, the fish apparently just dive deeper into the 15 metre deep nets out of harm's way.

2. Kumamoto Offshore Aquaculture Pilot Farm (Fig 1, Photo 2)

Six floating fish cages are being evaluated in conjunction with the Kumamoto platform. They include three 20 metre square flexible rubber cages plus two 15 metre square fibreglass cages with rubber connecting links and one 20 metre square steel framed cage.

All the cages at this site are equipped with 15 metre deep nets, giving a volume of 6000 cu. metres each for the 20 metre square cages and 3000 cu. metres for the 15 metre cages.

The Kumamoto service platform is a tripod jack-up rig. It consists of three 2 metre diameter legs supporting a 24 metre wide, triangularshaped superstructure with deckhouse.

Total height of the legs is 66 metres, the lower 10 metres being sunk into the seabed. The distance from the underside of the platform to the sea surface is 9 metres at low water. A landing stage is provided at one of the legs, with steps giving access to the top of the platform.

Like the Ehime platform, the Kumamoto facility features a computer-controlled centralised feeding system. The dry pellets are conveyed by ejector pump through 4 inch rubber hoses to the individual cages.

Similar cage monitoring systems to those on the Ehime platform are also installed. The activity of the fish is monitored by sonar and underwater video cameras, and instruments on environmental condition are also equipped.

One extra feature over the Ehime pilot farm is a radiotelemetry system which enables the monitored data to be transmitted to a land station. An intruder alarm system on the platform is linked to cage-mounted hydrophones which detect engine noise. This system will, if triggered, also transmit the warning ashore.

The system is equipped with a noise frequency analyser which can discriminate between the station's own workboats and other craft.

Planned yearly production is 270 tons of yellowtail and 30 tons of sea bream and striped jack.

Under the last summer's violent typhoon, like the Ehime pilot farm, the Kumamoto facilities took it all in their stride and survived undamaged.

But tidal durrents of over one knot have been recorded and this has necessitated heavy counterweights being attached to the cage nets to prevent them being deformed.

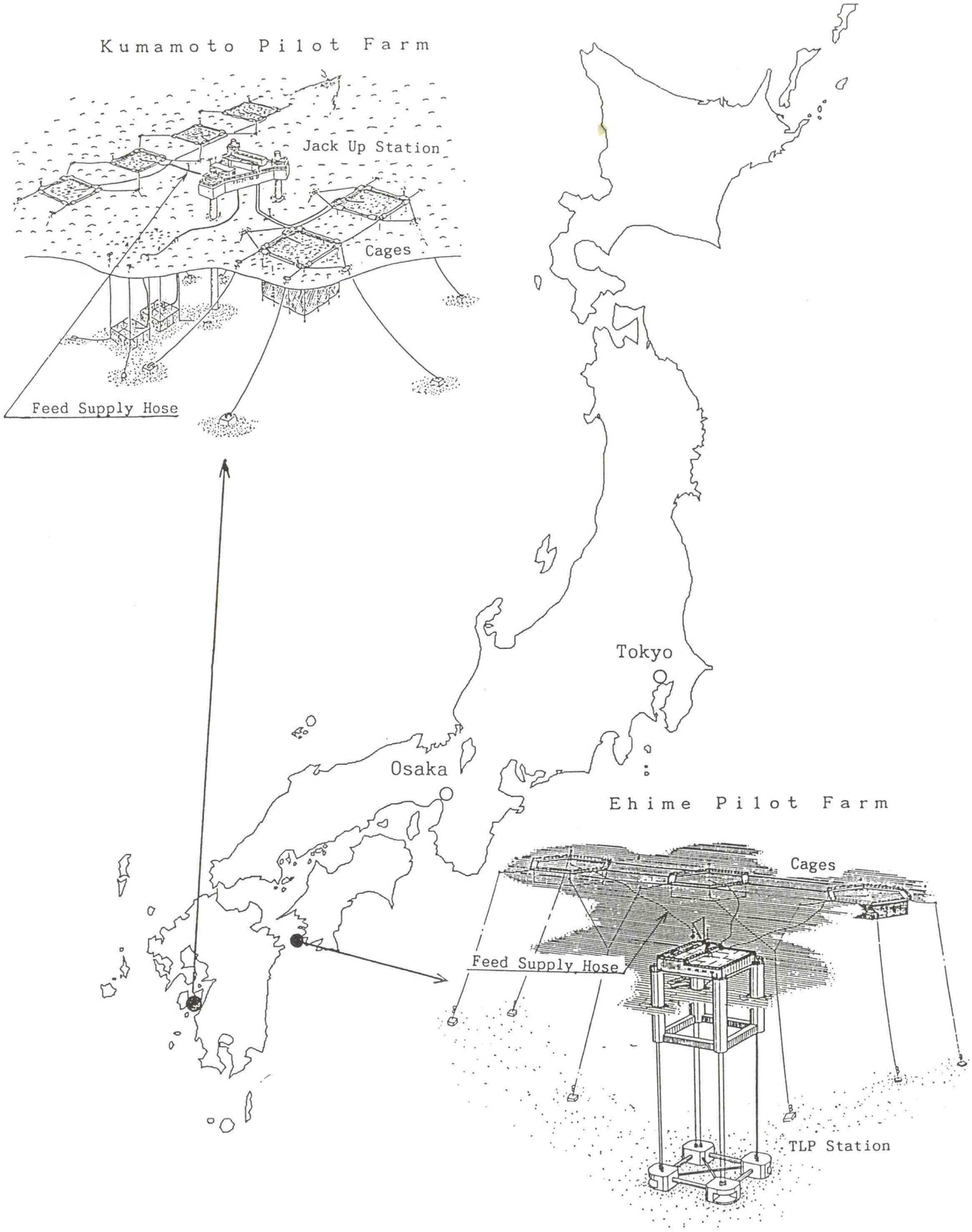
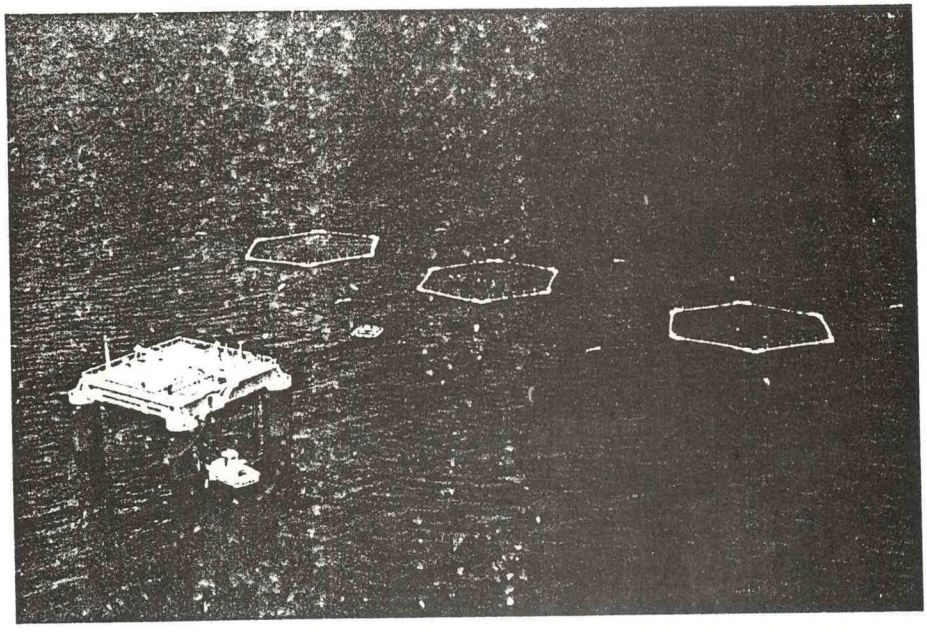


Fig1 View of Offshore Aquaculture Pilot Farm



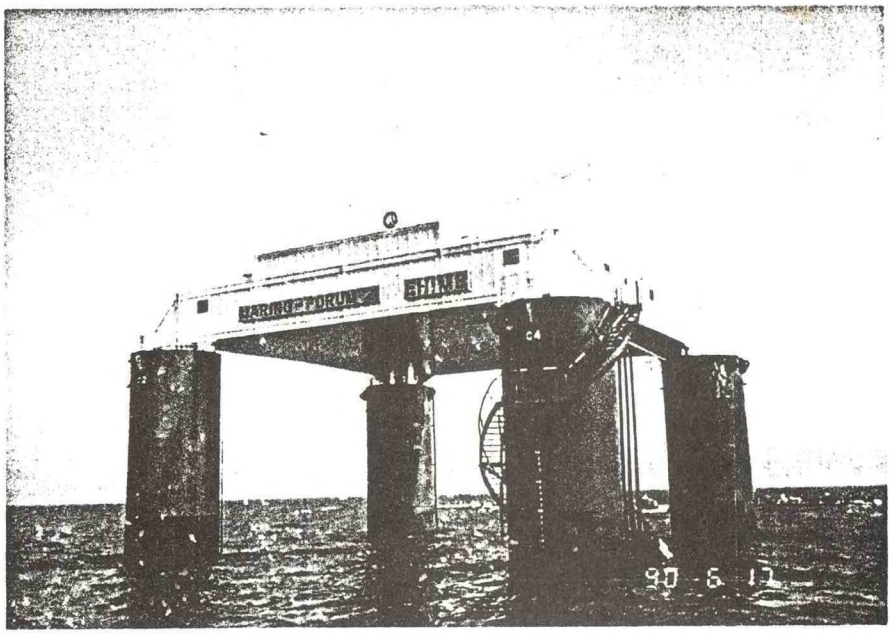
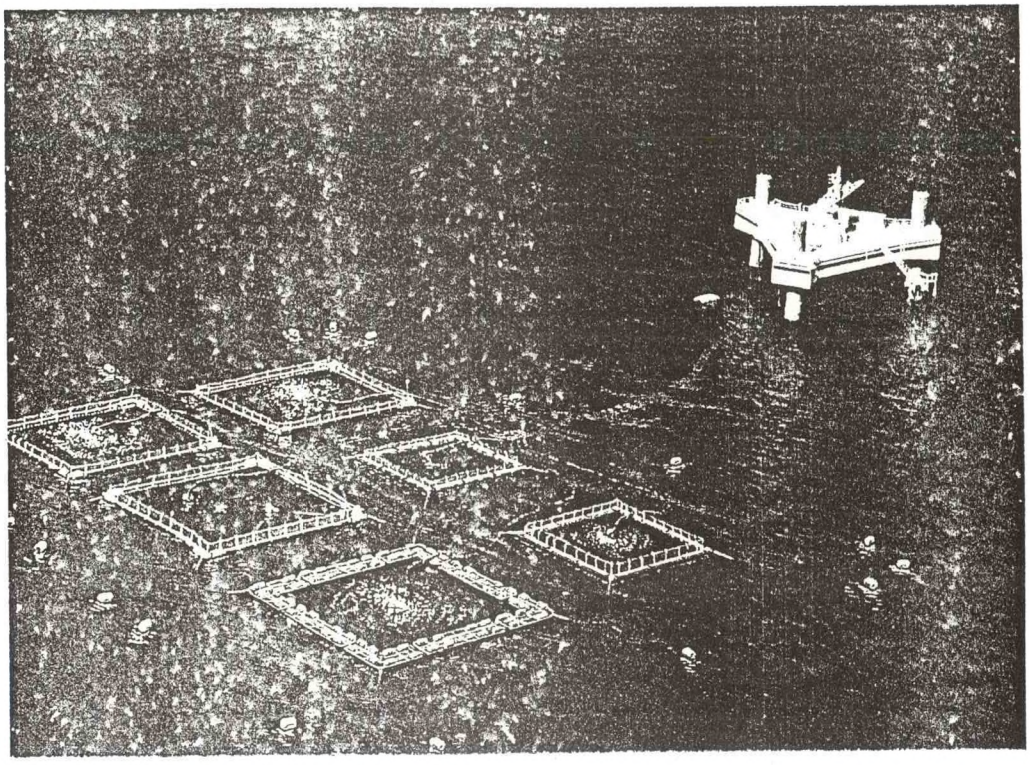


Photo1 Ehime Offshore Aquaculture Pilot Farm



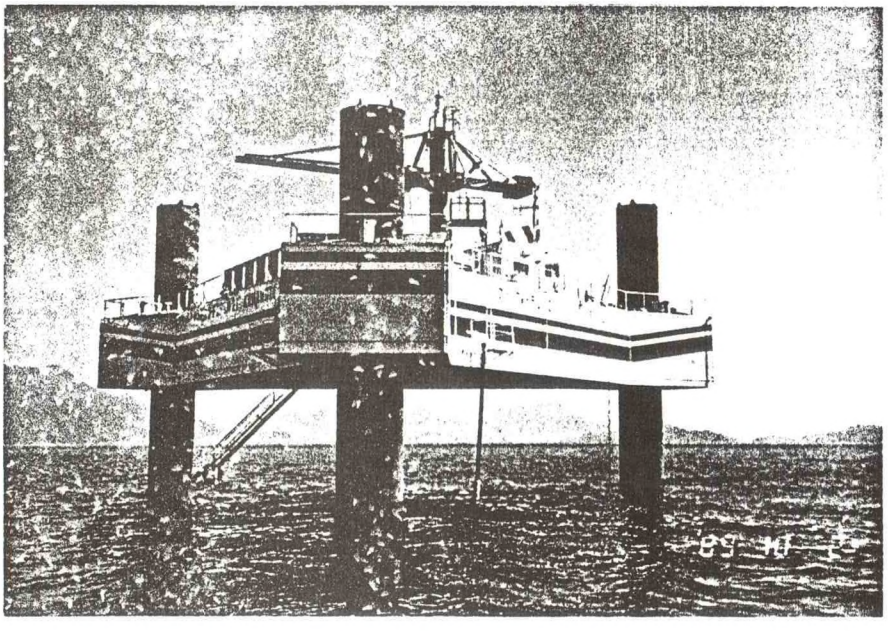


Photo2 Kumamoto Offshore Aquaculture Pilot Farm

CONCEPTUAL DESIGN STUDIES ON MULTI-PURPOSE OTEC APPLICATION

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1. INTRODUCTION

Ocean Thermal Energy Conversion (OTEC) systems utilize the temperature difference between the cold, deep seawater of 500 meters to 800 meters and the sun warmed surface water to generate electricity. Therefore, most of the suitable OTEC locations having a temperature difference of more than 20° C are located in the tropical zone which has many of the developing island nations requiring energy import. Besides producing electricity, the OTEC systems can also be designed to produce fresh water required by many of these countries. In addition the deep seawater pumped-up by the OTEC plant can be effectively utilized for mariculture, because it contains large amounts of nutrient. Because of these unique features, the OTEC development contributes not only to securing clean renewable energy, but also to regional economic growth in developing island nations.

Ocean Thermal Energy Conversion Association (OTECA), Japan was established in February, 1988 as a type of study group of OTEC systems. OTECA is constituted with 25 private companies and one national laboratory (Electrotechnical Laboratory). Member companies of OTECA include electric power companies, electric equipment companies, heavy industries, a steel company, construction companies, research institutes, a bank, trading companies and others. The objective of the Association is to coordinate OTEC activities to promote R & D, project development and plant construction for furthering international cooperation with developing nations. This paper presents an outline of the activities and some of the study results which OTECA has conducted and produced so far.

In Japan the government-sponsored project called "Sunshine Project" started in 1974. Mostly basic research on OTEC technology has been conducted in this program. In the private sector, Tokyo Electric Power Co., Inc. completed a 100 kilowatt closed cycle OTEC plant in the Republic of Nauru which was operated in 1981 for demonstration purposes. In addition, in 1982 Kyushu Electric Power Co., Inc. built a 50 kilowatt closed cycle OTEC plant and tested it for two years. Further in 1985 the University of Saga, Japan completed a 75 kilowatt Thermal Fluid Simulation Plant.

In spite of the above-described extensive efforts and accumulation of OTEC technology, commercial OTEC plants have not been constructed so far, presumably due to lack of economic justification. In recent years, in addition to continued research for enhancement of efficiency of power generating plant, increased research efforts have been made in Japan on how to utilize nutrient-rich deep seawater for mariculture. In 1986 research and development programs in this area were started under the auspices of Science and Technology Agency. One is the ocean-based mariculture-OTEC project in TOYAMA Bay, and the other is the land-based

TOYAMA Bay, and the other is the land-based mariculture project in Kochi. With the foregoing OTEC associated background in Japan, OTECA has conducted the following activities in each fiscal year since 1988, and the outline of the activities and the results in 1988 and 1989 are described in sections 2 & 3, respectively.

F.Yr.1988: Prelimimary studies and trial design of 1000 kilowatt multi-purpose OTEC Plant.

F.Yr.1989: Site survey and conceptual designs of multi-purpose OTEC plant for Christmas Island in the Republic of Kilibati and Viti Levu Island in the Republic of Fiji.

The activities of OTECA are still continuing in F. Yr 1990 as mentioned in the concluding remarks.

2. PRELIMINARY STUDIES AND TRIAL DESIGN

After establishment of OTECA, Japan in February 1988, four working groups were organized in order to study OTEC technology and to work out a trial design of 1000kw multi-purpose OTEC plant. The working groups were composed of the Site Survey WG, the Power Plant WG, the Cold Water Intake WG and the Multi-purpose Utilization WG. The following is the outline of the study conducted in F. Yr. 1988.

Site Selection

In order to select suitable candidate sites for study, the following basic conditions were assumed as selection criteria:

Temperature difference of seawater: 20° C or higher

Minimum temperature of surface seawater: 25° C or higher

Allowable length of cold water intake pipe:2km or shorter

Diplomatic relations:Countries are politically stable and accept foreign aid

Location of sites:Coutries and/or islands in Pacific Ocean and Indian Ocean

Others :Potential for multi-purpose use

On each of 26 candidate sites in 24 countries satisfying the above criteria, the following aspects were investigated by literature search.

Social, economic and energy factors

Oceanographical and meteorological factors

Ground conditions and geological factors

Water quality and environmental factors.

After reaching a judgement on the various factors investigated, 5 locations were tentatively selected as primary candidates for OTEC sites.

These were Republic of Maldives, Republic of Indonesia, Republic of Nauru, Republic of Kilibati and Republic of Tuvalu.

However, an actual site survey for obtaining all of the most recent information was considered to be required for the design studies.

Power Plant System

There are two types with respect to plant arrangement, which are the land type and barge mounted type. For this trial design the land type was adopted to provide independence from severe sea conditions and better working conditions for plant operators.

As to the plant cycle, there are three types of plant cycle: closed cycle, open cycle and hybrid cycle.

Although open and hybrid cycles have many advantages and attractive points in

some aspects such as fresh water generation, theses cycles were considered to require further research and development.

Therefore, the closed cycle was adopted because of reduced technical risk and plant efficiency.

In view of the range of operating temperature, ammonia and R-22 are both suitable as working fluids for the closed cycle OTEC. Ammonia is more favorable in cycle efficiency, while R-22 is easier to work with. Ammonia was selected because of the recent environmental problem with Freon gas.

Based on the ammonia closed cycle, a trial design was made on the following conditions:

Rated output at the generator terminal: 1,000kw

Temperature difference of sea water :20° C

Table 1 shows comparative design evaluation of three differnt cycles, and Figure 1 shows the heat balance of ammonia closed cycle selected for a trial design of 1000kw OTEC plant.

Cold Water Intake System

The construction cost of the intake pipe is one of the most important factors for an economical OTEC project. There are two basicaly different cold water intake systems, which are the pipeline and tunnel systems. Although the tunnel system seems to be more reliable after completion than the pipeline, the tunnel system is estimated to cost approximately twice as much as the pipeline system. Therefore, the pipeline system was adopted for this trial design.

As for the pipeline material following possible materials were considered:

High density polyethylene pipe
Concrete coated steel pipe
FRP hybrid pipe
Rubber hybrid pipe
Concrete hybrid pipe

As a result of studies, high density polyethylene pipe and concrete coated pipe were selected for the pipeline material because of the cost performance and past experiences. The concrete coated pipe is applicable in shallow water primarily because of its stability, and the polyethylene pipe is used for deep sea locations.

For the trial design of the intake pipeline, the floating type pipeline system of the high density polyethylene pipe was chosen because of less dependency on the seabed topography. Trial designs were made for the multipoint-moored floating type pipeline and the reverse catenary floating type pipeline.

The basic design conditions are as follows:

Intake depth for cold water:abt.500m

Cold water intake pipe:1.4m diameter x 2 lines

Warm water intake pipe:1.35m diameter x 2 lines

Allowable temperature increase of cold water:0.5° C

Figure 2 shows one of the selected trial designs of the intake pipeline.

Multi-purpose Utilization System

In order for the OTEC system to contribute to the society of its location, it is essential to obtain maximum utilization of all the products obtained from the OTEC plant, including electricity and pumped-up seawater. These product must benefit the social and economic status and natural environment of the specific site concerned.

As is well-known, deep seawater has three basic features. These are low temperature, rich nutrient and purity.

The candidate applications of the deep seawater are mariculture, agriculture, air

conditioning and low temperature storage.
Fresh water is often required in island nations, and in this study reverse osmosis system was adopted. Possibility of the open cycle and the hybrid cycle which have advantages with respect to fresh water production will be studied further at later stage by the Power Plant WG.

Assuming the Bali Island as a candidate location, a trial design was made on the following conditions:

Electric power available for
multi-purpose utilization : 250kw
Warm Seawater :10,750m3/h, 24.0° C(at the outlet of the heat exchanger)
Cold Seawater :8,760m3/h, 12.8° C(at the outlet of the heat exchanger)

Figure 3 shows the flow diagram of seawater utilization and Table 2 shows expected production plan of mariculture.
In this design, an Ocean Research & Training Center was incorporated to facilitate future technology transfer to the local people. Air conditioning of this Center is made using cold deep seawater.

Based on the trial design, a rough economic evaluation was made. Although this OTEC plant is not fully econmical, the economic impact of utilizing cooling energy as well as mariculture was found to be substantial.

Figure 4 shows OTEC system potential to contribute economic development of the regional local society.

Since the conceptual design of multi-purpose utilization depends largely upon the site condition, an actual site survey was recommended for practical planning.

3. SITE SURVEY AND CONCEPTUAL DESIGN OF MULTI-PURPOSE OTEC APPLICATIONS

In 1989, five candidate sites for OTEC plants were selected and survey teams were dispatched to these places.

Selected sites were Bali and Lombok in the Republic of Indonesia, Viti Levu in the Republic of Fiji, Christmas Island in the Republic of Kilibati and Pohnpei Island in the Federated States of Micronesia.
Past research and these site survey results regarding the islands' geographical conditions, possibility of large-scale tourism development and other factors led us to choose Viti Levu and Christmas Island as representative models for OTEC applications as proposed below.

Christmas Island

Christmas Island has limited access at present because there is only one airline flight a week from Hawaii.

Partly because of this, the island cannot be regarded for the time being as an appropriate site for large-scale tourist developmement. Nor is fishery conceivable as a business operation because of market limitations and the limited number of people involved. Therefore, this island did not seem to be a proper site to realize economically feasible multi-purpose OTEC systems in relatively short term.

However, Christmas Island is the world's largest coral island and it contains a great number of large and small lagoons. Further, it is located in the southern equatorial current in the East Pacific and is uniquely suited for basic/applied research on oceanography in tropical regions. It offers a perfect natural setting for basic research on deep seawater and its application, which is now commanding worldwide attention and is badly needed in a long term basis for expanding possibilities of multi-purpose OTEC applications. We have, therefore, studied the possibility of an OTEC project, leaving aside the question of profitability and searching instead for vision of what can be done here if official

funds, etc. can be invested. As a result, an International OTEC Center for Oceanographic Research was planned, with a large emphasis on deep seawater research and its application.

To facilitate large-scale utilization of the lagoon, the institute will be located east of Poland Village, on the southwest of the island. (See Figure 5.)

A closed cycle,land based OTEC power plant with gross power output of 1,000kw and net power output of 500kw is tentatively planned.

The seawater intake pipeline and the flowrate is as follows.

Deep seawater intake depth:Tetative design depth 600m
Overall length of deep seawater intake pipelines:1,310m
Number of intake pipelines:2
Seawater temp. difference : 20.5° C
Seawater intake flow rate:Deep seawater 9,000t/h
Surface seawater 11,000t/h

Figure 6. shows the Organization & Research subjects of the institute proposed.

The institute will contribute to the development of the economic well-being of surrounding island nations, as well as science, through the results obtained from deep seawater research.

Viti Levu Island

The OTEC concept on Viti Levu Island was prepared as another model to study the multi-purpose OTEC application incorporating fish farming and cooling energy supplied by deep seawater from the OTEC system. A research center is also included in this model. Korolevu Bay on the Coral Coast was selected as the candidate site for the OTEC plant.
(See Figure 7)

The 1000kw closed cycle OTEC plant was arranged with the following features.

Deep seawater intake depth:Tetative design depth 600m
Overall length of deep seawater intake pipelines:2,200m
Number of intake pipelines: 2
Seawater temp. difference : 20.9° C
Seawater intake flow rate : Deep seawater 8,860t/h
Surface seawater 10,410t/h

For multi-purpose application of OTEC the following basic concept was adopted.

(1)The cold seawater obtained from the OTEC plant will be used to serve as air-conditioning energy for nearby hotels and vegetable and mushroom cultivation. This could expand tourism revenues, promote vegetable self-sufficiency and increase empoyment in the Republic of Fiji.

(2)The cold seawater is rich in nutrients. After serving as a source of cooling energy, it can be appropriately mixed with the warm seawater from the same plant and utilized in larva and juvenile production, pond aquaculture and coastal aquaculture.
This will be aimed at increasing revenues from inshore fishery through the release of the larva and juvenile in coastal waters, and at promoting marine culture in both the coastal waters and the neighboring areas.

(3)The research center on deep seawater application including mariculture will transfer the related technology to Fiji and other island nations.
Based on this concept, the multi-purpose OTEC plant system was worked out as shown in Figure 8 and Figure 9.

In addition to the direct economic effects, the application of OTEC technology on Viti Levu Island can be expected to have various indirect advantages, as follows.

(1)The multipurpose plant will make possible the employment of about 1,000 local

persons, thus adding to increased employment.

(2)It is possible to encourage the construction of hotel buildings which can be operated at higher profitability due to cooling water supply from the OTEC plant. The hotels could attract additional tourist revenue and foreign currency.

(3)Fish farming projects should also benefit. There should be an increase in fishery revenue by expanding coastal resources through larva and juvenile release. This should foster the fish farming industry and popularize fish farming technology.

(4)Vegetable and mushroom cultivation should be enhanced with an accompanying increase in food self-sufficiency.

(5)There should be on improvement in the local technological level of knowledge through technology transfer.

4. CONCLUDING REMARKS

This paper has discussed the activities and some of the study results of OTECA, Japan during the fiscal years 1988 and 1989. Based on these results further research activities are currently being conducted as part of F. Yr. 1990 program. The principal conclusions and current research activities are summarized below.

(1)As a result of the trial design studies, the technical feasibility of 1000kw closed cycle OTEC plant has been confirmed and further research items have been identified. The research efforts to be conducted during the fiscal year 1990 include further design optimization of the closed cycle OTEC plant, the study of an open cycle OTEC , and motion simulation of the cold water intake pipe during installation.

(2)Multi-purpose utilization of OTEC systems were studied both in a general way and by example cases. It was confirmed that multi-purpose utilization provides the potential to enhance the total economy of OTEC systems and to contribute to regional development.

Fig.10 shows an expanded multi-purpose OTEC concept including future potential utilization of deep seawater which will require further long range research.

In order to investigate the potential of this area during F. Yr. 1990, a brief study on the increase of productivity of marine life by discharging nutrient-rich deep seawater to coastal areas, and also a general survey of the current status on possibilities to extract new materials by using deep seawater is being conducted.

(3)The total cost of the multi-purpose OTEC systems plant of the trial design in F. Yr. 1988 was estimated to be approximately 10 billion Yen. Preliminary economic analysis indicated that this plant was not economically feasible, even after taking the benefit of multi-purpose utilization into account. Of course, the extent of economic improvement in heavily dependent on the conditions of the specific sites and cost factors, and further efforts are required to maximize economic benefits of OTEC systems.

Quite aside from the near term economic impact of OTEC systems, the technology is expected to contribute to mankind in providing clean energy and enhancing livelihood and quality of life of developing nations. It is probable that official government funding will be required for implementation of OTEC technology.

(4)After analysis of various factors a selection of candidate sites for OTEC plants was made. The first round of site surveys was made in 1989. Visits were made to four islands in the Pacific Ocean. Two islands, Christmas Island in the Republic of kilibati and Viti Levu in the Republic of Fiji were revisited for further survey in the 1990. Other site possibilities are still under

investigation in the 1990 program.

(5)The International OTEC Center for Oceanogrphic Research was planned for Christmas Island with the long range view to promote OTEC. For Viti Levu Island, which has many favorable features as an OTEC installation, a multipurpose OTEC application was designed for the maximum utilization of OTEC potential.

In 1988 OTECA sent a delegation to Hawaii to visit PICHTR and NELH, and the author, on behalf of OTECA, Japan, wishes to thank these institutions for valuable exchanges of information. The author, as one of the members of the steering committe of OTECA, also wishes to thank all the members of OTECA for their extensive works which form the basis of this paper.

(Basic conditions)

Gross power output	1000 kw
Temperature difference of seawater	20.0C

(Assumed conditions)

Seawater temp. at Evaporater inlet	28.0C
Seawater temp. at Evaporater outlet	24.0C
Seawater temp. at Condensor inlet	8.0C
Seawater temp. at Condensor outlet	12.8C
Turbine efficiency for closed cycle turbine	82.0%
Turbine efficiency for open cycle turbine	75.0%
Gear loss for ammonia turbine	3.0%
Generator efficiency	94.0%
Inverter system efficiency for open cycle	94.0%
Seawater pump efficiency	74.0%
Working fluid pump efficiency	65.0%
Seawater velocity in intake pipe	0.8m/s

case	A	B	C
cycle	NH_3-Closed Cycle	R22-Closed Cycle	Open Cycle
Evaporating Temp.(°C)	22.8	22.8	22
Condensing Temp.(°C)	14.2	14.2	14
Warm Water Flow Rate (m^3/h)	10,750	10,750	12,400
Cold Water Flow Rate (m^3/h)	8,760	8,760	9,900
CWP Dia.(m)	1.4	1.4	1.5
No. of CWP	2	2	2
Turbine Type	Radial/Geared	Radial/Directly Connected	Axial/Directly Connected
Rotar Size (m)	0.6	1.0	3.0
Heat Exchanger Type	Shell/Plate	Shell/Plate	Shell-Plate
Heat Transfer area (m^2)			
Evaporator	6,250	6,970	-
Condenser	6,150	11,700	7,500
Pump (kW)			
Cold Seawater	225	209	235
Warm Seawater	207	199	230
Working fluid	38	119	12
Vacuum Compressor	-	-	156
Net Power Output(kW)	530	473	307

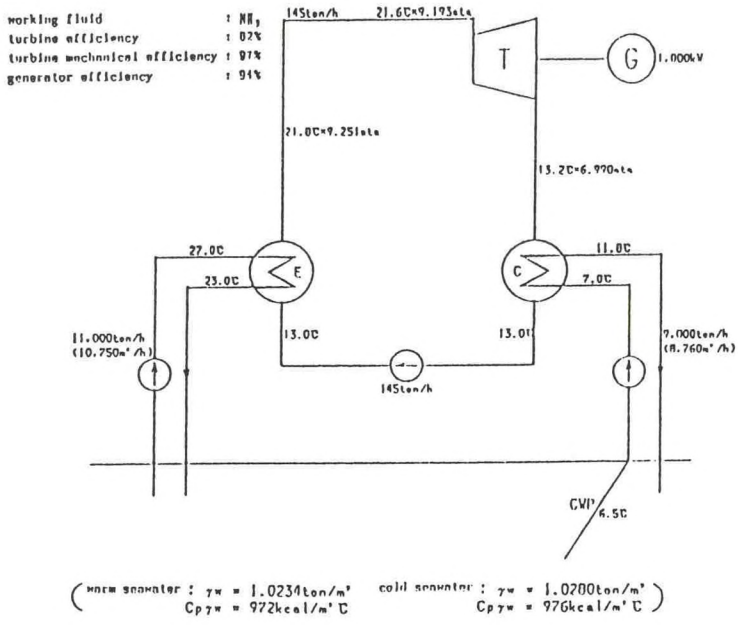


Figure 1 Heat Balance

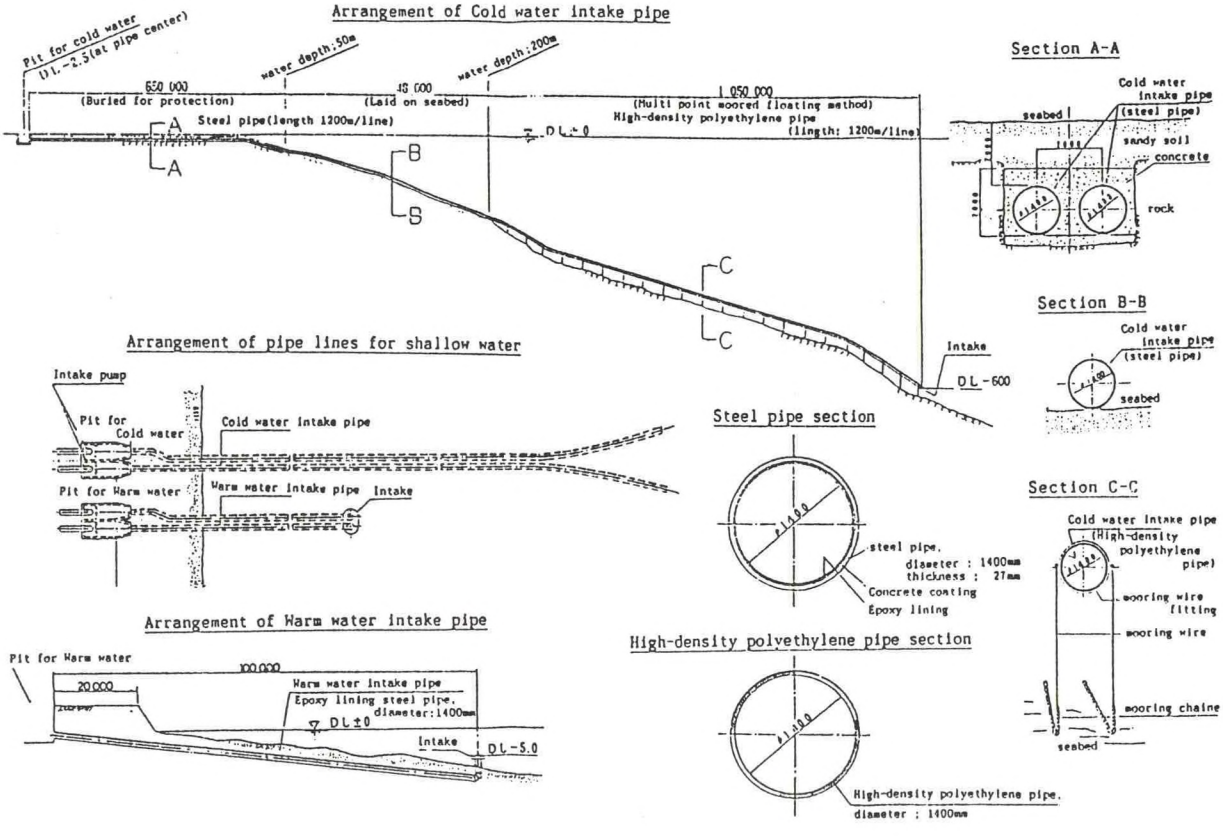


Figure 2 Pipeline Arrangements

Table 2 Mariculture Production Plan

DEPT.	SPECIES	ANNUAL RODUCTION	AREA	PRODUCTIVITY	WATER
Commercial Farming	• Jumbo Tiger Prawn	31.5T × 2= 63T	30ha	1.05T/ha • Time	
	• Milk Fish	48.0T × 2= 96T		1.60T/ha • Time	
	Total	79.5T × 2=159T			
Juvenile Culture	• Milk Fish	700,000 ×2 =1,400,000	8ha	350,000/ha • Time	
Pilot Culture	• Sea Bass	32.4T	7.2ha	4.50T/ha	Deep s.w. Surface s.w.
	• Brown-Spoted Grouper	1.8T	0.4ha	4.50T/ha	
	• Pearl-Spoted Rabbitfish	1.8T	0.4ha	4.50T/ha	
	• Flatfish	50.0T	0.9ha	10kg/ ㎡	Deep s.w.
Larval Rearing	• Jumbo Tiger Prawn	12,000,000			
	• Sea Bass	10,000,000			Deep s.w. Surface s.w. Fresh Water
Rearing Experiments	• Brown-Spoted Grouper • Pearl-Spoted Rabbitfish • Milk Fish	N.A.			
Agriculture Usage	• Highland Crops	N.A.	100㎡		Deep s.w.

Figure 3 Seawater Utilization Plan

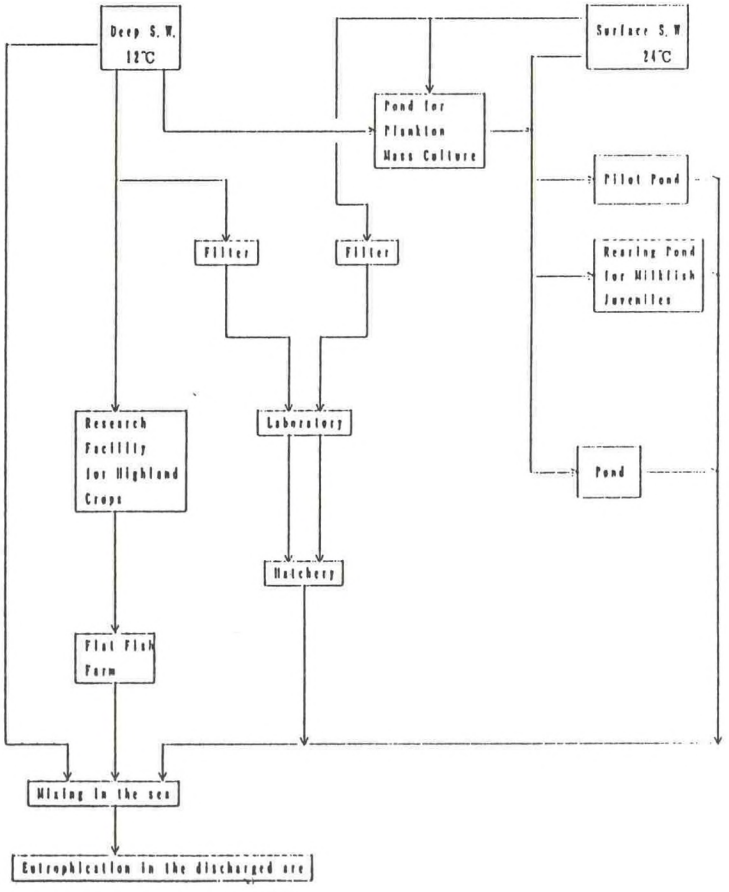
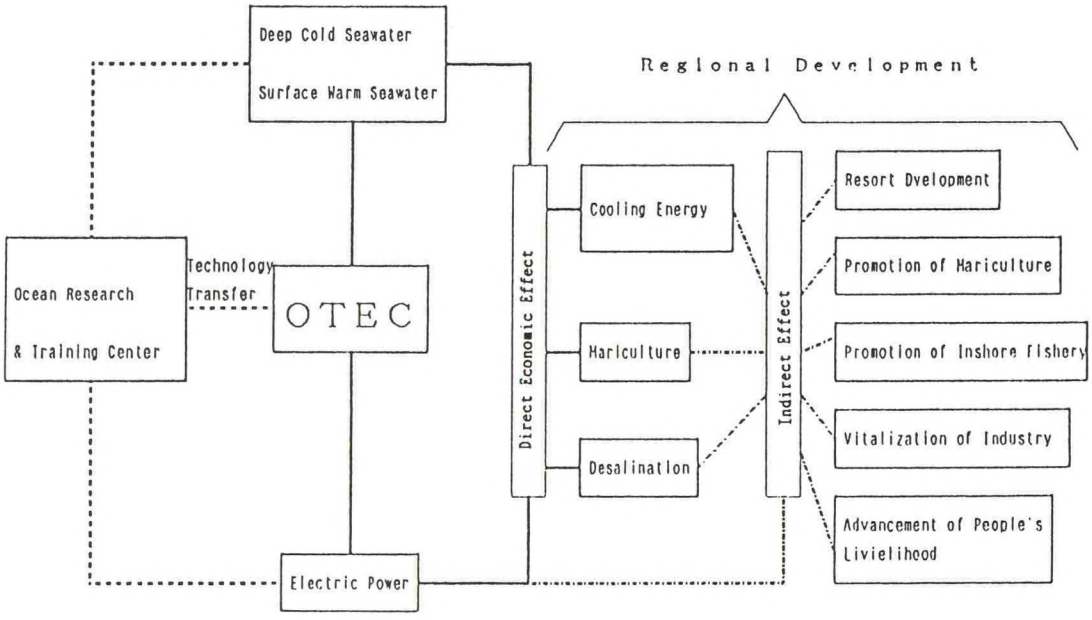


Figure 4 OTEC System Potential



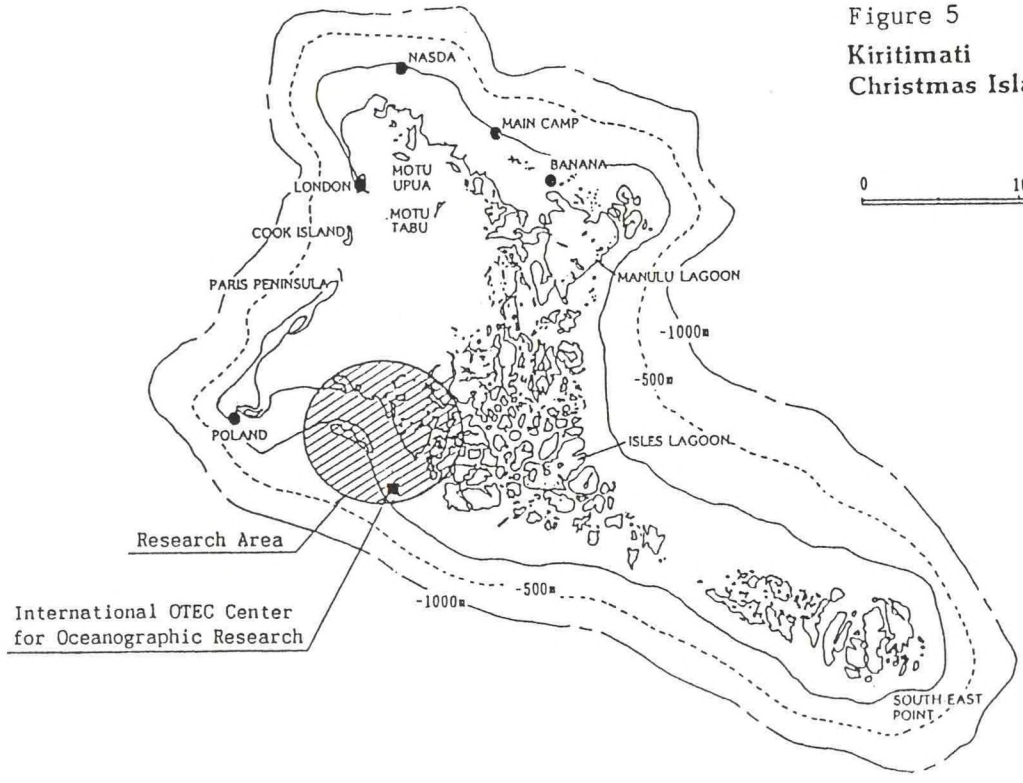
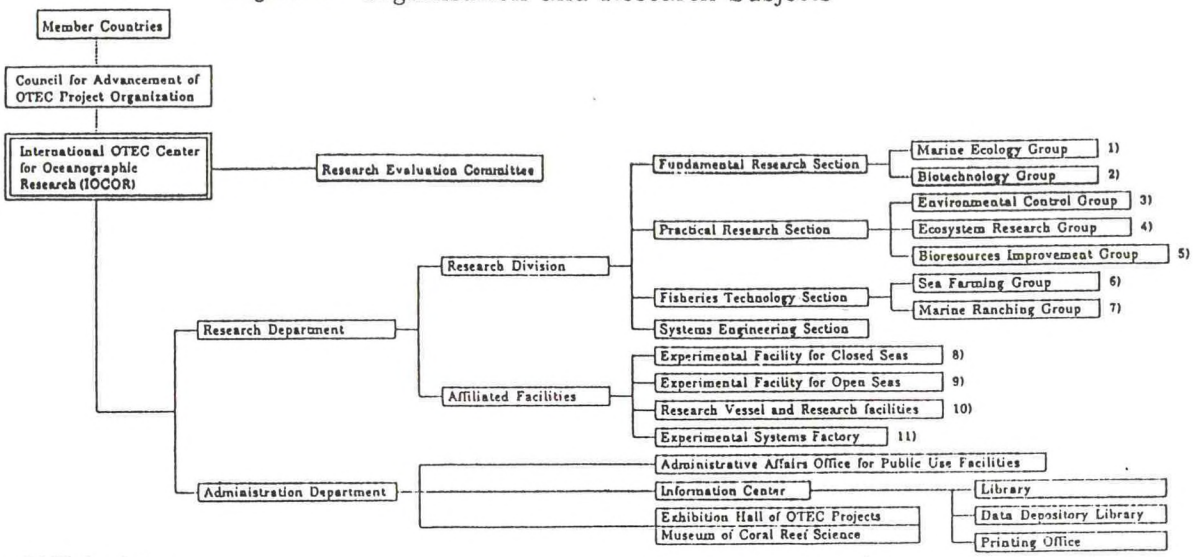


Figure 5
Kiritimati
Christmas Island

0 10 20 km

Figure 6 Organization and Research Subjects



<Brief Explanation>

1) Fundamental research for physical, chemical and biological oceanography in coral reef areas and surrounding waters
2) Fundamental research for production of useful materials by molecular biology, gene engineering and cellular engineering
3) Studies of environmental control at perimeters of coral reefs and lagoons
4) Research of coral reef ecosystem
5) Exploitation of coral reef productivity and development, increasing environmental control techniques
6) Selection of suitable species for sea farming fishery, in coral reef areas, and culture technology of fry and food organisms
7) Exploitation research for culture of biological resources in offing of coral reefs and lagoons
8) Indoor aquariums, outdoor experimental ponds, experimental lagoons, control systems management
9) Experimental and control facilities for marine ranching
10) Research vessel and research facilities management
11) Workshop for experimental structure and systems maintenance

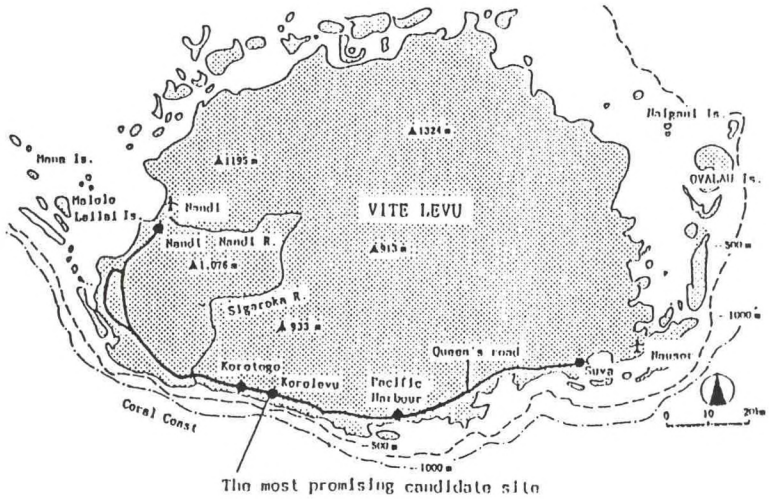


Figure 7 Viti Levu Island

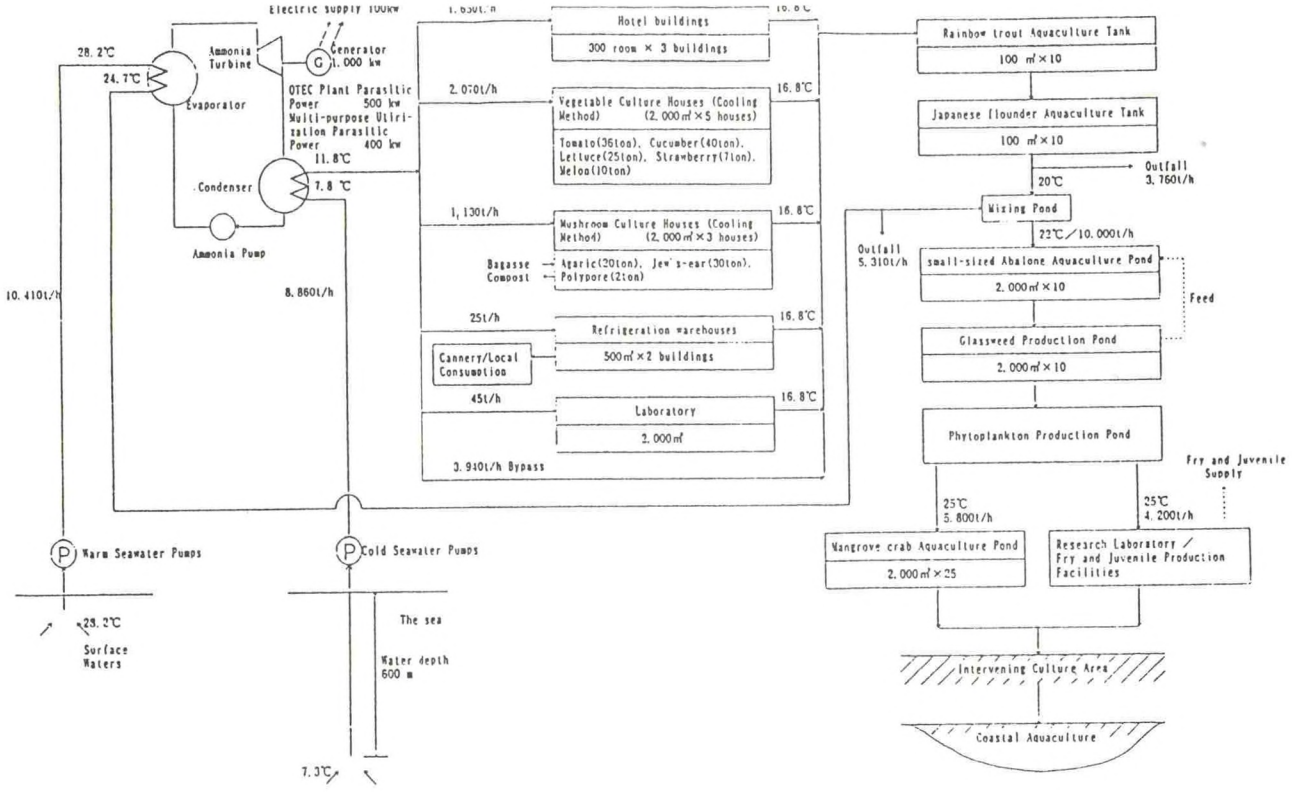


Figure 8 Plant System Diagram

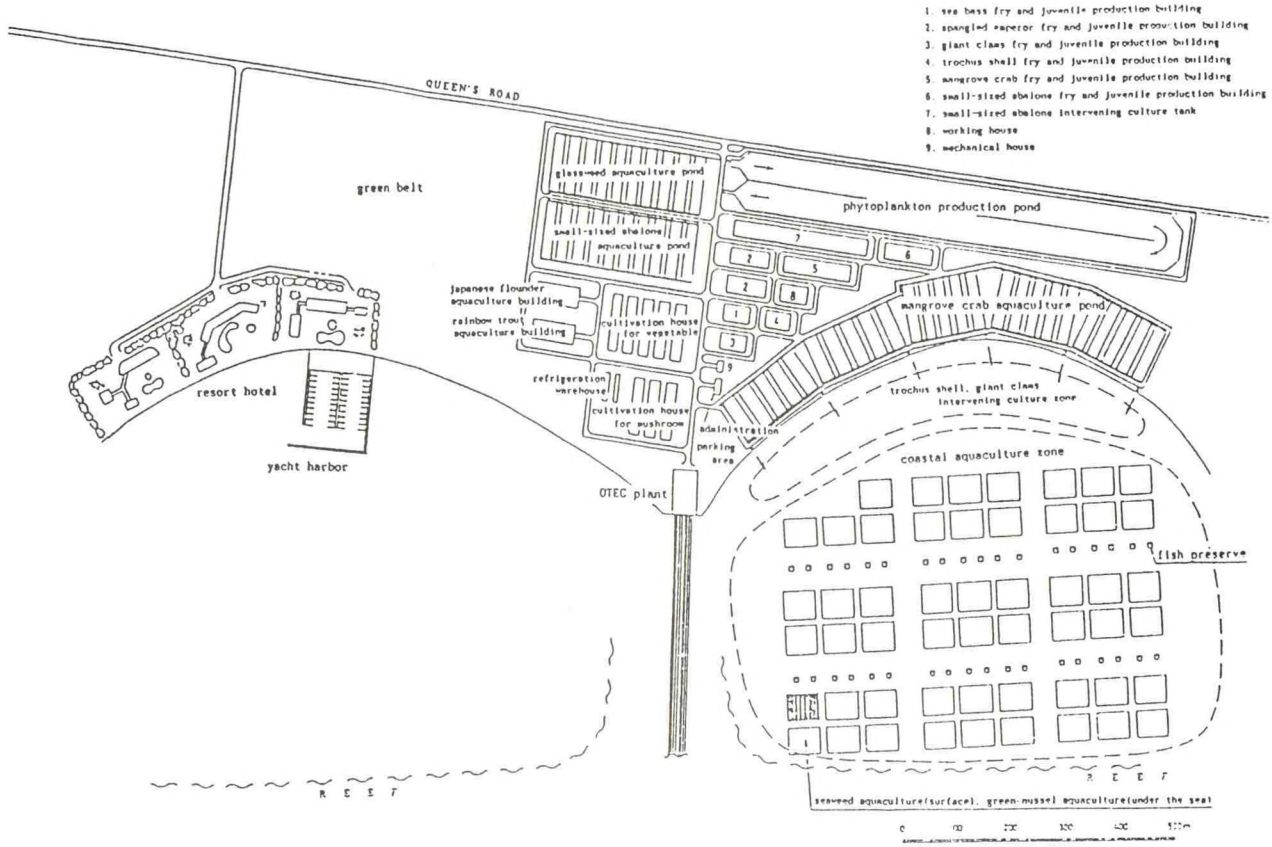


Figure 9 Facilities Arrangements

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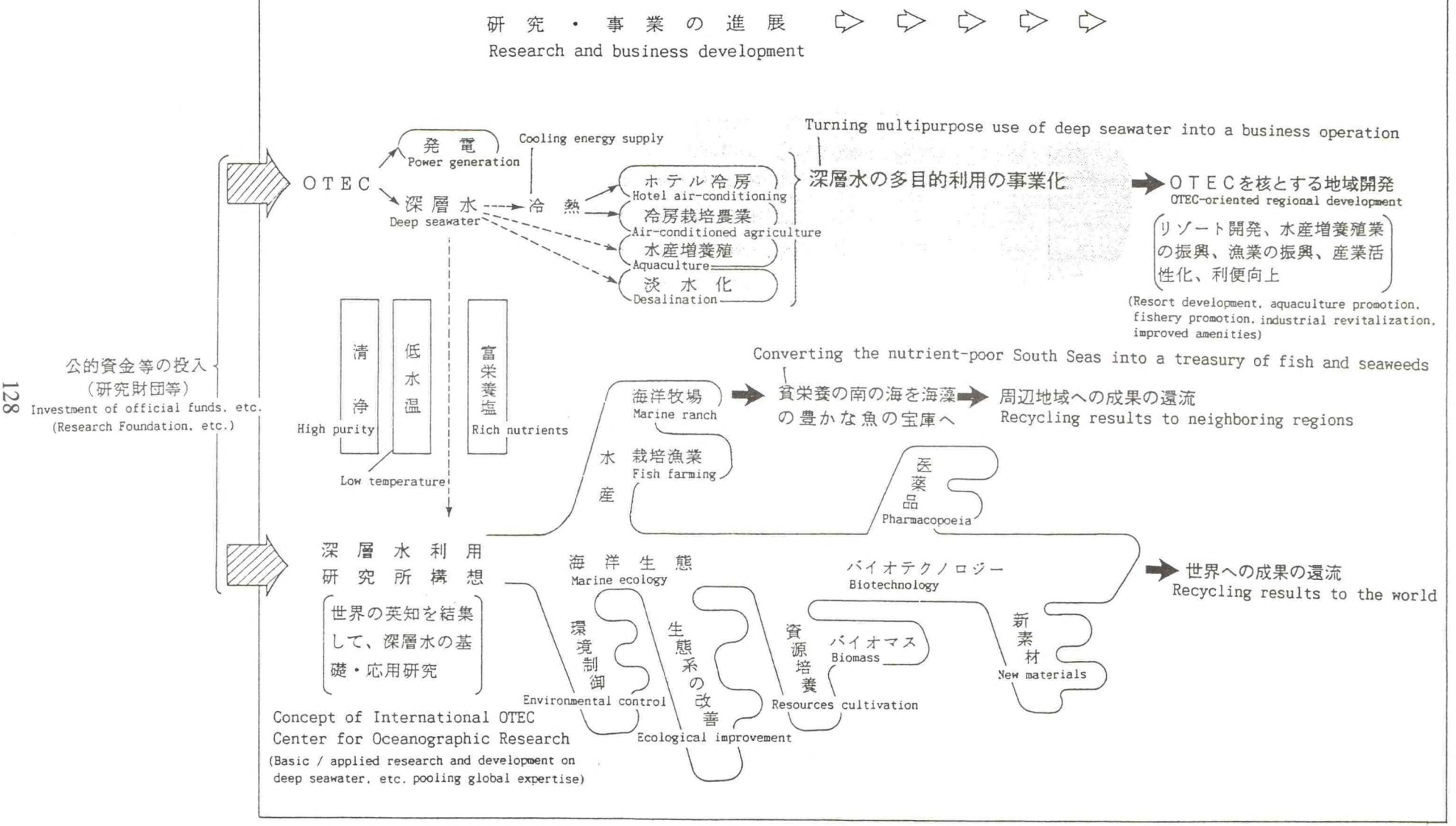
Figure 10 Multi-purpose OTEC Concept



Advanced Ship Technology Development

ADVANCES IN SHIPPING SAFETY

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Abstract. The Marine Board has devoted much of the last two years to developing a strategy for major safety reforms in the shipping industry. As we see it, the regime should focus primarily on human factors, including improvements in management and innovation in shipboard work practices; improvements in ship design, inspection, and maintenance; advances in maritime traffic management; and more effective spill response. The paper discusses the underlying problems and suggests specific measures that would improve safety and modernize the industry if implemented as part of a comprehensive program.

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Safety has been a continuing concern of the shipping industry for decades. But when the Exxon Valdez ran aground off the coast of Alaska in 1989, creating the largest oil spill ever in U.S. waters, it transformed the nature of the debate.

That accident brought into view the full extent of the iceberg, so to speak. Suddenly, debate no longer centered on whether safety improvements were necessary, or where to start chipping away at the problem. Rather, the industry perceived the need for major reform.

At the National Research Council, the Marine Board has devoted much of the last two years to defining the specific changes needed. (See Attachments A and B.) Based on committee studies and staff discussions, we envision a coordinated plan taking several basic approaches to change. These reforms would modernize and revitalize the industry and establish a rational, consistent, and efficient regulatory framework. Our focus has been on the U.S. trade, but the international character of the shipping industry makes many, if not all, of the findings relevant worldwide. Similarly, although we have focused primarily on one type of ship—tankers—many of the findings are relevant to all ships.

Our work clearly shows that, while the safety record is improving, the industry remains mired in outmoded traditions. And as we all know, the public is demanding a reduction in the risk of accidents and oil spills. Many links in the safety chain require urgent attention; the scope of the reform will require a heroic effort, including the discarding of time-honored practices. A halfhearted approach will not restore public confidence.

As we see it, the regime should focus primarily on human factors, including improvements in management and innovation in shipboard work practices; improvements in ship design, inspection, and maintenance; advances in maritime traffic management; and more effective spill response.

What the TITANIC did for safety of life on passenger lines, the EXXON VALDEZ should do for the safety of the shipping industry and the environment. It was a warning, a signal that it is time to rebuild the industry—and with a more reliable safety net.

Safety Has Improved—Somewhat

The accident record of recent years indicates the industry has been moving in the right direction, albeit neither far nor fast enough. It is difficult to pinpoint any specific reason, but the factors that have contributed to better safety include improved technology, refined operating procedures, and greater regulatory scrutiny.

Statistics clearly show that, over the past 20 years, there has been a marked decline in vessel accidents, vessel losses as a result of accidents, and personnel injuries. These trends are consistent across databases, and are independent of such variables as fleet size. (See Figures 1, 2, 3, and 4.)

Likewise, the impact of accidents on the environment has been diminished. Just as the rate of serious casualties to oil tankers has declined, oil spilled due to tanker accidents and operations has decreased substantially since the late 1970s, from nearly 1.5 million tons to 569,000 tons [1].

Nevertheless, there are continuing safety concerns that have yet to be resolved. These will be discussed shortly. There is some urgency here, due not because of public pressure to reduce accident risk, but also because developments now underway within the industry will tend to counteract safety improvements to date. For instance, tanker traffic to and around the United States is increasing, due primarily to the increase in oil imports; this increases the potential for accidents. And nearly 30

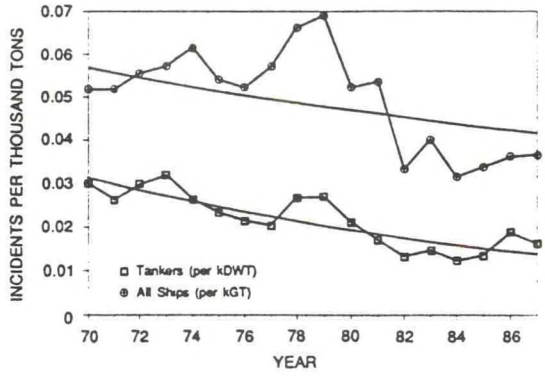

Figure 1. Reportable casualty rates of U.S.-flag ships, per thousand gross tons (uper curve), and U.S.-flag tank ships, per thousand deadweight tons (lower curve), 1970-86. For all vessels the decline has been nonlinear (power function) at a confidence level exceeding 99%. Data from U.S. Coast Guard Annual Statistical Summary [2].

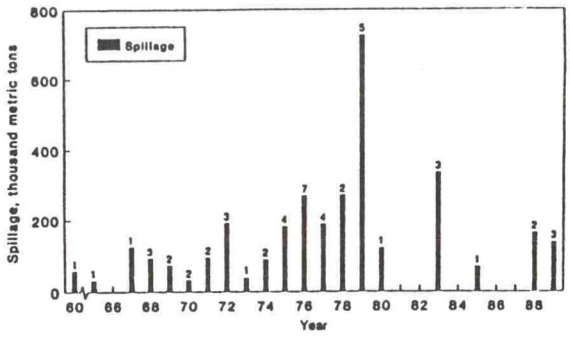

Figure 3. Tanker spillage and number of events—50 major oil spills, 1960-89. (No major spills 1961-64. Spillage is total volume lost and burned [1].)

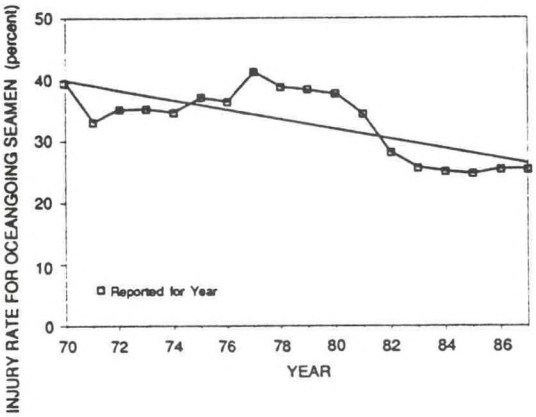

Figure 2. Annual injury rates per seagoing employee in U.S. deepwater vessels, 1970-87. The decline in the injury rate for oceangoing seamen since 1970 has been linear at a confidence level exceeding 99%. Data from Marine Index Bureau [2].

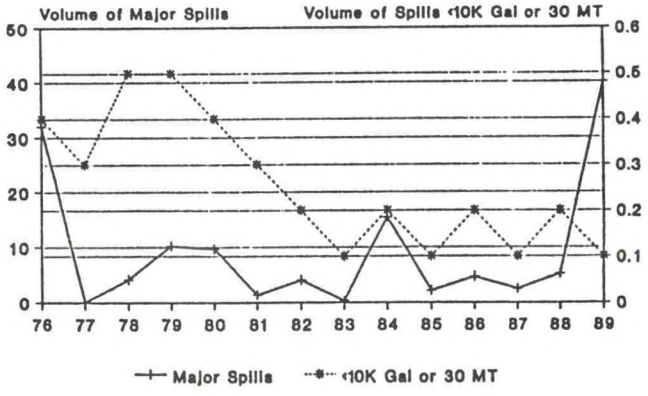

Figure 4. Tanker oil spills in U.S. waters—volume of spills. Data from U.S. Coast Guard / Temple, Barker & Sloane, Inc. [1]

percent of crew members on U.S.-flag vessels are injured each year [2]—a rate that would hardly be acceptable in say, the airline industry.

People are the Main Link

Ultimately, safety depends on people. Human error is the probable cause for 80 percent of vessel casualties, [3] based on the limited data available.

In the United States, the shipping environment is not optimal for fostering excellence. The maritime industry has been in decline for years; maritime-training academies and naval architecture schools have small enrollments.

Moreover, laws and regulations are outdated. Despite the steadily expanding variety of tanker types and trade routes, license standards for masters and mates still permit the operation of nearly any type or size of vessel. The Coast Guard should have more control over the qualifications of both licensed and unlicensed personnel; requirements should be stricter and more precise to reflect differences in vessel type and service.

Crewing standards are outdated as well. The structure required by U.S. law is based on obsolete technology. The division of shipboard labor into navigating and engineering teams, for example, is related to technology of the 1930s. This relic limits efficiency, with no clear safety rationale [2]. Such provisions have blocked innovation in manning.

Traditional work practices, which often are far from the norm of industrial practice, may need reform. Long work days are common in the maritime industry; fatigue appears to be a persistent precursor to casualties, although the cause-effect link is difficult to document [4]. Fatigue contributed to both the EXXON VALDEZ accident and the WORLD PRODIGY grounding in Rhode Island Sound, according to National Transportation Safety Board records [5] [6].

An important factor may be the increasing pace of work on modern ships. Turnaround time in port has been reduced, and there are too few opportunities for shore leave, rest, or relaxation. A recent study [7] recommended that the round-the-clock duties during today's brief and intense port calls be re-examined.

In the United States, many work practices are codified into law, including specific conditions and numerical requirements. This prevents regulators from keeping pace with changing conditions in the fleet; the present law is decades old and has been updated largely by piecemeal addition of specific provisions.

Even the time-honored shipboard hierarchy requires review. The absolute authority of the captain is, ironically, a source of navigation casualties. Most of the recent major polluting casualties took place with more than one person on the bridge; there is no precedent for questioning the captain's orders.

Such strict hierarchy is also less compatible with the broader individual responsibilities necessitated by smaller crews; the crew of a typical U.S. ocean-going ship is now about half the size of 30 years ago [2]. Many expect that future U.S. flag ships will be commanded by a single class of broadly qualified watch officers trained in navigational and technical skills as well as business and logistics.

Steps to improve training already are underway. Some U.S. shipping companies have undertaken programs to broaden crew members' skills, and maritime-education institutions have begun to offer courses in such topics as communication between masters and mates, and watch-keeping effectiveness.

The human element must be considered when any technological changes are introduced; ships should be considered sociotechnical systems. To date, relatively few human factors studies have been conducted in the maritime environment. Neglect of this essential component has negated many technological safety innovations of the past. The infamous TORREY CANYON spill in 1967 occurred partly because the captain, under scheduling pressure to make up time, took a shortcut through the intricate channels of the Scilly Islands.

There is no substitute for vigilant attention to safety, not only by ships' crews, but also throughout the industry. Over a period of time prior to the EXXON VALDEZ grounding, safety practices in the area had lapsed—with the tacit approval of all concerned. For instance, tankers had consistently violated traffic rules requiring vessels to slow for ice or wait for winds to abate rather than leave the normal channels [8]. Moreover, the requirement for piloting of tankers was reduce; pilots originally guided ships 70 miles from Valdez to open waters, but this distance was reduced to 12 miles.

Inspections Fail the Test

When the former cruise ship SCANDINAVIAN STAR was set afire by an arsonist last year, faulty equipment was blamed for compounding the blaze. As the Miami Herald noted in a recent editorial, the ship had been inspected twice not long before —by the U.S. Coast Guard and on behalf of the Bahamas, where the ship was registered. Moreover, Lloyd's Register of Shipping had made monthly inspections through the previous month. Somehow, inspectors missed the problems. The alarm system was hard to hear in the area where many passengers died, there was no sprinkler system (none was required) and some lifeboats were corroded.

This tragic situation is illustrative of a pervasive problem: Government inspections are manpower-limited. Inspection resources have been reduced, and the agency has faced competing demands on personnel, notably for drug interdiction [9]. Between 1981 and 1989, 890 jobs related to vessel and port safety were cut from rosters. Inspections were less frequent, less thorough, and conducted by less qualified personnel. Authority to inspect foreign ships in U.S. waters rarely was exercised [2].

Hull structural examinations of foreign-flag tankers, according to a 1989 Coast Guard study, "are at best minimal [10]." Despite the acknowledged limitations of government inspections, there are indications that shipowners have relied on them increasingly to uncover safety problems, as industry engineering staffs were cut drastically in the shipping depression of the 1980s [10].

Tanker inspection especially is a daunting task. In a 250,000 deadweight-ton carrier, for example, inspectors must cover 74 acres of cargo tank sections and 36 miles of longitudinal stiffeners [11]. Such an inspection might require 1,000 to 2,000 person-hours. By comparison, the Coast Guard spent an average of 7.6 "experienced" person-hours on each hull inspection over a recent two-year period [1].

Obviously, owners or their contract inspectors should conduct thorough inspections. But it is up to regulators to ensure that this is done, and the U.S. system clearly is not effective enough. To make more effective use of present staff, the Coast Guard could establish a system of annual inspections that would consist, at the primary level, of auditing management compliance with safety requirements. These requirements would be devised to cover all important areas, through, for example, mandatory recording of all routine safety tests and regular reporting to the Coast Guard of internal safety reviews. Then, based on assessment of management performance and safety records, the Coast Guard could target the time-consuming, hands-on inspections of ships to selected cases that warranted concern.

This system would provide for consistent overall oversight, while at the same time permitting extra scrutiny in cases where safety may have lapsed. A Marine Board committee has recommended this concept for inspections of offshore oil and gas development platforms [12].

A particular concern in improving the effectiveness of ship safety inspection is the need to extend the safe operation and service of today's ships, which will comprise most of the fleet for years to come. Owners are retaining older ships in service longer, due to rising construction costs (and the U.S.-flag fleet is the oldest of the major fleets). Older vessels are more likely to incur corrosion or metal fatigue. Older vessels also have more accidents, especially fires, explosions and structural/machinery damage [13].

Moreover, many ships have built-in design flaws. In the last 15 years, shipbuilders frequently have used high-tensile steel to achieve lighter (and cheaper) designs; but design and construction often were not well suited to the new materials, and some ships have high rates of structural failure [14]. A recent study of tankers carrying crude oil out of Valdez, Alaska found a startling frequency of major structural failures, due to poor design and construction and severe sea conditions [15].

Another factor in planning future ship inspection programs is the new requirement for double hulls on new vessels trading in U.S. waters. This requirement, part of the Oil Pollution Act of 1990 (OPA 90), will be phased in over 25 years. The added structure and void space inherent in double hulls will increase maintenance requirements and the risk of fires and explosions.

Clearly, the Coast Guard needs to place more emphasis on inspections, and this means more resources. OPA 90 gives the agency greater authority to prevent spills, and existing statutes give the agency authority to tighten inspection of both U.S.-flag and foreign-flag ships in U.S. waters. Congress should provide the funds and legislative support to implement these reforms promptly.

New Directions in Traffic Management

Imagine airliners in the crowded skies over New York or Tokyo, trying to avoid collisions or land without the aid of a permanent, automated air-traffic control system.

Ships, on the other hand, depend entirely on the attentiveness and skills of their crew members. In our increasingly crowded shipping lanes, this tradition clearly tempts fate.

Traffic in and around the United States already is heavy. Of the more than a third of the 1.7 billion tons of crude oil and products transported annually by sea worldwide, more than a third passes through U.S. waters [1].

The Department of Energy projects a 50 percent increase in import volume by the end of the century; the increase in shipments from foreign ports may be compounded by more lightering traffic in the Gulf of Mexico.

Needless to say, the need to manage this traffic properly is growing, and the present system is minimal at best. U.S. vessel traffic monitoring systems, for example, cover only a handful of ports and waterways and are mostly advisory in nature. The

level Coast Guard budgets of the 1980s were unable to support the technology required to keep up with the increasing activity in U.S. ports. Fortunately, OPA 90 authorizes a study to determine which ports and channels need new, expanded, or improved vessel traffic systems, and calls for recommendations by next summer for implementing the results.

The maritime industry clings to tradition. But as new technologies are introduced and traffic becomes more crowded and complex, ship navigation and piloting must change. The Marine Board now is reviewing the evolution of navigation and piloting, focusing on technological advances and their implications, the changing roles of the crew, pilots and safety personnel, and the related changes in training, licensing, and performance.

Faster and Better Spill Cleanup

Oil slicks spread with time. Thus, the longer it takes to mount a cleanup effort, the more difficult the task and the less promising the chances of success. This fact determines both the nature of effective response operations and the most promising directions for research. It also means that, in some cases, cleanup may not be worth the effort.

Clearly, better spill response is needed. Indeed, less than 4 percent of oil spilled, on average, is recovered. Accidents and oil spills will occur despite any improvements in crew standards, working conditions, inspections, or traffic control.

OPA 90 authorizes $27 million for a federal, interagency program of research and development on oil pollution. Spill surveillance is critical, and research in this area may provide significant return with only moderate funding. When the Exxon Valdez spill was still spreading, the distance from Valdez to one end of the slick was nearly 400 miles. Visual surveillance can't track such vast areas or determine the thickness of a slick. The possibilities for advances in surveillance capabilities are numerous. A new system should be developed employing synthetic-aperture radar and state-of-the-art ultraviolet/infrared scanners. Sensors are needed to distinguish oiled from unoiled shorelines. We should study the use of satellite data for surveillance. We also need technologies to allow quick response to minimize spills. Quick deployment of response equipment, in particular, should be a high priority, including dispersant application, fire boom deployment, and other containment and recovery operations. We also need shipboard countermeasures, the primary option during the first six hours after a spill. However, research on quick response is high risk, in that it might require major funding without quick results.

Treatment of contaminated shorelines is also a significant concern. More research is needed on the ecological consequences of different cleanup approaches. The complex interactions among different geological conditions, oil types, and cleanup techniques is not well understood; research might lead to a decision logic that would cover a number of different options, including the option of no cleanup. The public generally demands that all oil be removed, of course, but this is not feasible.

Finally, for response technologies such as burning of oil spills and the use of chemical agents and bioremediation, field tests using experimental spills should be conducted to develop operational data and guidelines. To date, field testing has been severely neglected; only one U.S. government approval for such tests has been requested since 1979. One request is currently under consideration.

We also need to conduct long-term ecological studies of selected habitats exposed to oil. Even after 20 years of laboratory studies, sensitivities and recovery times are difficult to assess or predict.

Finally, we need to develop criteria by which to judge when a contaminated area has been sufficiently restored. A regime of toxicological, chemical, and ecological studies should be established to assess the limitations of techniques for cleanup, recovery, and restoration of different habitats.

A Word About Data

A persistent difficulty encountered by the Marine Board in its work on maritime safety has been inadequate information. The problem falls into two categories: gaps in engineering knowledge and incomplete, inconsistent accident records.

Too little is known about the structural behavior of ships in accidents—exactly how the hull ruptures under particular conditions. There is no way to design a crashworthy tanker, for instance, without knowing much more about the precise damage incurred in a wide range of scenarios. Building such a database would entail extensive structural review following a large number of accidents. Databases also must include such details as the speed at impact and the shape of a grounding obstacle.

This brings me to the second point: Because accident records are not maintained in a complete and consistent manner, many important questions cannot be answered definitively. There is no way to confirm a link, for example, between the dramatic reduction in crew size in recent years and the improved safety record. Tanker accident databases are often ambiguous as to whether the "cause" refers to

the original casualty or to a secondary event leading to loss of cargo [1]. Moreover, different databases often must be cross-checked by hand in order to obtain a basic overall description of even one accident [1].

A worldwide effort is needed to standardize, gather, and evaluate safety data in order to identify trends and provide the technical basis for constructive management of maritime safety.

The Industry of the Future

By taking the approaches outlined here, the shipping industry can shed the manacles of tradition and be transformed into a smooth-running operation that is efficient, innovative, attendant to detail, responsive to change, and above all, safe.

We envision a well-rested crew that is not hampered by outdated work practices, ever vigilant of good safety practices. We envision ships that are structurally sound, designed to withstand accidents, and inspected effectively on a consistent basis. We envision manageable patterns of maritime traffic, properly monitored. And, because tanker accidents inevitably will occur, we envision efficient and effective oil spill cleanup.

To bring this vision to reality, we first need to bring management up to date. Managers need the knowledge, tools, and environment that will enable them to meet modern expectations for safety established by other industries in the transportation sector, and to satisfy public demand for fewer needless shipping accidents and environmental insults.

Second, we need to modernize laws. An important step has been taken with OPA 90, which includes, in addition to the provisions for double hulls, vessel traffic systems, and spill research, and assigns liability and strengthens accountability for oil spills and cleanup costs. But we need to go even further, adjusting, for example, outdated laws pertaining to shipboard work practices.

Third, we need in-depth research to better understand causes and effects of shipping accidents, human factors issues in the maritime industry, and effective oil spill cleanup. Finally, the results of these studies must be put to practical use.

Achieving such a dramatic transformation won't be easy. But there is no better time or reason than the present tumult over safety—which is, after all, a matter of life and death.

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Attachment A

Executive Summary

Commercial vessels throughout the world have reduced the size of their crews dramatically in the past few decades. Modern, automated U.S.-flag ships have crews of about 20. Thirty years ago, vessels of comparable tonnage had twice that number. In contrast to American standards, the most technologically advanced ships in the world fleet today have crews of about 10.

The trend toward smaller crews has been accompanied by increasing concern for safety. While the impacts of crew reductions on operations have been carefully studied, the effect on safety has not received widespread attention. The most fundamental question is whether smaller crews degrade safety. A related issue is whether international and domestic statutes regulating crew size adequately protect workers, vessels, and the environment, and unduly restrict the adoption of new technology. Another issue is the Coast Guard's role in ensuring that foreign-flag vessels, with smaller crews than permitted under U.S. law, do not compromise safety in domestic waters.

WHAT ARE THE SAFETY CONCERNS?

Concerns about the effect of crew reductions on safety relate primarily to three operational considerations.

1. *Fatigue*: Will there be greater demands placed on crew members, and if so, will they be less alert? Or, will smaller crews work the same or fewer hours and thus be no more likely to suffer fatigue than larger crews?

From Crew Size and Maritime Safety. National Research Council. 1990. National Academy Press.

2. *Training*: Will the crew be able to handle emergencies if automated systems fail? Will the crew be adequately trained to handle broader responsibilities and more sophisticated technology? Are higher or different levels of competence required?

3. *Maintenance*: Will crew reductions result in neglect of essential maintenance? To what extent will automation and technology advances improve reliability of ships' operating systems?

Lack of attention to these problems will raise the risk of injuries and vessel accidents with attendant social, economic and environmental costs.

WHAT IS THE SAFETY RECORD?

Available statistical information on maritime safety is inadequate to make definitive judgments about how various factors, including crew sizes, contribute to safety. Precise and uniformly defined information is needed to establish trends in safety performance and to make decisions about safety based on those trends. However, available safety statistics indicate the following:

- There has been a measurable and substantial reduction in vessel casualties (accidents) and personnel injuries during the past 20 years. These trends are consistent worldwide.
- During the same period, average crew size has declined substantially.
- Other factors have also changed. Technology has improved, operating procedures have been refined, and maritime operations have come under increased scrutiny by government and industry.

Vessel casualties and personnel injuries cannot be correlated with crew size based on available safety data. Thus it is not possible with available information to determine whether any causal relation—positive or negative—exists between crew size and safety. There are valid concerns about fatigue, training, and maintenance, but their effect on safety can be minimized through vigilance by management and labor organizations. Effective and thoroughly trained crew members and reliable automated ship systems become more important as crews are reduced.

ARE THERE HUMAN FACTORS CONCERNS? HOW CAN THEY BE MANAGED?

The introduction of new technology in ships should consider not only technology, but human factors related to it. Ships should be viewed as sociotechnical systems, consisting of technologies, personnel, organizational

structures, and an external environment. Change in any one of these subsystems may necessitate change in others. However, very few human factors studies have been conducted in the maritime field. Moreover, the Coast Guard does not have the necessary analytical tools to support decisions concerning the number of people needed to operate highly automated ships.

With appropriate training, organizational innovations, and ergonomic design, new vessel technology should not degrade safety. Training programs need to change as new technology is adopted, and licensing requirements need to be modernized. The general shift will be from specialized skills to a higher level of competence with a broader range of skills and more sophisticated technology.

HOW SHOULD SAFE CREW LEVELS BE ESTABLISHED?

In establishing safe crew levels, government and industry need to consider demands on crews on different vessels: specialized technologies, type of vessel service, the varied skills required, and the quality of management. Currently, the Coast Guard (and other national shipping safety administrations) relies in large part on laws, traditions, and informal guidance to determine manning levels. This piecemeal approach may have been effective when technology changed slowly and crews were larger, but today a consistent, internationally accepted method for determining safe manning is needed. The need for such a method will become more urgent with the worldwide adoption of new ship technology and innovative manning patterns. Systems engineering methods, including functional task analysis, offer an objective basis for determining crew sizes. The committee developed a systems engineering model to assess functions and tasks that could be used by the Coast Guard to determine safe manning levels for a variety of ship types and operating conditions.

A comprehensive international process for determining manning levels would include (1) a universally accepted statement of principles setting forth functional manning requirements, and (2) objective analysis tools to establish minimum safe manning scales. Such a process framework would help each vessel's flag state set manning levels and could be used by port states to assess whether vessels entering their waters are sufficiently manned. Internationally dictated manning scales are not desirable, since they would impose inappropriate standards on some ship operators and would hinder innovation for others.

DO U.S. MANNING LAWS NEED TO BE MODERNIZED?

U.S. manning laws have led to needless inefficiency and complexity and to unwarranted obstacles to the adoption of new ship operating technology.

Clearly, these statutes will effectively prohibit reducing crew sizes below current levels regardless of opportunities offered by technology. More importantly existing manning laws do not have a clearly identified emphasis on safety; in fact, they inhibit operational innovation without relation to safety aspects.

The Coast Guard has the authority to enforce safety requirements on foreign-flag vessels in U.S. ports. As a practical matter, the agency normally accepts manning levels established by other flag states as safe manning for entry into U.S. ports. However, manning decisions vary among the flag states. Consistent manning criteria among flag states and consistent enforcement authority by port states require a universally accepted analytical method for assessing safe manning similar to that developed by the committee. The International Maritime Organization (IMO) is the appropriate forum for developing such a method.

RECOMMENDATIONS

To foster safer shipping amid rapidly changing ship technologies, the committee recommends the following:

- Congress should modernize U.S. manning laws to allow innovation without degrading safety.
- The U.S. maritime industry, with the aid of the United States Department of Transportation, should implement a program to demonstrate the conditions under which reduced crew size can be considered safe. Among the demands on the crews that need to be evaluated are specialized technologies, type of vessel service, skills required, and the quality of management. Assessment and incorporation of worldwide developments to foster manning innovation should be an element of this program.
- The industry, with the aid of the U.S. Department of Transportation, should undertake a research program to determine how human factors such as fatigue and stress affect maritime safety.
- The Department of Transportation should gather, standardize, evaluate, and disseminate maritime safety data.
- The Coast Guard should use formal analytical methods, such as the approach developed by the committee, to make manning decisions. The goal should be to develop an internationally accepted method for establishing minimum safe manning levels.

The committee's complete conclusions and recommendations appear in Chapter 6.

EXECUTIVE SUMMARY

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This study, prompted by the March 1989 grounding of the EXXON VALDEZ in Prince William Sound, Alaska, focused on how alternative tank vessel (tanker and barge) designs might influence the safety of personnel, property, and the environment, and at what cost. In selecting designs to be considered, the committee included certain operational options that might minimize the oil spilled in an accident. The study did not consider means of averting accidents, altering the form of cargo, or responding to oil spills.

RISK OF SPILLS IN U.S. WATERS MAY BE INCREASING

The threat of pollution exists wherever tank vessels travel, and traffic in U.S. waters is increasing: Projections call for up to a 50 percent increase in imports of crude oil and petroleum products by the year 2000.

U.S. control over the condition of the tankers calling on U.S. ports is limited. More than 80 percent of these tankers are foreign flag. With the depletion of the present Alaskan oil fields, the proportion of U.S.-flag carriers is likely to decrease further during the coming decade.

One five-hundredth of 1 percent of the total amount of oil moving through U.S. waters is spilled. The 9,000 tons (on the average) of crude oil and petroleum products that is spilled annually in U.S. waters can be damaging from environmental, economic, and social perspectives. Large spills (30 tons, or about 10,000 U.S. gallons, and greater) comprise less than 3 percent of the events, but they cause nearly 95 percent of the accidental spillage in U.S. waters. Huge spills such as the EXXON VALDEZ can be devastating.

IMPROVED TANK VESSEL DESIGNS SHOULD REDUCE, BUT WILL NOT ELIMINATE, THE RISK OF OIL SPILLS

Improved tank vessel design is one way to reduce the risk of oil pollution, but the risk cannot be eliminated entirely. However, to assure some risk reduction, tank vessels of any design must be properly constructed, operated, inspected, and maintained. Whether adequate risk reduction can be achieved at reasonable cost through design changes is a controversial question; opinion varies widely.

From Tanker Spills: Prevention by Design.[1] National Research Council. 1991. National Academy Press.

Accidental oil spills, which constitute 20 percent of the total oil pollution from maritime operations and accidents, can result from collisions, groundings, structural failure, fires, explosions, or machinery failure. No single cause has dominated the historical record of accident-related oil spills, although groundings have been the dominant cause in U.S. waters, and the cause of the next large spill cannot be predicted. Therefore, all causes must be considered in tank vessel design.

Results of this study indicate that no single design is superior for all accident scenarios. Therefore, the Oil Pollution Act of 1990 (OPA 90), which mandated double hulls for tankers traveling in U.S. waters, should be viewed as only an interim step to reducing oil spills. More work remains to be done, as follows.

EXISTING TANK VESSEL DESIGN STANDARDS ARE NO LONGER ADEQUATE

Modern vessel design methods have produced such "efficient" structures that traditional allowances for errors, unknowns, and deterioration have been reduced to a significant degree. As a result, what were once secondary concerns can become critical; in short, modern tank vessels are less robust than their predecessors. Some ship classification societies, which set structural standards, are questioning publicly whether current strength criteria are adequate. The committee believes they are not adequate.

Existing design standards should be strengthened to ensure proper (1) corrosion protection (the surface area to be protected in double-hull vessels can be nearly three times that of single-hull ships); (2) dimensions of structural members; and (3) use of high-tensile steel. Concerted action should be taken by the U.S. Coast Guard, through the International Maritime Organization (IMO) and the classification societies, to effect these changes in a timely manner.

Furthermore, naval architects traditionally have not designed tank vessels, at the detail level, to withstand collisions and groundings. Design based on the possibility of accidents, a practice common in many industries, should be considered for tank vessels. Research should be conducted to confirm the promise and methodology of incorporating this approach into design practices, irrespective of whether vessels have double hulls or any other basic structural concept.

AVAILABLE INFORMATION IS INADEQUATE FOR DECISION MAKING

The paucity of data on tank vessel accidents and oil outflows, gaps in knowledge concerning vessel structural behavior in accidents (especially groundings, where characteristics of obstacles are critical yet undocumented), and uncertainties concerning the quantification of environmental benefits resulting from design improvements make any but the most primitive conclusions subject to conditional scenarios, assumptions, and judgments ranging from the informed to the intuitive.

The following conclusions are adequately supported with facts:

- Double hull vessels in low-energy (typically low-velocity) accidents should not pollute.
- Vessels that carry cargo in contact with a single skin (with the sea on the other side) will cause some pollution in any accident where a cargo tank is penetrated. However, certain design alternatives will minimize the amount of pollution in some specified scenarios.
- High-energy accidents nearly always result in pollution. The relative advantages of various design alternatives in reducing pollution from particular scenarios are highly dependent on the assumptions made in the scenarios.

- A comprehensive research effort can address the endemic lack of data and knowledge, and would result in placing decisions more nearly on a factual basis, rather than on the basis of informed opinion.

Until the gaps in understanding are filled, all other findings, by this committee or any other analyst, will be influenced by numerous variables including personal judgments. An example is the Det norske Veritas (DnV) report, which analyzes the pollution-prevention effectiveness of tank vessel design alternatives (detailed in Chapter 5 and Appendix F). In using DnV data to estimate oil outflow for design combinations (not calculated in the DnV report), the committee found that the results were driven by DnV assumptions regarding extent of damage and configurations of cargo tanks. In particular, outflows for small tankers appear inconsistent with results for large tankers, primarily because of the cargo tank configurations selected for the small tanker. Thus, outflow estimates should be viewed only as indicative examples rather than as absolutes.

In view of the above, the committee's judgment was by necessity a key element in every aspect of this report. However, the committee did reach a strong consensus on its findings, as follows.

DOUBLE HULLS SHOULD REDUCE POLLUTION FROM GROUNDINGS AND COLLISIONS

When OPA 90 requirements are fully implemented over the next 25 years, double hulls should save (in absence of other risk-reduction measures) an estimated 3,000 to 5,000 tons of oil spillage per year in U.S. waters from collisions and groundings, based on available historical data. The savings represent roughly half of the current average annual spillage from vessel accidents in U.S. waters. The added transport cost would be more than $700 million a year, or on the order of one cent per gallon transported. On the basis of cost-effectiveness, the double hull is among the best values of the designs evaluated by the committee.

Double hulls are particularly effective in low-energy (typically low velocity) groundings and collisions. Of the alternatives considered by the committee, this option is the only one that places two structural barriers between the entire cargo and the ocean; thus, the double hull can prevent outflow as long as the inner barrier is not breached.

In addition to providing sufficient between-hull spacing for grounding and collision protection as well as sufficient accessibility to all spaces for maintenance and inspection, double-hull designs must incorporate, to achieve full potential, adequate outer plate thickness, and cargo and ballast tank sizes and arrangements that assure adequate stability when the ship is damaged. Minimum thickness criteria for outer plates should be established promptly; in the interim, the minimum should be no less than the outer plate thickness required of new single-hull vessels.

Accessibility of void spaces for inspection and maintenance is a significant concern, which grows with the number of compartments (as in double hulls). A spacing of about 2 meters minimum between hulls in tank vessels over 20,000 deadweight tons (DWT) should allow room for inspection.

More research is needed to determine the spacing between hulls that best satisfies all concerns. To provide pollution protection, inter-hull spacing should be approximately the ship's beam divided by 15 (B/15) or 2 meters, whichever is greater. However, shipowners should not be required to make double-bottom heights (whether as part of a double hull or as an independent design) much greater than 3 meters; higher double bottoms should contain permanent fixed access to ensure adequate inspection of the underside of the inner bottom.

Further study of void space dimensions in small tank vessels (including those under 20,000 DWT) should be conducted to determine the impact of the "B/15 or 2 meter" criterion.

The latest single-skin tank vessel designs exceed international criteria meant to ensure adequate stability following hull damage. The introduction of more ballast compartments subject to flooding (as with double hulls and related concepts), and larger cargo tanks, could result in designs that are less stable, while still meeting current criteria. The committee is persuaded that current criteria do not ensure adequate stability following high-energy (high-speed) accidents. The criteria can and should be revised to ensure that double-hull and other possible new designs are not less stable following damage than single-hull tank vessels.

MERITS OF OTHER DESIGN ALTERNATIVES FOR NEW VESSELS

A total of 17 design concepts, as well as 3 combination concepts, were evaluated by the committee. Alternatives and combinations that received all evaluations -- technical, outflow performance, and cost -- were:

- double bottom
- double sides
- double hull
- hydrostatically balanced loading (hydrostatic control)
- smaller cargo tanks
- intermediate oil-tight deck with double sides (IOTD w/DS)
- double sides with hydrostatic control
- double hull with hydrostatic control

The committee did not identify any design as superior to the double hull for all accident scenarios. Double bottoms and smaller tanks do not offer comparable pollution-reduction potential, although each is cost-effective. Double sides are not cost-effective.

The committee sought to establish whether there were design alternatives that would meet or exceed the pollution control and cost-effectiveness of state-of-the-art tankers built to current standards (codified in the International Convention for the Prevention of Pollution from Ships, or MARPOL). OPA 90 establishes a different standard, specifying that design alternatives "provide protection ... equal to or greater than that provided by double hulls." However, there are no generally accepted criteria for evaluating the equivalency of two designs. The difficulty is that the results of any analysis of the performance of tank vessels depends on the assumptions and the particular accident scenario analyzed. Different designs may perform better in some situations and worse in others.

The committee considered adding an operational feature, hydrostatic control, to various structural alternatives for new tank vessels. This feature makes use of the laws of physics involving hydrostatic pressure to reduce or prevent oil outflow resulting from bottom damage. The combinations considered were double hulls with hydrostatic control, double sides with hydrostatic control, and a conventional single hull with hydrostatic control. These concepts are not considered as desirable as the double hull; the primary reasons are:

- the effectiveness of hydrostatic control depends on operators' strict adherence to rules, rather than on a permanent feature of vessel design and construction; and
- hydrostatic control does not provide complete protection against oil outflow, due to tidal variations or wave action following a grounding.

Therefore, the committee does not favor hydrostatically balanced design options for new tank vessels.

In theory, another design concept, which also employs hydrostatic principles, could perform better than the double hull in certain circumstances and scenarios. The IOTD w/DS could spill less oil in high-energy groundings (under circumstances that would have penetrated the inner hull of the double hull) and in some collisions (because it employs wider side tanks). This design is unique in that the pressure of seawater forced into the vessel (rather than oil flowing out) in the event of tank rupture would be significantly greater than the pressures available in all other design alternatives. Another favorable attribute of this design is that it employs less structure in void spaces than double hulls; this should result in less risk of corrosion and easier inspection.

However, significant factors may undermine the pollution-prevention benefits of this design, including the advantages of its hydrostatic pressure features. Because the cargo tanks have a single bottom, these tanks would be penetrated in groundings more often than would cargo tanks within a double hull; furthermore, when the bottom of an IOTD w/DS vessel is penetrated, at least some oil would be spilled (i.e., poorer performance than the double hull in low-energy groundings). Moreover, the spillage could be aggravated by tidal or wave action or ship motion subsequent to an accident. The cargo tanks of the IOTD w/DS would be a greater challenge to inspect than a single-hull vessel built under existing standards. An undetected structural failure of the middle deck of the IOTD w/DS would effectively transform the vessel into a conventional single-bottom tanker with equivalent outflow potential. Failure of mechanical features (i.e., valve actuators) that isolate upper and lower tanks, and operational mishaps (i.e., human error) that compromise the separation of upper and lower tanks, would eliminate the hydrostatic balance integrity of the ship. Finally, this design increases operational complexity with respect to loading, unloading, and preparation for docking.

Weighing the pros and cons, some committee members consider the IOTD w/DS a practical and innovative application of available technology, which, if treated as an equivalent to the double hull and allowed to trade in commerce to the United States, would reduce pollution in several classes of accidents, including high-energy groundings (which have caused some of the largest oil spills). Others of the committee hold the judgment that the gap between theoretical principles and practical application is wide, that the design and its implementation are unproven, and that, pending more extensive evaluation, the nation deserves designs employing physical barriers, such as double hulls, over those that continue to employ a single hull, such as the IOTD w/DS.

Some committee members recommend that the U.S. Coast Guard extend the committee's evaluation of the IOTD w/DS alternative to determine whether this design is equivalent or superior to the double hull standard of OPA 90. The results of this analysis should be presented to the Congress and the IMO for action, as appropriate. Committee members who are skeptical of this design recommend that a more extensive, critical evaluation be conducted, and the results evaluated by the IMO, before the Coast Guard takes action relative to OPA 90.

Any of the design options considered by the committee, if fully implemented in U.S. waters, would add roughly one or two cents per gallon to the cost of oil transported, which might be reflected in a similar increase in the cost of gasoline to consumers. This amounts to total annual costs of at least $340 million, and, at most, roughly $2 billion, depending on the design chosen.

Other design alternatives may be proposed in the course of future research. New proposals should be considered.

Regardless of designs chosen, certain features should be standard on all new tank vessels. Towing fittings of a design recommended by IMO would help in towing a vessel, if that should be necessary after an accident or machinery breakdown (conventional mooring fittings are not as sturdy). All new tankers and barges should be built with towing fittings mounted on the bow and stern.

In addition, all new tankers should have a reliable onboard system for transferring cargo from a damaged tank to an intact tank or another vessel. Practical concepts have been developed utilizing available equipment for this purpose. These features are likely to be less applicable to barges, as they are unmanned.

In addition, IMO and the Coast Guard should prohibit the placement of cargo piping in ballast tanks, to reduce the danger of fire and explosion due to hydrocarbon vapor leakage. Finally, the passive vacuum system (for use on fully loaded cargo tanks) deserves further research and development.

FEWER OPTIONS ARE AVAILABLE FOR BARGES

In general, fewer pollution-resistant design options are appropriate for barges. Barges are unmanned and their attendant tugs have minimal crew complements; thus, the dedicated presence of skilled personnel for operational control is limited.

Also, barges carry a wide range of petroleum products of varying densities and properties. The diversity in cargo-loading levels (depth of oil or product in tanks) required to implement hydrostatic control implies crew vigilance, knowledge, and presence to a degree not consistent with barge operations. At the same time, towed barges are less maneuverable than self-propelled ships and hence, more damage prone. Physical structural barriers for secondary containment, such as double hulls, double sides, or double bottoms, are more reliable for barge operations. The intermediate oil-tight deck might be adaptable for barges, but would require carefully controlled loading and discharge practices.

DOUBLE HULLS NEED NOT INCREASE INCIDENCE OF FIRES OR EXPLOSIONS, IMPAIR POST-ACCIDENT STABILITY, OR COMPLICATE SALVAGE

Various issues related to double bottoms, double sides, and double hulls (or any design incorporating large void spaces) have caused considerable controversy. Increased risk of fire and explosion, possible vessel instability after an accident, perceived salvage difficulties, and increased personnel hazards are cited by critics of these designs. The committee received various arguments along those lines but little conclusive evidence.

Void spaces involve risk of fires and explosions due to the potential accumulation of hydrocarbon vapors, which can enter through cracks or pits in bulkheads adjoining cargo tanks, or through a defect in the cargo piping system. Although double hulls have significantly increased void spaces compared to single-hull tankers (with up to three times the shell and bulkhead area exposed to corrosion), there is no reliable evidence of increased incidence of fires or explosions in existing double-bottom or double-hull ships.

However, the risk cannot be ignored; planned maintenance and thorough inspection are critical. Coast Guard inspections already are considered barely adequate, and owners must be relied upon to conduct complete inspections. Additional requirements for particular structural configurations, especially those increasing the need for proper maintenance and inspection, will add to the existing workload. Furthermore, most existing double-hull vessels carry petroleum products, which usually are less corrosive than crude oil. In double-hull crude carriers, diligence will be needed to monitor for corrosion from the cargo tank side as well as the ballast tank side, especially on horizontal surfaces. Means of detecting and combating the problem should be assessed as well.

Double-hull designs have large void spaces exposed to potential damage, flooding, and additional weight, which implies possible instability following an accident. However, tankers designed to international (MARPOL) standards tend to be exceptionally stable and generally exceed current damage stability requirements. Double-hull vessels can be designed not only to meet requirements for damage stability, but also to survive more severe accident damage than currently required.

The committee believes, however, that criteria for evaluating damage stability of double-hull tank vessels should be tightened to assure damage stability approaching that of conventional single-skin MARPOL tankers.

Salvage concerns are only partly supported. Piercing of void spaces of loaded ships (whether at bottom or sides) will cause sinkage and/or heeling depending on the position and size of the void. This may or may not be a problem, depending on whether the vessel remains firmly stranded following an initial grounding. Greater amounts of flooded void spaces would help keep a stranded ship firmly aground, thus reducing the possibility of pounding under wave action. However, this would increase the amount of cargo to be removed to refloat the ship, or the amount of water to be blown from flooded voids.

Most tankers grounding (or stranded as a result of grounding) at service speeds (14 to 16 knots) will remain firmly stranded; the possibility of losing the entire cargo from a stranded double-bottom tanker (where a single-bottom tanker would have survived) is remote. There are no salvage-related concerns that should limit the use of properly designed double hulls.

PERSONNEL HAZARDS DIFFER WITH VARIOUS DESIGNS, BUT ARE VERY DIFFICULT TO EVALUATE

Some design features may increase the hazard to the crew during normal operations. These include greater amounts of void spaces, which will have to be periodically inspected; void spaces lacking direct access to the weather deck (such as a double bottom or double hull); and greater numbers of cargo tanks, or cargo tanks located below other tanks (such as in the intermediate oil-tight deck design).

There is insufficient evidence to judge the degree of personnel risk associated with various designs. The committee believes these concerns do not represent unmanageable risks in any of the designs considered, but rather constitute important factors that will demand continuing vigilance on the part of ship operators.

EXISTING VESSELS WILL COMPRISE THE MAJORITY OF THE FLEET SERVING THE UNITED STATES FOR MANY YEARS

The phase-out of single-hull tank vessels trading to U.S. coastal ports will begin in 1995, and over the following 20 years they will be replaced with double-hull vessels. Therefore, means for improving pollution control on existing vessels should be considered.

Serious consideration should be given to requiring that all existing crude oil tankers promptly meet the latest IMO provisions for pollution prevention for new tankers (MARPOL). Most significant are the requirements for segregated ballast tanks (SBT carry only ballast, never cargo), crude oil washing (a system for rinsing out cargo tanks with oil), and possibly protective location of ballast tanks. The 1978 conference for the MARPOL convention recommended that IMO set a date by which new ship requirements would be applied to existing ships, thereby enhancing protection against operational outflow, but, in fact, this action never has been

implemented. A multi-year phase-in period would be necessary, as "pre-MARPOL" vessels would require shipyard work.

Another possibility is a requirement for hydrostatic control, which could be implemented immediately without structural overhaul, although more research is needed to determine the optimal method of achieving hydrostatic control. Moreover, the design and condition of each vessel would have to be checked, and all bulkheads inspected, to ensure sufficient strength to withstand the added liquid cargo sloshing. Finally, leakage from a hydrostatically loaded tank vessel following a grounding may be exacerbated by wave action, current, falling tide, or vessel heel or trim (inclination). Implementation of this concept for the entire tank vessel fleet serving the United States would increase the number of vessels operating in U.S. waters, thereby potentially increasing the risk of accidents. Moreover, the cost of this measure could be substantial and warrants further study. The passive vacuum system might be another alternative, depending on the results of further testing.

Retrofitting double hulls on existing tank vessels is possible, but potential difficulties could result from combining new and old structural members. Furthermore, retrofitting would be, in general, much more expensive than hydrostatic control. Replacement of the entire ship forward of the machinery space would entail fewer technical difficulties and would require less time in a shipyard; however, it may be more expensive than retrofitting a double hull.

The committee urges prompt evaluation of a multi-faceted program to improve pollution control for existing vessels. One element would be the complete implementation of existing MARPOL requirements. The second element would be the consideration of implementing hydrostatic control. Additional emergency features, such as towing fittings and emergency cargo transfer systems that can help reduce the consequences of casualties, also should be considered.

While the potential costs and benefits of such a program are difficult to evaluate, it is reasonable to conclude that such requirements might expedite the construction of new vessels with double hulls. Implementing hydrostatic control on existing vessels would reduce cargo capacity on the order of 15 to 20 percent. If all existing vessels had been built at present costs, the limited data available to the committee indicates that reducing cargo capacity to accommodate hydrostatic loading (if implemented immediately) would cost about $1.1 billion per year, while saving 3,700 to 4,300 tons of oil spilled annually. Existing vessels were built over many years at a wide range of costs, so the total cost could be considerably less than the dollar amount stated. The actual impact on ship rates would be influenced by the relationship between vessel supply and demand. If existing vessels were insufficient to meet the cargo capacity shortfall, then costs would increase until new vessels were built.

This simplified model does not consider the additional person-hours necessary to monitor and enforce hydrostatic control, nor the increased vessel traffic resulting from carrying less cargo in each vessel. Furthermore, the benefits (and costs) of this program would diminish as new vessels replaced existing ships.

In sum, this type of program for existing vessels deserves consideration because of the potential environmental benefits. The program should guard against encouraging retention of older vessels.[1] It is outside the scope of this committee to judge whether similar benefits could be achieved at more or less cost through non-design measures (such as crew training, electronic display charts, or vessel traffic systems).

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[1] Failure to require pre-MARPOL vessels to retrofit SBT requirements before employing hydrostatic control would give these vessels an economic advantage compared to newer vessels meeting MARPOL standards.

9

A COMPREHENSIVE RESEARCH PROGRAM SHOULD BE MOUNTED IN THE UNITED STATES

The state of knowledge regarding the precise circumstances and structural effects of actual tank vessel accidents is so inadequate that any assessment of design alternatives will produce results that are dependent on the chosen assumptions and accident scenarios -- artificial rather than actual criteria. This is true even of this study.

Design criteria tend to "fix" technology at a point in time, thus inhibiting innovation and removing the incentive to advance ship technology and design. Performance standards are preferable, in that they tend to promote new development in terms of structural and operational innovations that would result in meeting or surpassing the standards. However, to achieve that goal, needs include: (1) an integrated micro-understanding of the dynamics of ship structural failure, and related factors; (2) long-range research in failure theory; (3) protocols leading to mandatory engineering documentation of casualties; and (4) computational models resulting in outflow predictions.

Major research programs directed to design of a "spill-free" tanker are being mounted in other countries. Japan plans a seven-year study on alternative tanker designs. Norway plans a five-year study on tanker design, operations, and oil spill cleanup. The U.S. federal government, industry, and academia should cooperate in a coordinated, substantive research effort directed to:

- performing a comprehensive risk-assessment study that would lead to establishment of future risk-based design goals for tank vessels with attendant compliance guidance;
- accomplishing the basic research needs noted;
- testing and evaluation of design concepts (including theoretical analyses, model tests, and field trials);
- advancing the capability to assess and value natural resource damages (better understanding of the environmental effects of oil spills and the feasibility and cost of restoration, and the development of accepted methodology for valuing environmental benefits would permit more reliable cost-benefit analyses of vessel design alternatives and other means of pollution control); and
- achieving optimal pollution control by integrating use of design alternatives with operational considerations.

OPA 90 authorizes such a research program. The program should be coordinated with foreign research centers, notably in Norway and Japan, and the efforts of the IMO. A comprehensive research effort is essential if important, far-reaching decisions concerning the future of oil transportation by tanker are to be made on the basis of fact, as contrasted with informed opinion.

CHALLENGES IN AMERICAN SHIPBUILDING

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The United States shipbuilding industry is facing a crisis today which will ultimately determine its future existence. It is no secret that the industry has been in steep decline for a decade. Figure 1 illustrates the catastrophic reduction in commercial orders to American private yards over this period. In 1988 and 1989 not a single large merchant ship was contracted for building in the United States. As it stands today, U.S. private yards rank a poor 28th in the world competition for commercial tonnage (Figure 2). Had it not been for the robust shipbuilding program of the U.S. Navy over this same period of time (see Figure 3), there would be no shipbuilding industry in the United States to write about.

Much has been written about the causes for this shipbuilding malaise. Subsidized foreign competition, the high cost of U.S. labor, U.S. Government harassment and regulations, deterioration of the infrastructure, low productivity, all have been cited as reasons for the uncompetitiveness of U.S. shipbuilders, and the list goes on and on. No doubt statistics can be cited to support many of these causes, but several of them are not entirely valid. As an example, today U.S. shipbuilding labor rates are significantly below those of Japan and most of northern Europe. The overriding reason, the simple and obvious cause that swamps all others in comparison, is the low productivity of American yards. U.S. shipbuilders simply take too long to build a ship by a wide measure, and that translates into ships that cost too much. Although there is some indication that the U.S. shipbuilding industry is now closing the productivity gap, in the recent past Japan and

SHORTCOMING:
LIMITED PRODUCTION

Country	*Tonnage (M)*	*Percent of World Tonnage*	*Ranking*
Japan	5.96	24.3	1
South Korea	5.87	23.9	2
Yugoslavia	1.33	5.4	3
Brazil	1.03	4.2	4
China	1.0	4.0	5
Poland	.98	4.0	6
Italy	.91	3.7	7
West Germany	.86	3.5	8
⋮	⋮	⋮	⋮
U.S.	.04	0.2	28

Figure 2.

New Merchant Ships Under Construction or on Order at U.S. Private Shipyards

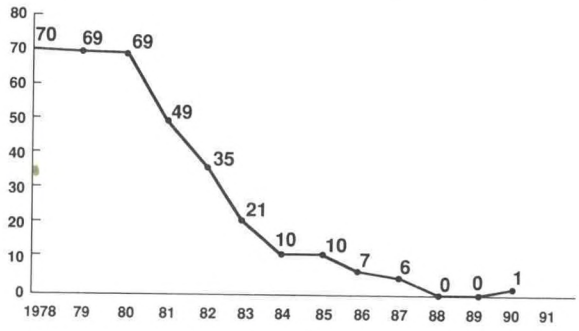

Figure 1.

RESOURCE TRENDS

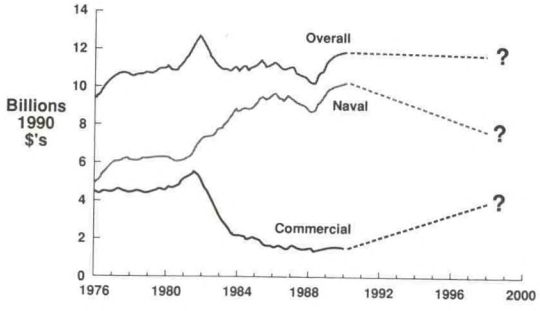

Figure 3.

and West Germany both have built commercial ships approximately twice as fast as U.S. yards and with approximately half the manhours. U.S. Navy ships are no exception. Figure 4 depicts the average cost of U.S. Navy surface combatants (frigates, destroyers and cruisers) in constant Fiscal Year 1990 dollars over a 25-year period. The average cost per year varies quite radically depending on the types of ships built per year (frigates or cruisers) and the numbers of ships built per year. However, the sharp upward trend is inescapable.

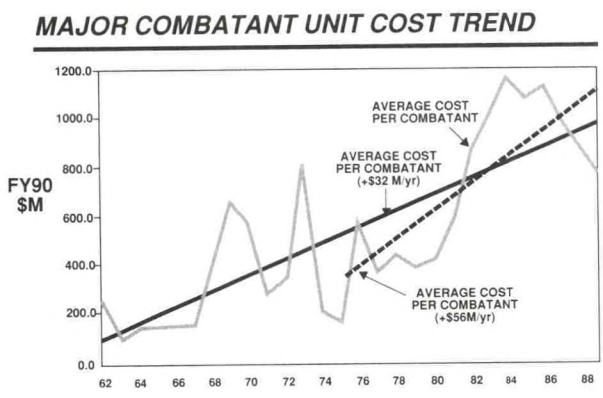

Figure 4.

If the United States is to sustain a shipbuilding industry, major changes are required. Going back to Figure 3, an average of eleven billion dollars per year (in constant Fiscal Year 1990 dollars) has been spent in U.S. shipyards over the past 15 years. As has been discussed above, the bulk of this spending in recent years has been for U.S. Navy ships, but this trend will now change. The U.S. Navy shipbuilding budget is projected to sharply decline. Some estimates predict the Fiscal Year 1995 budget to be less than 45 percent of the Fiscal Year 1990 budget in constant dollars. For the U.S. industry to be viable, a sharp increase in commercial shipbuilding will be required. This increase will materialize only with improvements in the productivity of U.S. yards.

The U.S. Navy faces a compound affordability crisis. The size of the U.S. Fleet will decrease radically with shrinking Defense appropriations and growing U.S. shipbuilding costs. Further, people maintenance costs (salaries, health care, family services, retirement, etc.) are a rapidly growing part of the U.S. Navy budget. If warships continue to be so manpower intensive in design, the U.S. Navy will have even fewer shipbuilding dollars in the future as health costs increase and retirees live longer.

Other factors are emerging that will dramatically impact the shipbuilding industries not only of the United States but worldwide. The spectre of *Exxon Valdez* has galvanized the U.S. public and consequently the U.S. Congress to an insistence upon environmental safeguards such as double hull construction for tankers (Oil Pollution Act of 1990) and perhaps other commercial ships plying U.S. waters and harbors. A stream of environmental legislation relative to ships has already inundated the U.S. Navy in recent years, as indicated in the matrix of Figure 5. Environmental laws and regulations, many of which pertain to the oceans and ships, are pouring forth from the U.S. Congress in geometric proportions (see Figure 6). Future ships will have to contain systems, possibly very expensive systems, that will prevent further environmental degradation of the oceans, harbors, inland waterways and the atmosphere. Even the most effective antifoulant ship hull coatings of today, such as the tributyltins (which, by maintaining a clean hull, drastically reduce drag and consequently fuel consumption), are being seriously challenged as environmentally toxic and are likely to be universally banned from use. Effective, environmentally benign alternatives which may affect ship design or materials will have to be developed. There is little doubt that the worldwide environmental movement will be a major factor in the ship designs of the future.

The commercial industry has been designing ships for years that minimize manning requirements. Automated machinery control systems, remote sensing, etc., are standard on modern

NAVY OPERATIONS AND APPLICABLE ENVIRONMENTAL LAW

Ships

Law								
Clean Air Act	Clean Water Act	Resource Conservation and Recovery Act	Safe Drinking Water Act	Toxic Substance Control Act	National Environmental Policy Act	Act To Prevent Pollution From Ships	Marine Protection Research and Sanctuaries Act	
(CAA)	(CWA)	(RCRA)	(SDEA)	(TSCA)	(NEPA)	PL–96–478	PL–92–632	Operations/Waste Sources
	X					X		Bilge Oily Waste
	X					X		Ballast Oily Waste
						X		Refueling at Sea
	X					X		Flight Dock Drainage
	X					X		Sewage (Human Waste)
	X							Graywater Discharge
	X						X	Hazardous Wastes
				X				Hazardous Materials
	X			X	X			Antifouling Paint Leechate
X								Stack Emissions
X								Halon/CFC Discharge
				X				PCB Equipment
	X							Firefighting Foam (AFFF)
X								Asbestos Work/Disposal
		X				X		Trash Disposal
						X		Plastics Waste Disposal
	X	X				X		Medical Waste Disposal
					X			Major Exercises

Shipboard Pollution Abatement

Figure 5.

ENVIRONMENTAL LAWS & REGULATIONS

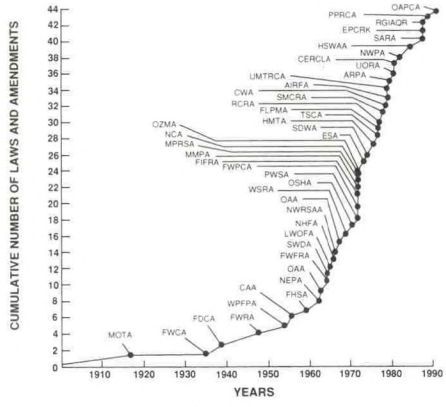

Figure 6.

commercial vessels. A modern large-capacity tanker today operates with a crew of no more than 21. The Navy, however, has been reluctant to accept comprehensive manning reduction through widescale automation of its shipboard systems for a variety of reasons, not the least of which is battle damage control. A stricken ship in battle, as has been dramatically illustrated several times in recent years in the Falklands conflict and in the Persian Gulf, requires manpower in sufficient numbers to save the ship. This manning reduction issue will be a difficult challenge to designers of future naval ships, particularly surface combatants. But, as mentioned previously, "people costs" are swallowing up the U.S. Navy budget and must be controlled.

The United States from its very embryonic beginnings has been a seafaring nation and an innovative, prolific shipbuilder. From the time of Alfred Thayer Mahan and the Great White Fleet of the late nineteenth century, a strong responsive Navy has been a cornerstone of United States policy and essential for protection of U.S. worldwide interests and commerce. Because of this, a great deal of effort is being focused upon solutions to the shipbuilding dilemmas outlined in the preceding paragraphs. Several of the concepts, innovations, technologies and processes

that are now either being introduced or are being seriously examined in the United States, with particular emphasis on programs underway at the David Taylor Research Center for U.S. Navy applications, are presented in the following text.

The U.S. Navy designs, builds and maintains a large variety of major ships. Included in this assortment are aircraft carriers, seven different types of major amphibious ships (LHA, LHD, LPD, LPH, LKA, LSD and LST) and numerous types of logistics ships (AOE, AE, AO, AOR, etc.). Each type and class is markedly different. This variety drives costly inefficiencies in construction and life cycle costs. A concept being explored by the David Taylor Research Center is depicted in Figure 7 in which a common hull design of about 40,000 tons would serve a multitude of applications. In addition to the Navy variants (aircraft carrier variant, amphibious variant and logistics variant), the design could be extended to include a sealift variant and a merchant variant. The basic design would incorporate the latest advancements in ship propulsion machinery such as fully integrated electric drive propulsion system, intercooled/regenerative (ICR) gas turbine prime movers, and advanced, efficient noncavitating propulsors (see Figure 8). Such machinery concepts allow maximum arrangement flexibility (elimination of the ponderous mechanical drive train), fuel efficiencies (ICR gas turbine engines) and lend themselves to common machinery modular design as well as offering the Navy advantages in signature reduction of its ships. Ingalls Shipbuilding of Litton Industries, Inc., in cooperation with the David Taylor Research Center, is investigating means of constructing the different functional payloads of each variant in modules and the design of the common hull form to efficiently accept the modules as depicted in Figure 9. In contrast to the inefficient, tailored, individualized buildup of each ship functional component (main propulsion machinery, auxiliary machinery, berthing facilities, mess deck facilities, etc.) in the shipbuilding yard, standardized functional modules could be manufactured in serial production throughout the country and shipped to the building yard for

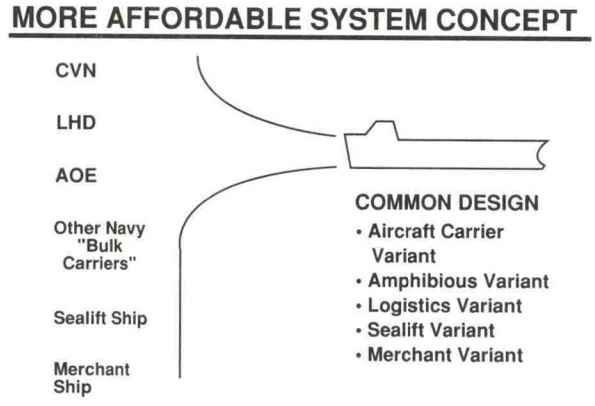

Figure 7.

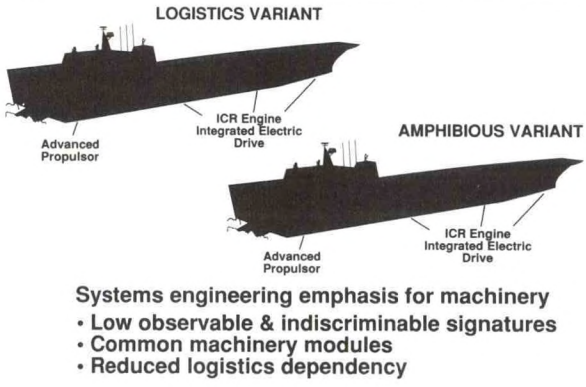

Figure 8.

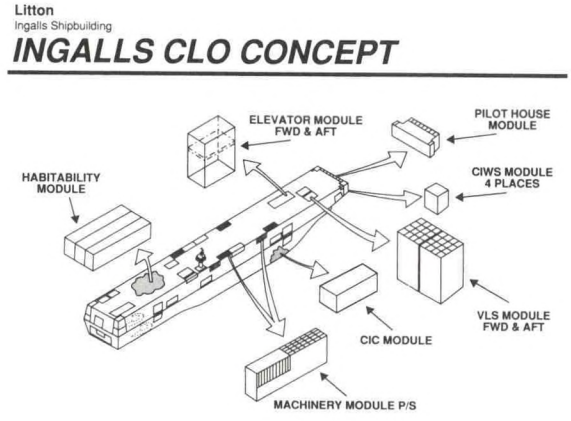

Figure 9.

assembly into the standardized common hull (Figure 10).

In designing the common hull, serious consideration is being given to incorporation of double hull construction. The double hull design not only offers environmental protection against spills when the outer hull is ruptured, but also provides naval ships with added protection against weapon impact. Further, specific double hull designs may introduce some construction savings and efficiencies by providing unobstructed paths between the hulls for the running of electrical conduits and piping and by facilitating outfitting within the smooth inner hull. Such a design is depicted in Figure 11. The double hull concept on the right is constructed entirely using longitudinal webs between the double hull plates rather than the conventional single hull construction on the left that utilizes both transverse and longitudinal strength members. This concept is under investigation and being refined by the David Taylor Research Center as well as the Newport News Shipbuilding and Drydock Company and Ingalls Shipbuilding of Litton Industries, Inc. under their Independent Research and Development Programs. A similar design is currently being employed by the Japanese in the construction of two *Epoch* Class product oil tankers by the Hitachi Zosen Corporation at the Maizuru Yard on the west coast of Japan. These designs introduce new problems in fabrication technology and processes. The difficulty of conventional welding within the restricted space between the hulls is an example. The David Taylor Research Center is demonstrating a Programmable Automated Welding System (PAWS) capable of repeatable, extremely high quality operation and especially well suited to long-seam, single-sided welds required to produce the double hull design of Figure 11. Also being investigated is use of High Strength Low Alloy steels such as HSLA 80 and HSLA 100 (developed by the David Taylor Research Center) with the benefit of high strength for considerably less material and fabrication costs.

The ship construction industry lags other industries in the use of composite materials—the automobile industry, the aircraft industry and the pleasure craft industry being specific examples. However, new tailored materials and fabrication technology and lower cost of composite materials are forcing an ever increasing usage in marine applications. Composite ventilation ducting, piping, pumps, valves, machinery foundations, heat exchangers, diesel engine blocks, and deck houses all are finding their way into new and existing ships both commercial and naval. Considerable success is being achieved at government facilities like the David Taylor Research Center and the Naval Research Laboratory and in industry in developing shipboard

NOTIONAL SHIPBUILDING INFRASTRUCTURE

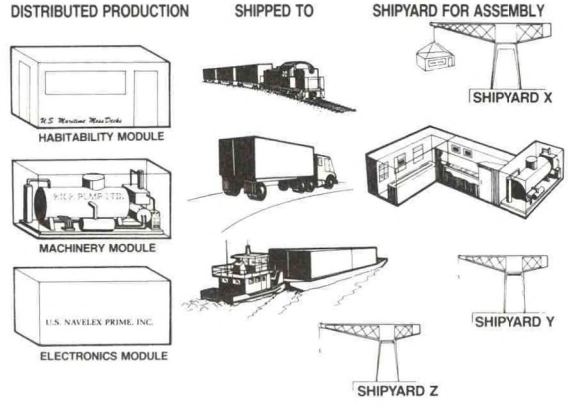

Figure 10.

DOUBLE HULL STRUCTURE

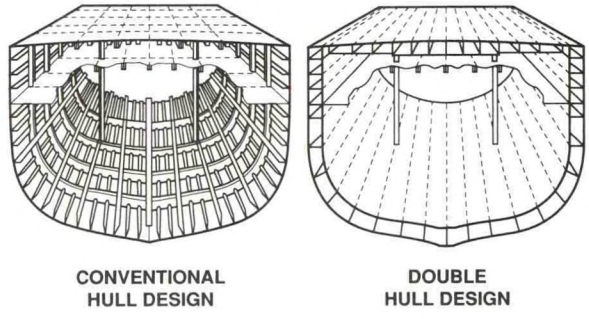

Figure 11.

composite materials that have low flammability, do not produce toxic gases when burned, are easily and inexpensively repaired and can be nondestructively tested for internal flaws or damage. The long life, low maintenance, high strength to weight and, in many applications, low cost characteristics of these materials will significantly impact future ship construction. The Navy gets an added advantage in that these materials tend to exhibit excellent low signature characteristics.



Figure 12.

Large naval ships like aircraft carriers with their 5000-man crews and long deployments tend to operate like little cities especially with respect to the generation of high quantities of trash and waste products. It is no longer acceptable to discharge untreated waste into the oceans and certain nonbiodegradable materials such as plastics are being banned in total from discharging into the oceans by international agreements. Stowage and holding of the waste generated by the "5000-inhabitant city" that is an aircraft carrier on a long deployment severely stresses the capacity of the ship. Figure 12 is a photograph of high volume plastic waste being stowed in an aircraft carrier head facility. An aircraft carrier generates 1,100 pounds of plastic waste per day occupying 800 cubic feet. On an extended deployment, heads, berthing quarters, lockers, etc., could become filled with such debris. A shipboard prototype machine has recently been developed at the David Taylor Research Center into which bags of plastic waste can be dumped. The machine shreds the waste and then compacts it with the addition of heat into a solid billet of dense sterile plastic (Figure 13) which can be easily stored aboard ship effecting a volume reduction of 30 to one. Further, when the ship returns to base, these billets are transferred to a processing plant that manufactures plastic lumber that serves a variety of uses from marine shoring planks and pilings to landscaping barriers. Figure 14 is a photograph of a park bench fabricated out of shipboard plastic waste that has been returned to the David

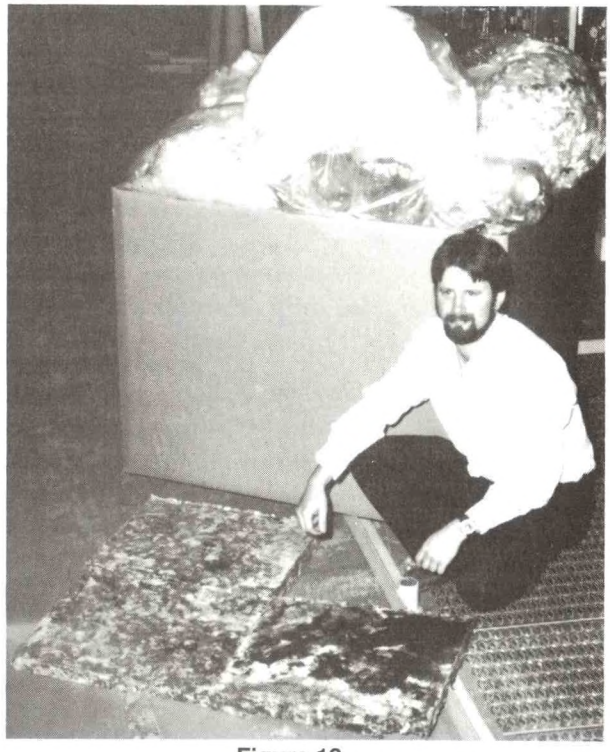

Figure 13.



Figure 14.

Taylor Research Center for its recreational use and is roughly equivalent to one day's plastic waste from a destroyer. A complete family of shipboard environmental equipment has been developed at the David Taylor Research Center, many designs of which either are now standard or becoming standard on naval ships of the United States and other NATO countries. These include shredders of biodegradable material, trash compactors, oil/water separators and human waste sanitation systems. Additional work ongoing at the David Taylor Research Center focused on developing new shipboard products that will allow ships to meet increasing environmental requirements at low cost are advanced antifoulant hull coatings that are both effective and non toxic by replacing tributyltin with natural antifoulant alternatives and efficient refrigerator and air conditioning designs that operate on chlorofluorocarbon (CFC) substitutes.

As mentioned earlier, naval ship manning reduction is an affordability mandate for the U.S. Navy and other navies faced with decreases in Defense spending. In order to reduce the need for heavy manpower requirements for shipboard damage control, in particular firefighting, the David Taylor Research Center is investigating several areas of innovative design and new technology. Some examples are a fully automated ship ventilation system that can precisely control air flow throughout the ship from a central station, the application of intumescent paints on interior bulkheads that substantially restricts heat transfer from a burning compartment, and the use of rugged composite valves that do not expand like metal valves when subjected to high temperatures making them inoperable.

The time is ripe for dramatic changes in the U.S. shipbuilding industry. The world market for new construction of commercial shipping is now experiencing a sharp increase (see Figure 15) after years of saturation. Figure 16 breaks down the new construction needs into types of shipping. Additionally, the U.S. Navy must continue a shipbuilding program in order to meet the worldwide commitments and demands of American foreign and domestic policy. Productivity must increase in American yards to meet this dual challenge. This paper has described some opportunities being pursued at the David Taylor Research Center. Other institutions in both the private and public sectors are active in shipbuilding research and development and are offering impressive innovations. New ship designs tailored to modular construction that can serve a multitude of applications both commercial and naval, serial production of standardized modules servicing the construction yards, utilization of new materials and design techniques, all can be contributors to the change. The environmental demands that will be imposed upon the shipbuilding industry can be met with innovative, affordable technology and designs even now being introduced aboard ships of the U.S. Navy. Thanks to a reasonably healthy U.S. Navy

MARKET FORECAST

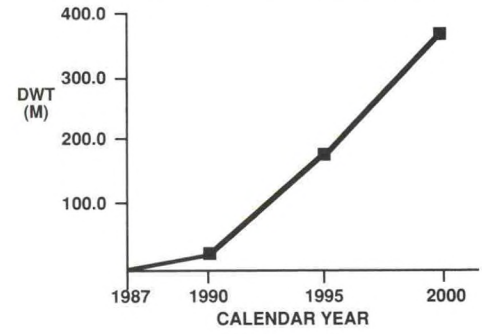

Figure 15.

MARKET FORECAST

(MILLIONS OF DWT)

TYPE	EXISTING FLEET	ADD 1990	ADD 1990-1995	ADD 1995-2000
Tankers	250	-	70	85
Bulkers	210	14	55	75
Other Cargo	130	6	30	25
Gas/Chem.	10	-	5	5
TOTAL	**600**	**20**	**160**	**190**

Figure 16.

shipbuilding research and development budget over the past decade, the industry will not be starting from scratch. But change is required.

In the late 1930's the United States shipbuilding industry experienced an unprecedented transformation. From the depths of the worst depression in modern times, U.S. yards exploded to meet the demands of World War II. New mass production oriented designs and construction techniques were introduced. New materials and fabrication technology were employed. The infrastructure was expanded with new yards, new management, new suppliers, and a substantially new workforce, i.e., the introduction of women ("Rosey the Riveter") into shipyards. This revolution occurred in the short time of a few years in the late 1930's/early 1940's. As reported in *The Naval Engineers Journal*, March 1989, Volume 101, Number 2, in "Maintaining a Maritime Force in War and Peace" by Raymond Ramsay, the results were dramatic. 71,702 military ships and craft were constructed between 7 December 1941 and 15 August 1948. Indeed, this number includes 59,715 small amphibious craft, but even excluding the small craft, leaves roughly 12,000 military ships constructed in somewhat under seven years. The average construction times from keel laying to launch were remarkably short, i.e., 16 months for a heavy cruiser, 23 months for a large aircraft carrier, 12 months for a destroyer and 11 months for a submarine. Additionally, during the war years (1941-1945) 5,777 nonmilitary ships were built to 126 different designs. At the same time, U.S. yards were extremely active in ship repair and conversion. The number of ships repaired or converted in 1942 was 5,158; in 1943 the num-ber was 17,172; in 1944, it grew to 22,014, and in 1945, it peaked at 23,558.

Although the situation facing the American shipbuilding industry today is not even remotely comparable in scale to the perils facing the nation in the early 1940's, the capacity for revolution in the shipbuilding industry was amply demonstrated in World War II. The situation in the world today demands a revolution in U.S. shipbuilding if it is to survive, and if the U.S. Navy is to continue building quality ships in sufficient numbers to maintain its world commitments. As only partially described in this paper, the tools of revolution either exist or are under development at numerous facilities throughout the United States including leading shipbuilders, the David Taylor Research Center and other private and public sector institutions. What is needed is the national will and policy to ignite the explosion. Like World War II, survival is at stake, but it is survival of an industry. The new enemy is old technology, old paradigms, uninformed and unmotivated management, certain "traditions" and much, much more. There will be no quick victories in this revolution and setbacks will be prevalent, but a start is required. The competition will not wait. Time is of the essence.

The Flarecraft: A Revolutionary Concept in Marine Transportation

Richard M. Shamp
President, ESA Inc.

A new revolutionary type of boat has been developed and brought to the marketplace. It is called FLARECRAFT.

The Flarecraft uses ground-effect technology by compressing air under its patented flare wing. It cruises over water and waves with minimum power at 75 mph, quietly and safely. No special license is required. It is easier to drive than a car.

Flarecraft is a boat with a good deal of "airplane" in its veins. That results not only in its distinctive appearance, but in a combination of speed, comfort, and fuel efficiency unheard of on the water.

To attain its speed, a planing boat has had to sacrifice load carrying capability, seaworthiness, and comfort. At high speeds, planing boats start to become airborne. From about 60 knots on they are only poorly realized aircraft, or more accurately, missiles that occasionally make contact with the water.

The Flarecraft uses a ram air cushion, or more properly, the ground effect, to rise from the water. By trapping air underneath its patented low aspect wings(like a pelican) it gains lift from the increased pressure on the underside of the airfoil. This is in contrast to an airplane that gains lift from a decrease in pressure on the upper surface of the airfoil. The primary advantage of operating in ground effect is that there is a marked reduction in drag. As compared to flight, ground effect can offer a lift-to-drag ratio increase of up to 500 percent. This allows a dramatic drop in power requirements, lowers fuel consumption, and increase payloads. Plus, the closer the craft gets to the water, the more stable it becomes.

At low speeds the Flarecraft handles just like a displacement trimaran, drawing very little water, and is quite stable. At about 15 mph the boat starts to plane on the center hull's step with the winds and outer floats providing some lift and stability, making it more comfortable than a typical planing boat at these speeds. As speed increases, so does lift, until at about 42 mph you gradually rise away from the water. It will fly from 1' to 8' over the water, depending on the power. Your only controls are a steering wheel, throttle, and trim tab. It's so stable that you can release the wheel and let it steer itself; it's agile enough to be able to bank into a 300 foot radius turn at top speed. Landings are safe and simple, only requiring a reduction in power to decrease lift. Even if the engine fails, its landing will still be gradual and stable even with hands off.

While the idea of this sort of high-speed low level flight might be intimidating to some boaters, the Flarecraft has been built to be as reassuring as possible. Using high-technology composite construction, it is strong, light, unsinkable, easily dismantled for trailering, and requires minimal maintenance. It has been designed by some of the top aeronautical and marine engineers in the world.

The initial prototypes that have been built and satisfactorily tested are a 450 pound payload (two passengers) and a 2000 pound payload unit (five passengers). The smaller one has been tested up to 75 mph and the larger unit has been tested up to 150 mph.

Units using the ground effect principle may be built in any size, up to 100-200 passengers. Their uses are myriad. They can be used for recreation, transportation (ferries and smaller), interdiction(Customs and Coast Guard), patrol craft (police and military), robotically controlled vehicles for many applications etc., etc.

The units are going into production at this time. Distributors have been set up around the world and we hope they will be seen world wide within a year.

I have brochures of the vessels and a tape if you would like to view it.



SUPERCONDUCTING ELECTROMAGNETIC THRUSTER (SCEMT) LABORATORY: DESIGN, CONSTRUCTION, AND OPERATION

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Newport, Rhode Island 02841-5047

Introduction

The Superconducting Electromagnetic Thruster (SCEMT) Laboratory is a unique test facility for the study of sea water electrodynamics and magnetohydrodynamics (MHD). Operational as of September 1990, it is located at the Naval Underwater Systems Center (NUSC), Newport, Rhode Island. Figure 1 shows a plan view of the SCEMT sea water tunnel.

The (SCEMT) is based on a rather straightforward concept. Superconducting magnet coils mounted around a sea water duct induce a magnetic field through the sea water. In addition, two direct-current electrodes mounted inside the duct produce a flow of current through the electrically conducting sea water orthogonal to the magnetic field vector and the sea water flow direction. The result is the Lorentz force or a body force acting on the flowing volume

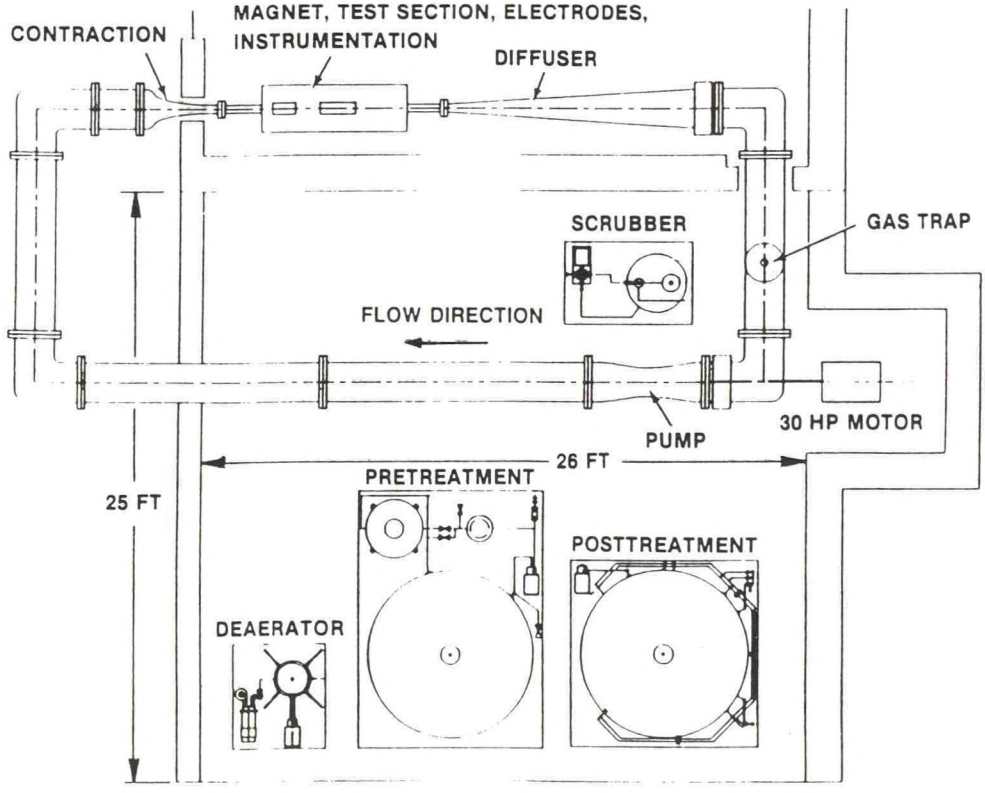

Figure 1. SCEMT and MHD Sea Water Tunnel

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of sea water, thus accelerating that fluid and providing thrust to a vehicle. The key attraction of this concept is the elimination of rotating machinery currently present in naval propulsion systems, resulting in significant noise and vibration reductions.

The superconducting magnet, an existing magnet, was refurbished and tested. It is a saddle dipole configuration with a maximum magnetic induction of 4 tesla. The warm bore diameter is 170 mm and the length of the uniform field is approximately 1 meter. The direct-current power supply is capable of fully charging the superconducting magnet in less than 20 minutes. Plans are currently underway to fabricate and install new magnets of higher fields and different configurations.

Cryogenic systems consist of a distribution system as well as storage, control, and monitoring systems for the liquid helium (LHe) and liquid nitrogen (LN_2).

State-of-the-art electrodes using dimensionally stable anode (DSA) technology were used on this project for both anode and cathode. In addition, new developments will be explored that result in environmentally acceptable oxygen evolving or in gasless electrodes for future use.

The sea water tunnel, test section, and superconducting magnet were integrated along with an instrumentation suite for MHD measurements prior to initial MHD testing. Many parameters associated with thruster performance and efficiency can be evaluated in the SCEMT Laboratory. These parameters include the magnetic field strength, magnetic field homogeneity, electrode size and current density, sea water quality and gas evolution, duct size and shape, hydrodynamic thrust output and effects. The SCEMT test section is instrumented such that the electrode voltage and current; the magnetic field; the thruster pressure increase; and the water velocity, temperature, and salinity can be measured and analyzed.

SCEMT Laboratory Hardware and Configuration

The SCEMT Laboratory hardware can be subdivided into three categories: that associated with the sea water tunnel, that associated with the super-conducting magnet, and that associated with the MHD test section. As illustrated in figure 2, the sea water tunnel hardware consists of the sea water loop subsystem, the verification test section subsystem, the pre-treatment subsystem, and the posttreatment subsystem. The major subsystems supporting the super conducting magnet include the magnet direct-current charging power supply and the cryogenic storage and distribution subsystems. The MHD test section includes the test section and instrumentation, the high-power electrodes, and the electrode power supply. Future upgrades of specific subsystems such as magnets and test sections of higher performance and alternate configurations are planned. Figure 3 is a perspective view of the facility showing the major components of the SCEMT Laboratory.

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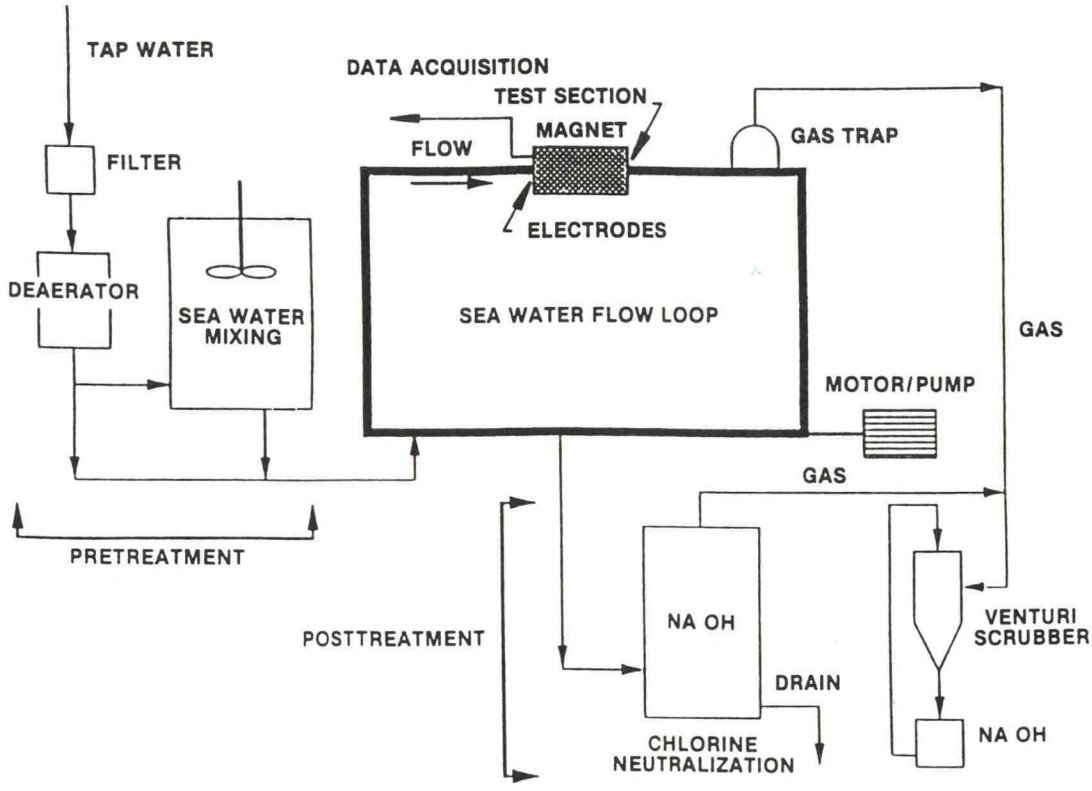

Figure 2. Major Components of the SCEMT Laboratory and Sea Water MHD Test Section

Control and Instrumentation

Instrumentation Plan. The control and instrumentation plan is subdivided into three categories: (1) the instrumentation required to safely operate and monitor the sea water tunnel and supporting facilities, (2) the instrumentation associated with operating and monitoring the superconducting magnet, and (3) the instrumentation required to acquire experimental data for the MHD process. The MHD instrumentation is primarily concerned with the sensors associated with the MHD test section.

Sea Water Tunnel Control and Instrumentation. Pertinent parameters are monitored in real time at the control room panel. These parameters include test section inlet pressure, inlet contraction and test section pressure differentials; pump speed and pressure differential; and water pH and concentration levels of hydrogen and chlorine. Signals for particular parameters relevant to MHD testing are also connected to the data acquisition system. All sequenced control operations consisting of opening/closing valves and starting/stopping equipment are performed manually in the field with the exception of

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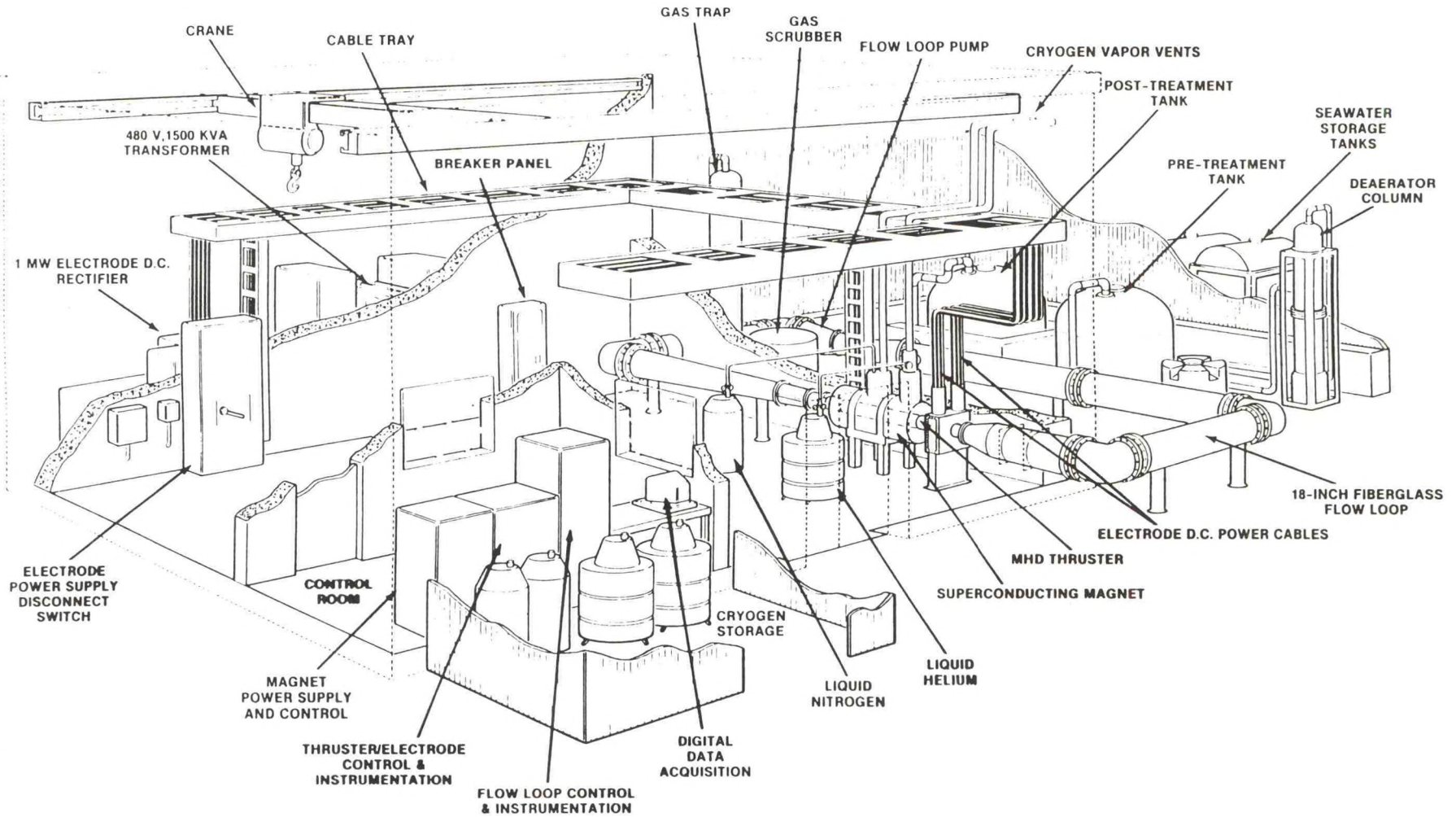

Figure 3. Superconducting Electromagnetic Thruster Laboratory

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the loop circulation pump and the flow loop valve. These operations are controlled remotely from the control room. Interfacing of control and sensor signals to and from the control room is done through a patch panel on the termination board in the control room. Instrument sensors that penetrate the loop or are otherwise exposed to hydrogen use zener barriers for safety.

Superconducting Magnet Control and Instrumentation. A number of the superconducting magnet parameters are used to indicate the operational status of the magnet during cooldown, charging, testing, discharging, and to provide feedback signals to control loops. These parameters include the liquid helium level, bore magnetic field, current, and voltage. Preparation and charging of the magnet is performed manually. Once the magnet is charged, the liquid nitrogen is automatically maintained by a supply system while the liquid helium supply is maintained manually. The magnetic field distribution was mapped prior to installation at NUSC using a gauss meter with a positioning fixture. Once the mapping was performed during this test series, a Hall probe was permanently placed within the MHD test section to measure the magnetic field at a point close to the flow channel. This signal is monitored in real time during testing and is sent to the data acquisition computer. The helium level, current, and voltage are monitored in real time.

MHD Test Section Instrumentation

Instrumentation necessary to measure the pertinent parameters involved in the sea water MHD process was included in the test section. The MHD test section, or thruster section, is the flow channel that houses the high-current electrodes and passes through the warm bore of the superconducting saddle dipole magnet.

Pressure measurements consist of both absolute and differential measurements and use transducers resistant to the high pH, contaminated salt water. The temperature sensors are platinum resistance, temperature-dectector type sensors. Water flow velocity is determined using the previously calibrated differential pressure in the sea water tunnel contraction.

Voltage taps consist of twisted pairs and shielded cables and indicate electrode voltage and sea water electrical conductivity.

Bubble visualization data are acquired downstream of the test section at the test section window array to characterize the size density and velocity of the bubbles produced as a result of electrolysis. This instrumentation consists of a gated video camera, a laser light source, and a video recorder.

Summary

The SCEMT Laboratory was designed, built, and successfully tested on schedule. This laboratory consists of the facilities and hardware necessary to conduct basic research in sea water magnetohydrodynamics propulsion. The four major subsystems, which include the sea water flow loop, the MHD thruster, the superconducting magnet, and the data acquisition system, were tested

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individually prior to laboratory integration. Results of theprocess was included in the MHD initial low-power MHD test series demonstrate the capabilities of the SCEMT Laboratory and provide a basis for the design of subsequent test programs. Future test programs will investigate high-power MHD, alternate thruster geometries, electrochemical processes, and higher magnetic fields.

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SAFETY ASSESSMENT OF HIGH SPEED VESSEL TRAFFIC USING COMPUTER SIMULATION

Yujiro Murayama, Masayoshi Numano, Keiko Okuzumi
Junji Fukuto, Fujio Kaneko, Kunihiko Tanaka
System Engineering Division, Ship Research Institute, Ministry of Transport

Introduction

Marine traffic for passengers and cargoes are highly congested in a cosmopolice such as Tokyo. The water front is also developed both for business and pleasure traffic. However, recent progress in ship building technology makes it possible to sail high speed vessels.

Standards for high speed vessels are now being investigated in Japan, incorporating standards for ship structure, fire protection and traffic safety.

Above all, the evaluation of the high speed vessels as components of the marine traffic is difficult, although the mechanical performance can be easily evaluated. It is necessary to recognize the need for high speed marine traffic to acquire the social acceptance about its safety and availability.

In the present paper, the procedure for the evaluation of high speed vessel traffic using computer simulation is proposed and discussed. The index of the evaluation, which is essential for the evaluation, is also discussed and the safety margin is proposed as the index.

Safety Assessment of Marine Traffic

Procedure of assessment

Individuality of each vessel is one of the features of marine traffic compared with land traffic. A view point of the vessel operators, such as captains and pilots is, therefore, suitable for the assessment of the marine traffic. From that point of view, a statistical approach which results in a probability of collision and stranding is not sufficient and a case study based upon the properly selected scenarios is useful. A procedure of the safety assessment is proposed as follows.

(1) Selection of the view point for the evaluation.
(2) Listing all the environmental factors and vessel performance ones which affect the marine traffic.
(3) Selection of the scenarios which isolate an effect of each factor.
(4) Selection of indices for safety margin corresponding to each factor.
(5) Execution of computer simulation according to those scenarios.
(6) Calculation of evaluation indices from the simulation results.
(7) Final assessment by a subjective evaluation of experts with calculated indices.

View point of evaluation

In the evaluation of the traffic, various view points can be considered. To control traffic, effectiveness and safety are expressed as statistical values. On the other hand, to operate each traffic component, which is one vessel of the marine traffic, effectiveness and safety are expressed as the integration of those in all cases. In marine traffic, an operator such as a captain and a pilot, is responsible for all affairs related to their own ship. The view point of the operator is, therefore, essential for the evaluation of the marine traffic.

Safety margin

Evaluation indices which represent the

safety of the evaluated system should be decided. The indices are calculated from some examination results. The safety can be defined as the opposition of the danger. In case of the marine traffic in a highly congested sea area, the danger is represented by the collision danger. The safety of the marine traffic is, therefore, often evaluated by collision probability. It is useful for the statistical approach to evaluate by collision probability.

The safety assessment of the marine traffic, however, requires the evaluation at the present state. Mechanisms of the occurrence of collision danger and keeping navigation safety by avoiding dangers should be cleared. Every system which is properly designed keeps its safety in ordinary conditions. A static performance of the system is evaluated by a document examination. When various environmental factors disturb the system performance, the system compensates the disturbance and keeps its safety dynamically. If each disturbance of the external factors can be assumed so small that it can be regarded as perturbation, the ability to compensate each disturbance can be evaluated by each respective index, which can be summed up as the total safety margin. Each index has respective value between the lower, necessary, value and the upper, sufficient, value. The total safety margin can be, therefore, defined as the weighted logical summation of all indices according to the mechanism of the compensation.[2,3]

Computer Simulation of Marine Traffic

Simulation model

The environmental condition includes a natural condition, a geographic one and a traffic one. The natural condition includes weather, sea state, wind and current. The geographic condition includes water depth, coast lines and remarked objects. The traffic condition includes vessel traffic, regal traffic routes and various vessel traffic services. Each condition has respective accuracy for the evaluation of the collision avoidance which is the chief objective of the marine traffic in a congested sea area.

The vessel condition is also one of the most effective conditions of the evaluation. Each vessel has not only its maneuverability and its outlook, but also its ability for collecting informations and decision-making which is the skill of the vessel operator.

The accuracy of each model is decided according to the simulation scenario. A simple model of maneuverability is sufficient for the safety assessment of marine traffic. In the scenario, some perturbations on some evaluation factors are set and the results of the simulation lead to respective evaluation indices.

Simulation system

To perform the evaluation simulation, a flexible computer simulation system should be constructed. In Ship Research Institute, a computer simulation system 'SISANAM(Simulation System for Automatic Ship Navigation and Vessel Traffic Management)' has been constructed for the evaluation of the intelligent ship.[1,4] The simulation system performs a real time simulation of vessel traffic in Tokyo Bay with visual monitors of a sight from a bridge, a RADAR/ARPA(Automatic RADAR Plotting Aids) etc.. The system is explained shortly in the appendix. For the manner in which high speed vessel traffic are treated in the present paper, the simulation system had to be slightly modified. First, the sight from a bridge is improved for the use of the ship operation because the old SISANAM had not an adequate man-machine-interface for the vessel operation. Secondly, the simulation period, which means a time

interval for changing each state variables in the simulation is shortened because more rapid change of the state variables is required to realize a high speed vessel simulation. Although a hard ware restriction such as a cpu speed, a drawing speed etc. prevents the sufficient improvement, some results of the real time simulation for the high speed vessel traffic can be acquired.

Simulation scenario

In the present paper, only a collision danger is considered for simplicity. In fact, the collision danger is the biggest problem in a highly congested sea area. A scenario is considered to be a sequence of the occurrence of the dangerous situation and the recovery of it. The occurrence of the dangerous situation is started at an encounter between several vessels. The encounter condition includes an encounter angle, a recognized distance, an approaching speed, types and number of encounter vessels etc.. As the recovery of the collision danger requires an adequate information about the encounter, a natural environmental condition which affects the visual information and onboard devices which support the vessel operator collecting the information.

The scenarios are selected to clear the effect of the encounter condition and the information about the encounter.

Simulation results

Some vessel operation simulations are performed to evaluate the effects of the information about the encounter condition on the collision avoidance.

The simulation results are evaluated both from the view point of the operator of the high speed vessel and the operator of the target vessel which is an ordinary speed vessel.

As the simulations are performed coincide with the preparation of the integrated examination planned in 1991, only a qualitative evaluation has been made. The results show that a high speed vessel can clear various encounters easier than an ordinary speed vessel. In spite of the high speed vessel being easy to operate, the evaluation from the view point of the operator of the encountered ordinary speed one is not so good that the ordinary speed one couldn't avoid collision by itself. It is because there is some ambiguity in the behavior of the high speed vessel and a distance of a point of approach is too short for the ordinary speed one.

Indices of the safety margin should represent margin in time and distance in the collision avoidance maneuver from the view point both of a high speed vessel and of an ordinary speed one.

Concluding Remarks

High speed vessels will be used in marine traffic more popularly than now. Safety assessment of high speed vessel traffic is necessary before their practical use. The safety assessment includes evaluation of collision danger and smoothness of traffic. High speed vessels should not menace or disturb other vessels as well as avoiding collision. A statistical approach is often adopted, where several kinds of probabilities and statistics are estimated. An assessment by the statistical approach is not sufficient because it doesn't include dynamics explicitly in the traffic. It is, therefore, useful to investigate typical cases by a computer simulation.

The investigation by a computer simulation can be modeled as follows.
(1) Environments and functions in vessels are simulated to a sufficient degree,
(2) A behavior of a vessel in

collision danger is simulated, where the effects of environmental factors, vessel performance and operators are taken into account,
(3) Scenarios are selected according to which effect of each factor is obviously cleared,
(4) Simulation results are analyzed and respective indices are calculated,
(5) Mechanisms of the occurrence of danger and the recovery of it is cleared and the mechanism for the compensation of each disturbance is also cleared. Logical summation of all indices according to the mechanisms expresses a total safety margin of the vessel traffic,
(6) Final assessment is made subjectively by experts of vessel operations with the aid of the calculated indices.

As the simulations for the assessment are now being performed, a quantitative evaluation hasn't been obtained yet. As a qualitative evaluation, a safety margin can be regarded as sufficient time from the view point of a high speed vessel operator and sufficient distance from that of an ordinary one.

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Appendix

Computer simulation system, modified for high speed vessel simulation

Hard ware composition A host computer of the system is a multi-process one with a vessel operation terminal and a RADAR/ARPA monitor. Two graphic work stations are connected through network, which show a sight from a bridge of one of the vessels in the simulation. The sight covers 60 degrees horizontally and 24 degrees vertically. One can operate a vessel by a rudder angle and a vessel velocity order using a steering wheel and a lever, respectively.

Soft ware characteristics A simulation is governed by a set of data called a simulation scenario. The scenario decides various environmental conditions and vessel performances etc. by constructing respective data and using respective processes. A simulated world is expressed as state variables in a global memory section which is renewed by respective processes at respective intervals. Processes included in the simulation perform respective roles such as realizing vessel motions etc. and are initiated and driven at different time intervals according to the class of each process. In this simulation system, data and program are completely separated. An object oriented construction of the simulation can be, therefore, attained using a simulation scenario and a set of processes, which enables a flexible simulation.

BASIC RESEARCH ON GUIDE WAY

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1. Introduction

In Japan, many ports and harbors were built facing the open sea after the Second World War. As many of these new ports and harbors are located in regions with severe natural environment (in terms of waves and wind), their functions are significantly hindered in certain seasons. Although fishing harbors were used to be constructed at calm sea at one time, many fishing harbors were built in regions with severe natural conditions facing the open sea together with the development of fishery and advent of the 200 mile exclusive fishery zone. As a result, securing the safety of fishing boats that enter and clear harbor in stormy weather became an objective of fishing harbor improvement in addition to securing safety of fishing boats moored inside the harbor.

In this research, we investigate the interrelation between the condition of the waves outside the harbor and the problems that exist in harbors of today, and propose problems at the time of entering harbors under strong wind waves. Then "Guide Way" is proposed as a new harbor facility to solve the problems at the time of entering and clearing harbor. The kinetic energy of the ships when they are drifted by wind waves as they enter the harbor is estimated to determine its structural form and strength. Therefore, a numerical simulation concerning the behavior of ships drifted by wind waves and an experiment of a drifting model ship in a wind tunnel with water tank are carried out to confirm the fundamental properties of a drifting ship. We examine the basic structure of "Guide Way" for fishing harbors.

2. The problems of entry into general ports and fishing harbors under strong wind waves

2.1 Entry problem at general ports

2.1.1 Wave characteristics of ports and problems of entry

Fig. 1 shows the duration of waves exceeding certain height and frequency of their occurrence during winter in Port N facing Sea of Japan. On the other hand, Table 1 shows the limit condition of entry according to researches (Kubo et. al, 1990) that have been conducted in the past. Though the limit of operation in which entry of ships is possible is determined by various conditions and cannot be determined unconditionally, it can be seen to be about 2 meters in terms of wave height. Combining this limit value with the wave characteristics at Port N shown in Fig. 1, the possibility of a ship having to wait outside the port for 24 hours is about 10 times during a winter season.

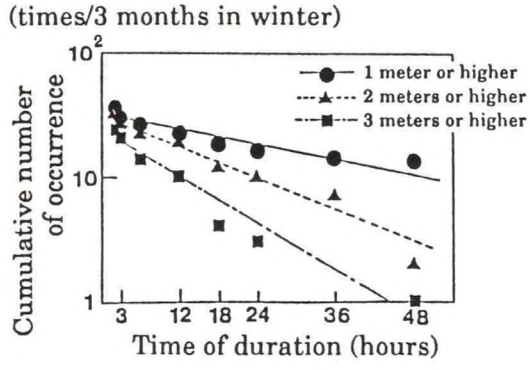

Figure 1. Characteristics of Wave Duration in Winter at Port N Facing Sea of Japan

2.1.2 Problems of ports under strong wind waves as seen from seamen

Fig. 2 is a regional division of problems of ports

Table 1. Limit Condition of Entry

Name of harbor	Kind of Ship	Limit conditions	Remarks
	Supertankers	Wind velocity 15 m/sec, wave height 1 m current 1 knot	Referred to the results of a questionnaire carried out by the Supertanker Safety Council of Japan Maritime Disaster Prevention Association
7 major harbors in the jurisdiction of the First District Port Construction Bureau	All kinds of ships	Wind force 6 – 7 (10 – 17 m/sec), wave class 4 – 5 (about 2.5 m)	Referred to the results of a questionnaire carried out by Harbor Safety Measure Study
West Port of Niigata		Wind velocity 10 – 15 m/sec, wave height 2.0 – 2.5 m	Compared ship entry according to ship entry record and wave height outside the harbor
	Ocean liners	Wind velocity 10 – 15 m/sec wave height 1 – 2 m, visibility 1000 – 2000 m, UKC is about 10% of draft	Referred to data owned by shipping companies and the results of a questionnaire to pilots

as seen from seamen which was obtained through study of data (Kubo et. al, 1990) owned by shipping companies and questionnaires to pilots. The characteristics are as follows:

1) Southwestern Pacific region
Influenced strongly by swell caused by typhoons which occur from summer to fall, resulting in hindrance of safety of moored ships such as interruption of cargo handling and breakage of mooring line.

2) Bays and inland seas
These Ports are favored by climatic and oceanic conditions. In terms of harbor improvement, high-quality improvements are being made.

3) Regions from North Kanto to East Hokkaido
Safe mooring is hindered by the impact of wind waves and swell as well as by delay in improvement of breakwater. Waiting for harbor entry is also caused by stormy weather.

4) Regions facing Sea of Japan
Influenced tremendously by wind and waves of winter monsoon. Existing conditions including delay in improvement of counter facilities such as breakwater and shortage of tug boats cause problems such as not being able to enter port due to stormy weather, accidents while being moored, interruption of cargo handling and difficulty of ship handling inside port.

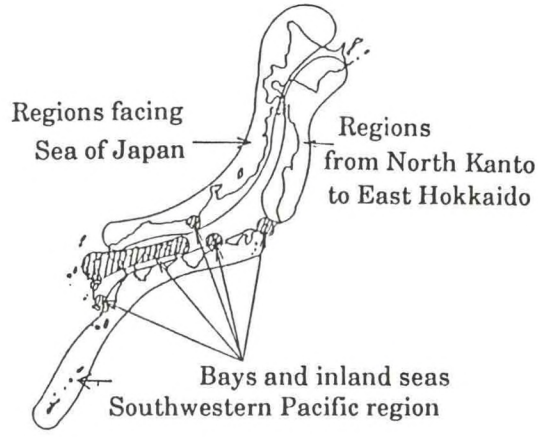

Figure 2. Regional Division as Seen from Problems of Ports

Thus the problems of present ports are clarified through natural environment and opinions of seamen. As these problems were also recognized by people preparing sailing schedule, a questionnaire concerning sailing schedule was carried out to shipping companies operating their ships on domestic route. According to the questionnaire, it is found that the impression of ports with

severe natural environment is not good and that shipping companies tend to avoid sending their ships to ports facing Sea of Japan in winter. Consequently, as shown in Fig. 3, this has lead to reduction in number of ships entering ports facing Sea of Japan in winter. Such reduction in number of ship services to the ports of Sea of Japan in winter is considered to be one of reasons in lower economic position of regions on the Sea of Japan side. Taking some measures in terms of port improvement and seeking to create ports that can operate steadily throughout the year (weather-proof ports) will be important to realize substantial promotion of these regions.

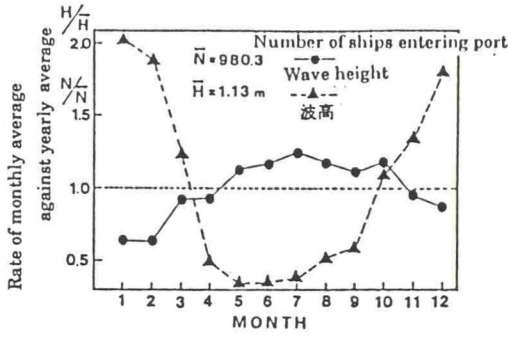

Figure 3. Relation Between Number of Ships Entering Port and Offshore Wave Height at Port N Facing Sea of Japan

2.2 Entry problem at fishing harbors

2.2.1 Problems of harbor entry of fishing boats as seen from sailing directions and casualties

Table 2 is a list of fishing harbors included in sailing directions (Maritime Safety Agency, 1985, 1986, 1987, 1988, 1989) that have severe wave conditions and require cautions upon entry.

Further, Table 3 is a list of fishing boat casualties that occurred near the harbor entrance due to stormy weather (Marine Accidents Inquiry Agency, 1984, 1985, 1988). As casualties of fishing boats often lead to accidents which result in injury or death, improvement of safety at the time of harbor entry is considered indispensable in securing the population that supports the fishery.

Table 2. Precautions for Harbor Entry Listed in Sailing Directions

Name of Harbor	Precautions for harbor entry
Tokachi Harbor	Full caution is required with regard to ship handling when there is strong wind in northeast or southeast direction because chopping seas are created at the tip of the south breakwater and swell usually turns into beam seas. Local fishermen do not enter the harbor at night under such conditions.
Yaene Harbor	Waves are high near the harbor entrance when westerly is strong, making entry difficult.
Fukui Harbor, Mikuni District	Chopping seas are created when northwestern wind is strong, creating difficulties in maintaining direction.
Tottori Harbor	The area near the harbor entrance gets rough when there is strong northern wind to make entry sometimes difficult.

Table 3. Cases of Casualties Near the Harbor Entrance

Name of harbor	Kind of ship	Summary of casualty
Fishing Harbor of Sakazuki, Hokkaido	35 ton fishing boat	Went aground after being pushed by high waves. (Convergence of waves is having negative impact on harbor entry and clearance.)
Fishing Harbor of Nakanosaku, Fukushima Prefecture	59 ton fishing boat	Shipwreck caused by swell and high waves. (Swell in eastern direction is dangerous as it creates high waves in shallow water.)
Fishing Harbor of Nobeoka, Miyazaki Prefecture	6 ton fishing boat	Capsized after running into high waves in a narrow channel. (Accidents have frequently occurred at the narrowest portion of the channel due to extraordinary high waves.)
Fishing Harbor of Kumaishi, Hokkaido	39 ton fishing boat	The fisherman fell into water due to the rolling of the boat after being hit by a beam sea when going into the harbor entrance during high waves.

2.2.2 Present conditions of fishing harbors facing Sea of Japan in winter

We visited harbor H facing Sea of Japan to clearly understand the problems at fishing harbors under stormy weather, and inquired the local people about the actual situation and performed the hearing study on the safety of ships when entering the harbor and about "Guide Way".

Fig. 4 is an outlined diagram of Harbor H. One of the characteristics of improvements that are provided to this harbor is the placement of several breakwaters offshore from the harbor entrance to improve the safety of ships entering the harbor. Although the placement of these offshore breakwater has secured the safety of harbor entrance to a certain degree, the desire to further improve the harbor entry is strong in the results of our hearing study.

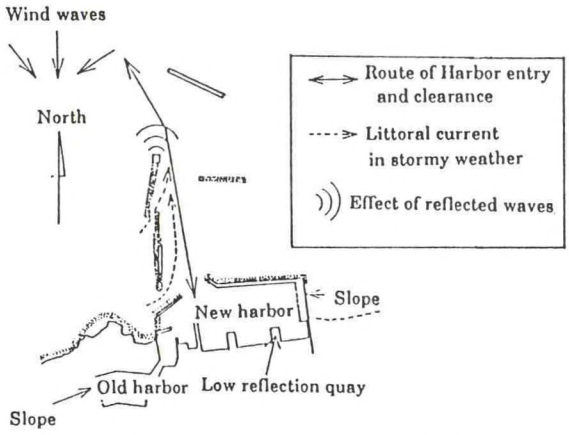

Figure 4. An Example of Present Condition of Fishing Harbors Facing Sea of Japan

3. Proposal for improvement of harbor entry problem

As mentioned above, harbor entry of ships becomes difficult when the condition of wind waves is severe. Under such circumstances, expenses are increased at general ports as ships has to wait offshore, while safety is hindered at fishing harbors. Therefore, the conditions with which a port needs to equip itself to enable safe entry and clearance in stormy weather are as follows:

1) Make a small leeway for entering ships so that narrow port entrance can be passed safely.
2) Tug boats and pilot boats can go outside the port safely.
3) Safe changing of ships by pilots is possible

In view of these requirements, placement of "Guide Way" as shown in Fig. 5 is proposed at the entrance of ports and harbors facing the open sea with severe natural environment. In other words, it is a method of having ships navigate along the facility, thereby dissolving the leeways from becoming big. Meanwhile, the psychological safety that Guide Way provides as a support at the time of strong drift is expected to be significant even if ships do not navigate along the facility. In addition, the facility itself has certain wave dissipating effect, enabling boats such as pilot boats and tug boats to go out of the port in stormy weather. Moreover, placement of a pilot station will enable safe changing of ships by pilots. Performances required in such a facility include the following:

A) Has sufficient capacity to absorb kinetic energy so that it can safely catch drifting of ships.
B) Has small reaction force to prevent giving damage to ships.
C) The reflection ratio of the facility is as small as possible so that ships can come close.
D) Is a structure that can endure severe natural conditions (wave, wind, current)
E) Ships can navigate smoothly along the facility.
F) Will not couse significant changes in littoral current or sediment at the fairway or the harbor.
G) Has adequate scale in terms of durability and maintenance.

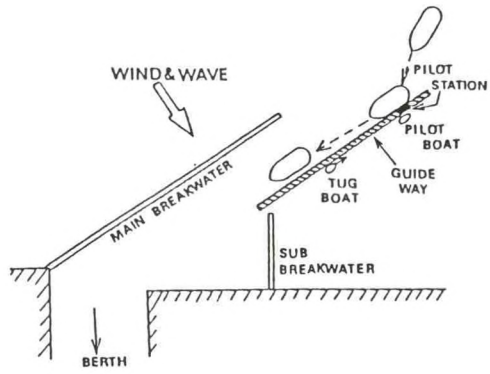

Figure 5. Concept Diagram of Guide Way

4. Basic research on Guide Way

The experiments of the ship drifting until reaching steady state when a beam wind blows a

tunnel with water tank, and simple numerical simulations are carried out. In addition, the fundamental structure is conceived with 20 G.T. fishing boat in mind to examine the possibility of realization.

4.1 Behavior of ships drifting from wind waves

4.1.1 Apparatus and method of the experiment
As shown in Fig. 6, the experiment is conducted at the open wind tunnel with water tank at Kobe University of Mercantile Marine. In the experiment on drifting of ship by wind, a 1/50 model of a three islander (in full load condition) is placed in local wind velocity of 15-35 m/sec, using simultaneous filming by four video cameras to measure the drift speed and the bearing of the model ship and performing simple measurement of wind current by floating small pieces of paper at the same time.

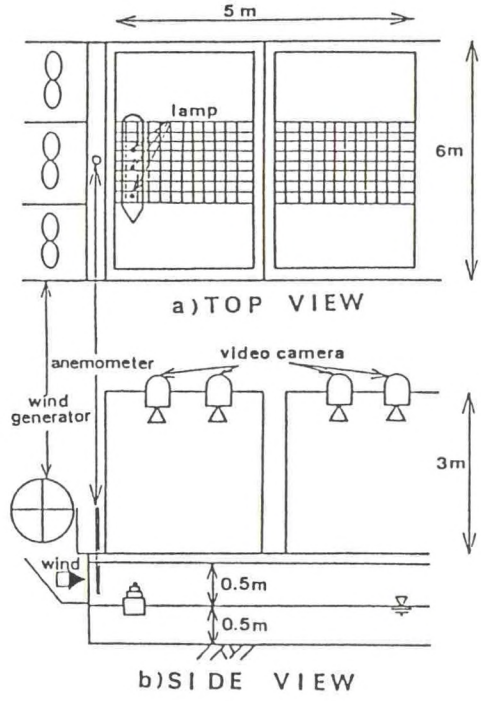

Figure 6. Experimental Arrangement of a Ship Drifting by Wind

4.1.2 Method of numerical simulation
As shown in Fig. 7, assuming that the movement of a ship drifting leeward is a O-XY plane motion, the movement can be described as follows:

$$m_x\dot{u} - m_y v\dot{\psi} = X_a - X_w + X_w' \quad — (1)$$
$$m_y\dot{v} - m_x u\dot{\psi} = Y_a - Y_w + Y_w' \quad — (2)$$
$$I_{zz}\ddot{\psi} = N_a + N_w + N_w' \quad — (3)$$

where,
- m_x : normal virtual mass of the ship
- m_y : side virtual mass of the ship
- I_{zz} : virtual moment of inertia of the ship
- u : normal velocity
- v : side velocity
- ψ : ship bearing

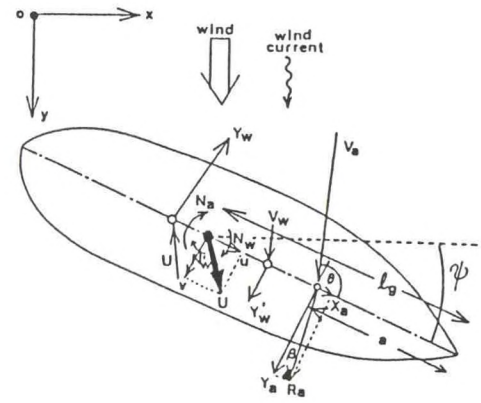

Figure 7. Definition of the Coordinate System of Drifting Ship

X_a, Y_a and N_a are external wind forces for which the following experimental formulas (Iwai et. al, 1962) are used,

$$R_a = 0.5\rho_a C_a V_a^2(A_a\cos^2\theta + B_a\sin^2\theta) \quad — (4)$$
$$X_a = R_a\cos\beta \quad — (5)$$
$$Y_a = R_a\sin\beta \quad — (6)$$
$$N_a = (l_g - a)\,Y_a \quad — (7)$$
$$a/L_{pp} = 0.291 + 0.0023\theta \quad — (8)$$
$$\beta = 90\,\{1 - 0.15\,(\theta/90) - 0.80\,(1 - \theta/90)^3\} \quad — (9)$$
$$C_a = 1.325 - 0.05\cos2\theta - 0.35\cos4\theta - 0.175\cos6\theta \quad — (10)$$

where,
R_a: wind force, ρ_a: air density, C_a: drag coefficeint, V_a: relative wind velocity, A_a: front view, B_a: side view, θ: angle of relative wind velocity, β: angle of wind force, a: acting point of wind force, l_g: center of gravity, L_{pp}: length between perpendicular (2.26 m).

Further, Y_w and N_w are water pressures that act on the ship by the drifting of the ship for which the following experimental fomulas are used,

$$Y_w = 0.5\rho_w C_w U^2 L_{pp} d \quad — (11)$$
$$N_w = 0.5\rho_w C_m U^2 L_{pp}^2 d \quad — (12)$$

where,

ρ_w: water density, C_w: side coefficient of current force, C_m: moment coefficient of current force, U: drifting speed, d: draft.

Further, Y_w' and N_w' are water pressures that act on the ship by wind current for which the following experimental formulas are used,

$$Y_w' = 0.5\rho_w C_w V_w^2 L_{pp} d \quad — (13)$$

$$N_w' = 0.5\rho_w C_m V_w^2 L_{pp}^2 d \quad — (14)$$

where, V_w is the speed of wind current. X_w and X_w' are ignored in the simulation because side force exceeds regardless of the drifting direction. In numerical simulation, Euler's integral is performed to obtain positions of the ship, drifting angle and drifting speed at each time after starting the simulation.

4.1.3 Drifting of ships according to experiment and numerical simulation

Fig. 8 shows the drifting speed of a ship by wind obtained by experiment and simulation. The calculated value when wind current is taken into consideration (wind current is regarded as 1/66 of wind velocity in the experiment) shows a fairy good agreement with experimental one. As a result, it becomes clear that drifting speed in steady state is about 1/20 of wind velocity and that drifting speed reaches steady state in about 1/2 distance of the ship length after starting to drift. Further, the same tendency is observed in an experiment where wind velocity and the wind receiving side are altered.

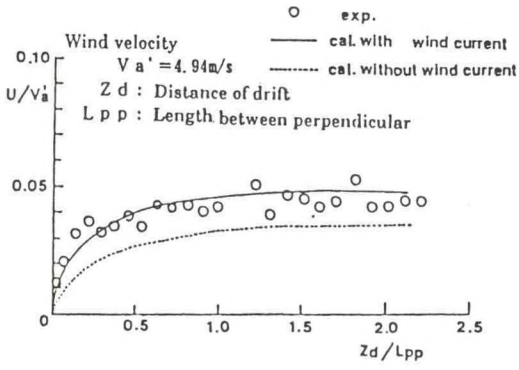

Figure 8. Drifting Speed When Only Wind is Acting

4.1.4 Drifting speed of ships under wind waves

The drifting speed of a ship is obtained through a simple balance of force as shown in the following equation,

$$1/2\rho_a C_a B_a (V_a - U)^2 + 1/2\rho_w g L (K_r\zeta_0)^2 = 1/2\rho_w C_w L d (U - V_w)^2 \quad — (15)$$

where,

ρ_a: air density, ρ_w: water density, C_a: side force coefficient, C_w: side coefficient of current force, B_a: side view, L: ship length, d: draft, K_r: ship's reflection ratio against incident waves, V_a: wind velocity, V_w: wind current velocity, g: gravity acceleration, U: drifting speed, ζ_0: amplitude of incident waves.

The first term on the left hand side of Eq. (15) refers to wind pressure, the second term to steady state drifting force and the right hand side to current pressure which acts as resistance. Here, wind current velocity V_w can be expressed as $V_w = 0.0168V_a$ by substituting 35 degrees as latitude to wind factor in infinite water depth (JSCE, 1971). In addition, the amplitude of incident waves ζ_0 can be expressed as a function of wind velocity V_a (Ishida, 1988) and shall be $\zeta_0 = 0.0075V_a$ according to observation data of wind velocity and wave height at Port K facing Sea of Japan. By substituting these values to Eq. (15), Eq. (15) can ultimately be written in the following equation,

$$U/V_a = \{- B - (B^2 - 4AC)^{1/2}\} / (2A) \quad — (16)$$

where,

$$A = \rho_a C_a B_a - \rho_w C_w L d$$

$$B = 0.0336\rho_w C_w L d - 2\rho_a C_a B_a$$

$$C = \rho_a C_a B_a + 5.625 \cdot 10^{-5} \cdot \rho_w g L K_r^2 - 2.8224 \cdot 10^{-4} \cdot \rho_w C_w L d$$

To confirm whether it is possible to apply Eq. (16), steady state drifting velocity under wind and that under waves are compared with the results from the water tank experiment.

Since the experiment under wind is already performed in 4.1.3, an experiment of ship drifting under waves is performed as shown in Fig. 9.

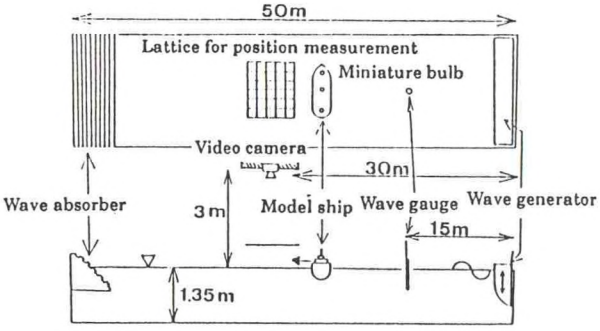

Figure 9. Ship Drifting Experiment Using Regular Waves

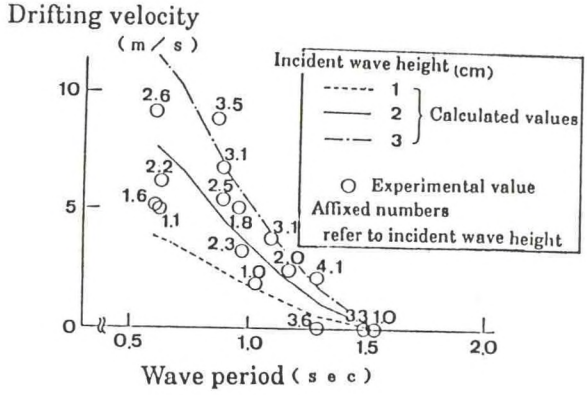

Figure 10. Steady State Drifting Velocity Under Waves

By substituting the specifications of the model ship that was used in the experiment (L = 2.26 m, d = 0.147 m, B_a = 0.2975 m^2) to Eq. (16) when only wind is acting, the value U/V_a = 0.048 is obtained in the experiment as opposed to U/V_a = 0.050. Fig. 10 shows the experiment for cases under waves and steady state drifting velocity calculated from Eq. (16). The value calculated by two-dimensional boundary element method (Kubo et. al, 1990) is used for the reflection ratio K_r of the ship. Thus, it is confirmed that calculations can represent experiments relatively well even in cases where only waves are acting. It is assumed from the above that steady state drifting velocity of a ship under wind waves can be calculated through Eq. (16).

4.2 Guide Way at fishing harbors

4.2.1 Kinetic energy of fishing boats acting on the Guide Way

Using the hearing study carried out at fishing harbors as reference, condition for the use of Guide Way shall be set to wind velocity of 15 m/sec and significant wave height of 2 m. When coming in contact with Guide Way while drifting, drifting velocity will be U/V_a = 1/20.47 if Eq. (16) is applied to a subject 20 G.T. fishing boat (L = 14.9 m, B_a = 13.5 m^2, C_a = 1.1, C_w = 0.7, K_r = 0), which is approximately 1/20 of wind velocity. Further, since the usual sea speed of a 20 G.T. fishing boat is about 10 knots, the velocity at which it will come in contact with Guide Way shall be set to 2.6 m/sec. Furthermore, a study (Motora et. al, 1981) has suggested the possibility of broaching-to caused by the relation between the ship's length, wavelength and ship's velocity. Since broaching-to occurs at velocity of 14 knots in the case of 20 G.T. fishing boat and its speed of harbor entry is about 5 knots, it coming in contact with Guide Way in broaching-to state will not be considered here. Thus, the kinetic energy ascting on Guide Way shall be about 10 t-m.

4.2.2 The concept of energy absorption device

Although the ship that is being considered now is 20 G.T. fishing boat, the limit of reaction force at the energy absorption device shall be equal to the limit of elasticity of the hull of the ship in question. The absorbing kinetic energy needs to 10 t-m and it is necessary to minimize the limit of reaction force. Moreover, considering the 1/4 point berthing to Guide Way, it is dif-ficult to take the entire side of the hull for shock receiving area. The method of shock receiving needs to be decided so that shock receiving area will become larger than certain area due to restriction from the allowable reaction force.

4.2.3 Fundamental structure of Guide Way

As mentioned in 3, there are various performances required in Guide Way. When conceiving the fundamental structure, however, the requirements (A) through (D) will have to be fulfilled at first. Therefore, the fundamental structure of Guide Way is conceived as shown in Fig. 11. In this facility, shock receiving area is made large by adopting a net as shock receiving surface and the net system enables to minimize the reflection ratio and reaction force.

Furthermore, the above require-ments can be met with regard to energy absorption by adopting a dashpot that can take long stroke.

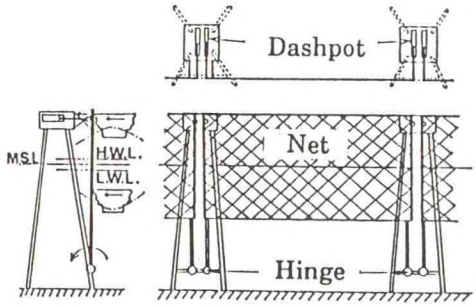

Figure 11. Fundamental structure of Guide Way

5. Conclusion

In harbor constructions that have been performed up to now, the emphasis was on reducing waves inside harbor by extending break-water. Nevertheless, breakwater is not necessarily a sufficient measure for ships entering harbor at entrance. On the contrary, making harbor entrance narrow causes an obstacle for ships that are difficult to handle in stormy weather. Therefore, it is necessary to secure the sufficient tranquility at harbors through a facility in addition to breakwater from the viewpoint of the safety of ship entry.

"Guide Way" has been presented as one of the means towards this goal. Further, the fundamental structure is conceived with 20 G. T. fishing boat in mind to examine the possibility of realization. While many problems, including shock absorbing system, structural form, durability of materials, need to be solved in order to apply this structure to real situation, the effort towards realization of "Guide Way" will continue with zeal in the future.

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RESEARCH AND DEVELOPMENT PROGRAMME OF TECHNO-SUPERLINER

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Technological Research Association
of Techno-Superliner

1. INTRODUCTION

Following the recommendation of the Council for Transport Technology, a five year R & D programme for Techno-Superliner was launched in 1989, in order to contribute to the enhancement of ship technology and the reformation of seaborne transportation.

A target of the Programme is to accomplish the technological foundation for developing and building of a super high-speed ocean going cargo vessel, named "Techno-Superliner'93" with a performance of 50 knot in speed, 1,000 tons in payload, and over 500 nautical miles in range. In addition, sufficient seaworthiness of the vessel capable to navigate on schedule, even though in rough seas is desired.

2. BACKGROUND

Conventional merchant vessels represented by tankers, bulk carriers and container ships still play a significant role in mass transportation comparatively at a low speed. Meanwhile, ongoing changes in economic social structures such as small-lot but high-value production with a wide variety and dispersion of production facilities both domestically and abroad require much faster marine transport. Civil aviation, the general choice for fast transportation, is rapidly expanding, centered on the transport of manufactured goods and fresh foodstuffs re-

sulting from development of the world economy and expansion of the trade. Trucking is also progressing rapidly in land capitalizing on door-to-door service and a reasonable rate.

These modes of transport, however,considerably vary in speed, rate and capacity. The social economy demands an intermediate means of transport to fill the gaps among them. In addition, limitations on airport and express ways will bring worries of a peak in civil aviation and trucking sooner or later.

In the event Techno-Superliner makes its debut in seaborne transportation, it is prospected that the ship has an impact upon physical distribution systems and contributes for shifting the modes.

3.THE ASSOCIATION OF TECHNO-SUPERLINER

In order to accomplish the R & D Programme, Technological Research Association of Techno-Superliner was established in 1989 by seven leading shipbuilders as follows;

Hitachi Zosen Corporation
Ishikawajima-Harima Heavy Industries Co. Ltd.
Kawasaki Heavy Industries, Ltd.
Mitsubishi Heavy Industries, Ltd.
Mitsui Engineering & Shipbuilding Co. Ltd.
NKK Corporation
Sumitomo Heavy Industries, Ltd.

These shipbuilding companies have shown the will and ability to explore advanced and innovative new hull form concepts cooperatively and to overcome all fundamental breakthrough technologies necessary for developing and realizing those concepts. They also have wide experience today in manufacturing almost all kinds of high-speed vessels which are still small and current type.

The term of this R & D Programme is for 5 years from 1989 to 1993, throughout which the technological foundation for Techno-Superliner will be established through analysis, experiments and tests. The last year of the Programme will be devoted to confirm these technologies by scale model tests in actual seas. Debut of the actual ships is expected to be made in the latter half of the

1990s, so that each shipbuilder should provide his own design and construction technologies in a few years succeeding to the technological foundation achieved by the Programme.

The R & D Programme has a total budget of about 10 billion Yen for five years.

4. TECHNOLOGICAL IDEAS

There are three forces to support a total ship weight, viz., buoyancy, dynamic lift and air pressure. Each of them shows advantages and disadvantages itself as the ship supporting force and no one can satisfy individually the four main requirements of a large and high-speed ocean going cargo vessel, Techno-Superliner. Therefore, pursuit of a hybrid hull form concept which combines the supporting forces in multiple is considered inevitable.

At the first stage of the Programme, we have started study in taking two hull forms as most promissing concepts. The one is an innovative hull form concept that is a combination of fully submerged hydrofoils and a submerged hull which is supporting about a half of the ship weight. This concept features superior seaworthiness, in particular, easy ride, because it has no hull element near the water surface except the struts. However, comparatively a large engine power necessary and poor stability without natural restoration are considered to be improved. The other is an advanced hull form concept similar to the surface effect ships that are supported by air pressure mainly and bouyancy of catamaran subsidiary, though it has comparatively long and narrow dimensions and with small control fins. That concept features superior powering performance due to its small hull form resistance and light structural weight. However, anxiety still remains on its comparatively poor seaworthiness, in particular, high-level accelerations and fragilation of seals. These weeknesses are also considered to be overcome in the Programme.

5. RESEARCH SUBJECTS OF THE PROGRAMME

Research subjects of the R & D Programme that we are now challenging are on four main items as

folows;

(1) New hybrid hull form concepts with high-performance,

(2) Application of new materials and the most reasonable hull structures,

(3) Sufficient and reliable water-jet propulsion systems,

(4) Sophisticated motion and ride control technologies.

Hydrodynamic characteristics of the elements, of which new hull form configurations consist, are investigated theoretically and experimentally first, not only in smooth water but in waves and manoeuvring conditions. The means to predict performance of the configurations together with ways to improve it are also investigated.

Then,a survey is made to confirm feasibility of the hull form concepts as a integrated commercial ship system.

Strong and durable materials should be applied in order to improve the structural safety and the maintenance cost. Pursuit of the most reasonable hull constructions is considered a very important subject to reduce the hull weights and ensure the structural safety. Evaluation of the strength including fatigue problem will be made by predicting of loads and impacts due to waves precisely.

As diversion of a light-weight gas turbine engine which has been developed for aeroplanes is presupposed to a main engine of Techno-Superliner, research on the propulsion systems emphasizes on large power transmissions, water-jet pumps and pipings, in order to raise the efficiency and the reliability of the systems.

Research on a control technology using underwater fins/flaps or regulating air pressure is another important subject to maintain the ship attitude normally or to make the ship oscillations tender. The R & D Programme of Techno-Superliner is progressing favorably now on its halfway. Basic and common subjects have almost been accomplished and our interest is directed now to the individual subjects specified to each concept.

6. CIRCUMSTANTIAL IMPROVEMENT FOR TECHNO-SUPERLINER

A task of the Association assigned is exclusively on research

& development of Techno-Superliner in technology, therefore , other tasks like a circumstantial improvement for Techno-Superliner, such as to investigate into the infra-structure and to make its own rules/regulationsare left to the government and the other associations. A few tasks have already been branched out practically. Anyway, these tasks are considered very important in order to let forwarders take Techno-Superliner into a new physical distribution system.

7. CONCLUSIONS

As described in the above, the R & D Programme of Techno-Superliner is progressing favorably on its halfway. Several achievements have been already obtained at the present time.

The performance of Techno-Superliner that is 50 knot in speed, 1,000 tons in payload and 500 nautical miles in range and with excellent seaworthiness means only a technological target of the Programme that is considered to be very difficult to satisfy those four requirements concurrently. Accordingly, if this difficulty is overcome in our Programme with success,ship owners and forwarders will be able to select many optional designs according to their ships missions in the near future.

We believe that the R & D Programme of Techno-Superliner will surely contribute to the enhancement of ship technology and the reformation of seaborne trnsportation toward the 21st century.

REPORT ON THE SHIOJI MARU EXPERIMENT

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Advisor,
Shipbuilding & Ocean Development Headquarters
Mitsubishi Heavy Industries

1. Outline

It was reported in the previous meeting that the so-called "Intelligent Ship Project" in which under the circumstances of having aimed at the development of innovative elementary technology for highly automatic operating systems with high level artificial intelligence, with the technology to realize operation of ships without operating crew involvement, a joint research project for R & D had been carried out by members, the majority of whom joined from major shipbuilders (*) under the organization of the Shipbuilding Research Association of Japan since 1983 was finished after the verification of the integrated functions was conducted with the synthetic navigation simulation carried out in Fiscal year 1988.

The whole configuration and the relationship between each constitutional element is shown in Fig 1.1.

* ; Ishikawajima-Harima Heavy Industries, Kawasaki Heavy Industries, Sumitomo Heavy Industries, NKK, Hitachi Zosen, Mitsui Engineering and Shipbuilding and Mitsubishi Heavy Industries.

In order to develop the practical application of such elementary technology it seems to be the most reliable procedure that the development of practical application will be carried out as the support system for operation by crew and the actual results are obtained by stages.

Therefore, resulting from the achievements of R & D, an automatic berthing and unberthing system, a grounding prevention system and an integrated

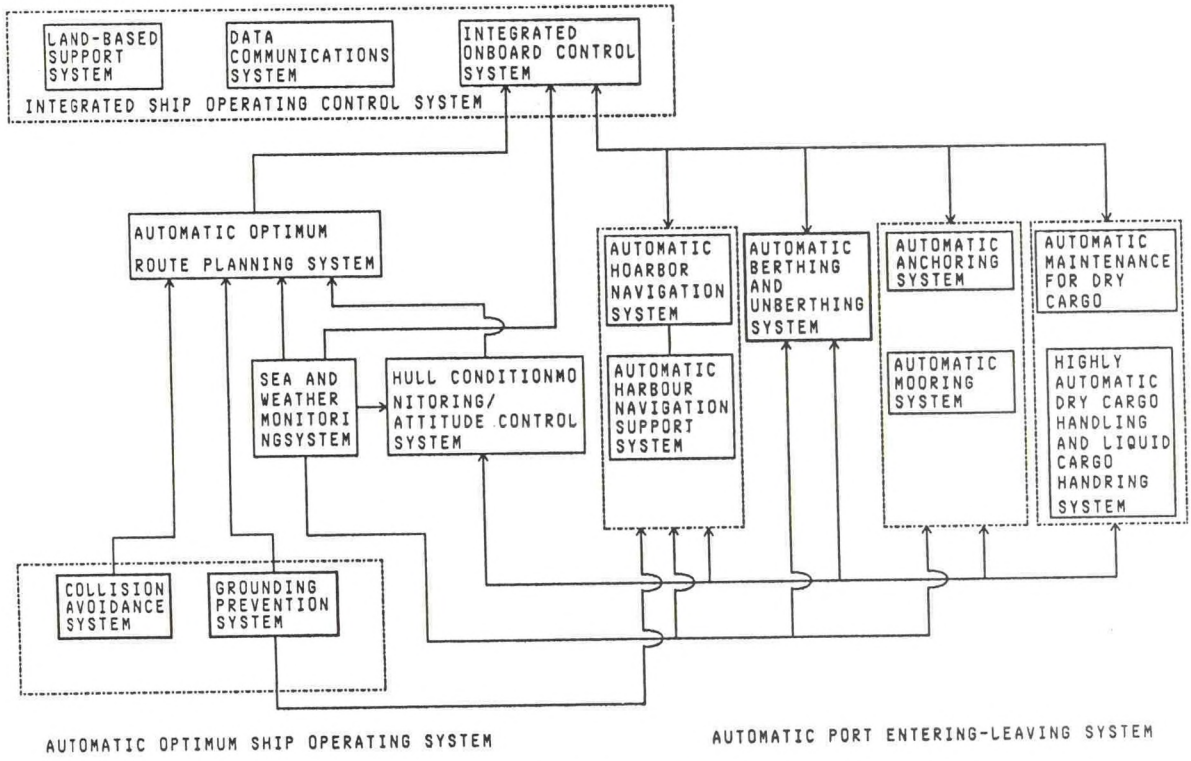

Fig.1.1 HIGHLY ADVANCED AUTOMATIC SHIP OPERATING SYSTEM

operation control system had been taken up by seven major shipbuilding companies as subjects of actual shipboard experiments to be carried out as a joint autonomous project, on the grounds that these would be feasibly put into practical application both from technical and economical points of view, and further it would be agreed by shipping companies. Thus an experiment using an existing ship was conducted during Fiscal year 1989.

During the experiment, the equipment and systems which had been developed and produced by way of R&D of fundamental technology were installed aboard Shioji Maru (Fig. 1.2), a training ship owned by Tokyo University of Mercantile Marine, and verification and evaluationof functions under practical ship operational conditions as well as effectiveness as a supporting system were to be confirmed. An evaluation principally on the effectiveness from the viewpoint of ship operation was performed by the evaluation committee which comprized highly knowledgeable and experienced members from shipping companies, universities and governmental organizations.

Following is a brief summary report of the shipboard experiment.

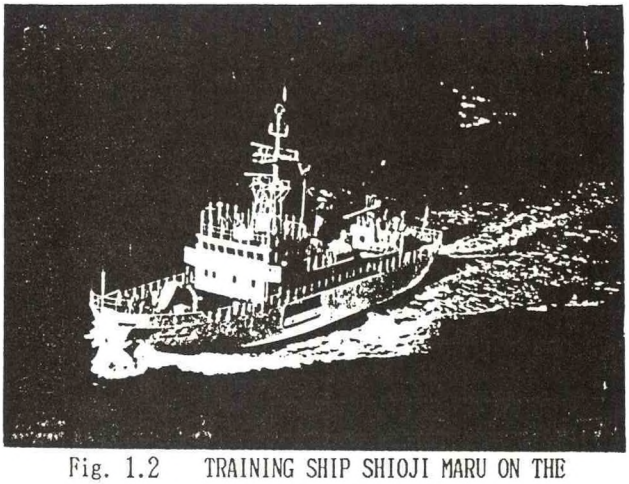

Fig. 1.2 TRAINING SHIP SHIOJI MARU ON THE EXPERIMENT

2. Outline of the experiment

The experiment was organized and jointly managed by seven shipbuilding companies who promoted the activity by organizing a special committee for the actual ship experiment using Shioji Maru, and with the condition that the Shioji Maru as referred to above would be used as an experimental ship, an agreement had been concluded with the university on the cooperative research to be conducted together.
Out of three of the above seven companies took charge of the experiment as follows:

① Automatic berthing trial by an automatic berthing and unberthing system	Hitachi
② Experiment of monitor the ship course using a grounding prevention system	Sumitomo
③ Collision avoidance maneuvering experiment using an integrated on-board control system	Mitsubishi

Coordination of the modification of the shipboard data transmission system aboard the Shioji Maru was carried out by Ishikawajima-Harima.

The preliminary experiment was conducted for three consecutive weeks commencing early in December, 1989 and the evaluation test was carried out on January 11, 1990.

The selected site for the collision avoidance maneuvering and grounding prevention experiments was off Tateyama Bay located to the south of Uraga Suido Traffic Route while the fitting-out quay of Oppama Shipyard located just at the entrance to the Uraga Suido Traffic Route was offered by Sumitomo for the berthing experiment.

The sea area for the experiment is shown in Fig.2.1

3. Detail of the experiment

3.1 Berthing experiment by an automatic berthing and unberthing system

Various systems had been developed by the abovementioned R and D aimed at unmanned automatic berthing and unberthing. Representative systems among them were the ship position recognition system, the berthing and unberthing control system and the instruction system to tugs.

As no tug would be used for this experiment, it was aimed at confirming whether the control during the berthing could be kept satisfactorily by the combined use of the ship position recognition and the berthing and unberthing control systems. In parallel with the experiment several adjustments were made; the redesigning of the ship position recognition system into a compact one; the additional installation of a gyro for rate integration to control berthing and unberthing; the development of communication software with shipboard LAN; the new design of a graphic system to indicate the ship postion; the application of a mathematical model of ship motion of the Shioji Maru; the improvement of a control parameter; etc.

After the adjustment of systems and a confirmation of safety had been completed, the fitting-out quay of Oppama Shipyard, the berthing experiment towards a goal temporarily located 10 meters off the quay was finally conducted. The results of the experiment are shown in Fig. 3.1.1.

As shown in this figure by the locus of ship positions plotted at one minute intervals, the ship berthed smoothly following a reasonable course.

The results of the experiment were discussed for evaluation on the following points.

① Transition: Smooth transition is to be made from manual maneuvering to automatic maneuvering.
② Berthing course: The ship is to be berthed along a smooth course.
③ Sequence and meaning of orders: Orders for maneuver should be reasonable from the view point of an experienced captain.
④ Approaching speed: The ship should approach the quay at a speed safe enough both to the ship and quay.
⑤ Accurate berthing position: The position should be appropriate enough taking into consideration the surrounding conditions at the time.
⑥ All of the above should be met at the normal surrounding condition.

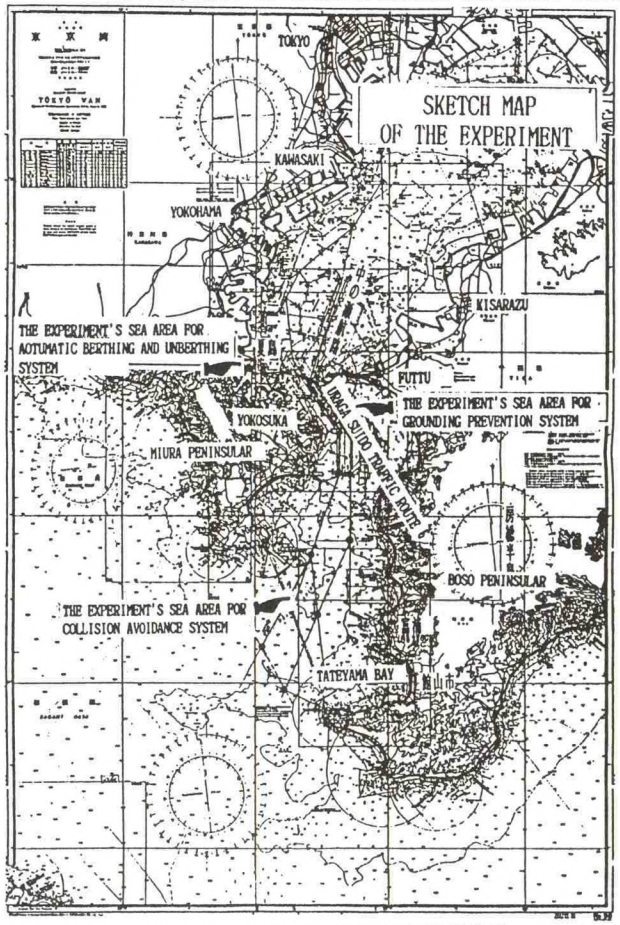

Fig.2.1 THE SEA AREA FOR THE EXPERIMENT

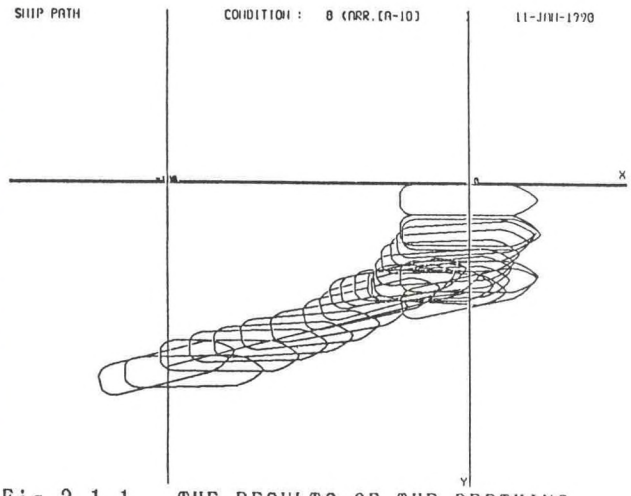

Fig.3.1.1 THE RESULTS OF THE BERTHING EXPERIMENT

After the evaluation, it was concluded that the objective was generally satisfactorily achieved as planned although the following items should be studied in due course of practical application in the future.

① The utility range for the ship position recognition system to be expanded as sufficent for the actual ship.
② The software for the control system for berthing and unberthing to be improved.
③ The limits of the level of the influence of enviroment condition as weather to be reconfirmed.
④ As a supporting system, development of positioning function at the berth will be additionally requested.

3.2 Grounding prevention system

During the course of R and D as referred to above, ship course monitoring system as a main system and the sonar for finding under water obstacles as an auxiliary system had been developed.

The basis of grounding prevention is in the monitoring of ship course on digital charts, and this will depend on the accuracy of determining the ship position.

Therefore the main issue is how to increase the accuracy in the ship poition determination. During the experiment the goal was to confirm the accuracy of the determined position which could be obtained by matching the digital chart with radar plotting.

Radar video matching with digital charts shown in Fig 3.2.1.

During the experiment, ships' positions by LORAN C and the position by DECCA were measured and by the preparation of an error histogram for every ship's positon, a comparative study with the ship's position by automatic matching of radar video and digital chart.

The longitude results indicated that the frequency distribution of the determined position errors were distributed between -0.7 and -4.7% with a peak of -3.8%, for a radar range of six miles.

Regarding latitude, when the radar range was six miles, the frequency distribution of the errors in position measurement was such that the error distribution was between -1.0 and +1.8% with a peak of +0.1%, thereby found to be well in the targeted error range of ±2%.

Thus, it was confirmed that the accuracy in determining a ship's positon by matching of radar video and digital chart would be superior to other positioning systems, even if that accuracy is influenced by the topographic conditions of the coast in the experimental sea area.

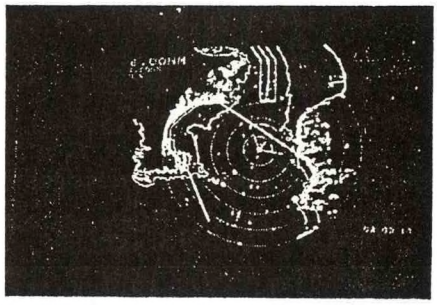

Fig.3.2.1 RADAR VIDEO MATCHING WITH DIGITAL CHART

The results of the experiment were subjected to evaluation for the following points.

① Automatic input of information on the navigation routes: Following the course planning, chart numbers should be chosen automatically, and charts should also be changed automatically.
② High accuracy automatic plotting of ship's own position: Plotting should be made automatically by matching a digital chart with radar video. Intervals for matching should be approximately 90 seconds, and, if necessary, to be supplemented at 10 second intervals according to location of the estimated postion.
③ Automatic detection of underwater obstacles: Dangerous water depth lines, shorelines, ship route lines, etc. are to be extracted from the digital charts and such information is to be

identified in color.

④ Automatic judgment of the degree of risk: In accordance with the ship type and speed of the Shioji Maru, the level of risk is to be established, and an alarm should be given according to the monitoring level as shown in Fig. 3.2.2.

⑤ Automatic output of risk information: When danger will be forthcoming, automatic output of information is to be given to the upper stream system.

After the evaluation the grounding prevention system was confirmed to be generally satisfactory and effective as a supporting system to monitor the navigation channel, while the following items should be studied in due course of practical application in the future.

① The time required to deal with the exchange of charts, the change of radar range, etc. to be shortened.

② The accuracy of positioning by radar matching to be improved.

③ The method and the indication contents to be improved.

④ Updating of hydrographical information to be rapidly.

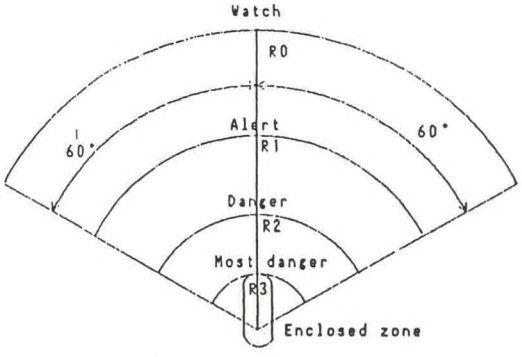

Fig.3.2.2 LEVELS OF SURVEILLANCE

3.3 Collision Avoidance system

The purpose of the experiment was to verify the future possibilities of practical use of fundamental functions of a integrated on board system as developed.

During the experiment, all functions of the on-board integrated systems, i.e. the data base management function and the shipboard LAN control function, as well as the collision prevention maneuvering function, which was a part of the shipboard integrated control system (Captain Expert System) utilizing AI, were confirmed both as a automatical collision avoidance system and as a practical maneuvering support system.

Before starting the experiment, the experimental system was supplemented and extended by the addition of the knowledge based on the judgment of the captain, and the rules and regulations regarding the collision avoidance maneuvering in port and indication functions as a support system, necessary graphic were added.

The basic function of a collision avoidance system is to develop a collision prevention algorithm, i.e. automatic planning to find a avoiding route from collision with another ship to select by tree-search from among various selected courses. The principle of route planning for collision avoidance is shown in Fig. 3.3.1

The supporting function for ship maneuvering is composed of the information display of an operating conditions for navigation and the conditions for collision avoidance, and by these functions, necessary data for the evaluation is given. Display examples are shown in Figs. 3.3.2 and 3.3.3

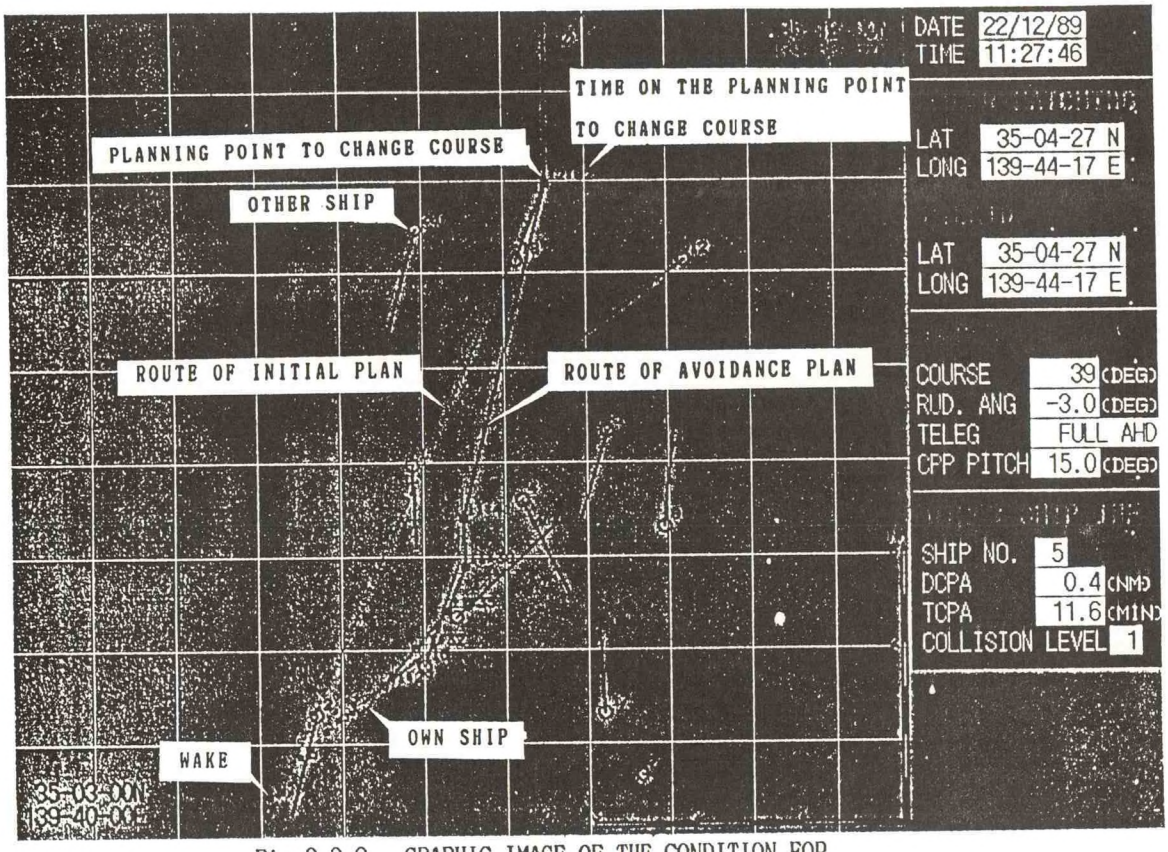

Fig.3.3.2 GRAPHIC IMAGE OF THE CONDITION FOR COLLISION AVOIDANCE

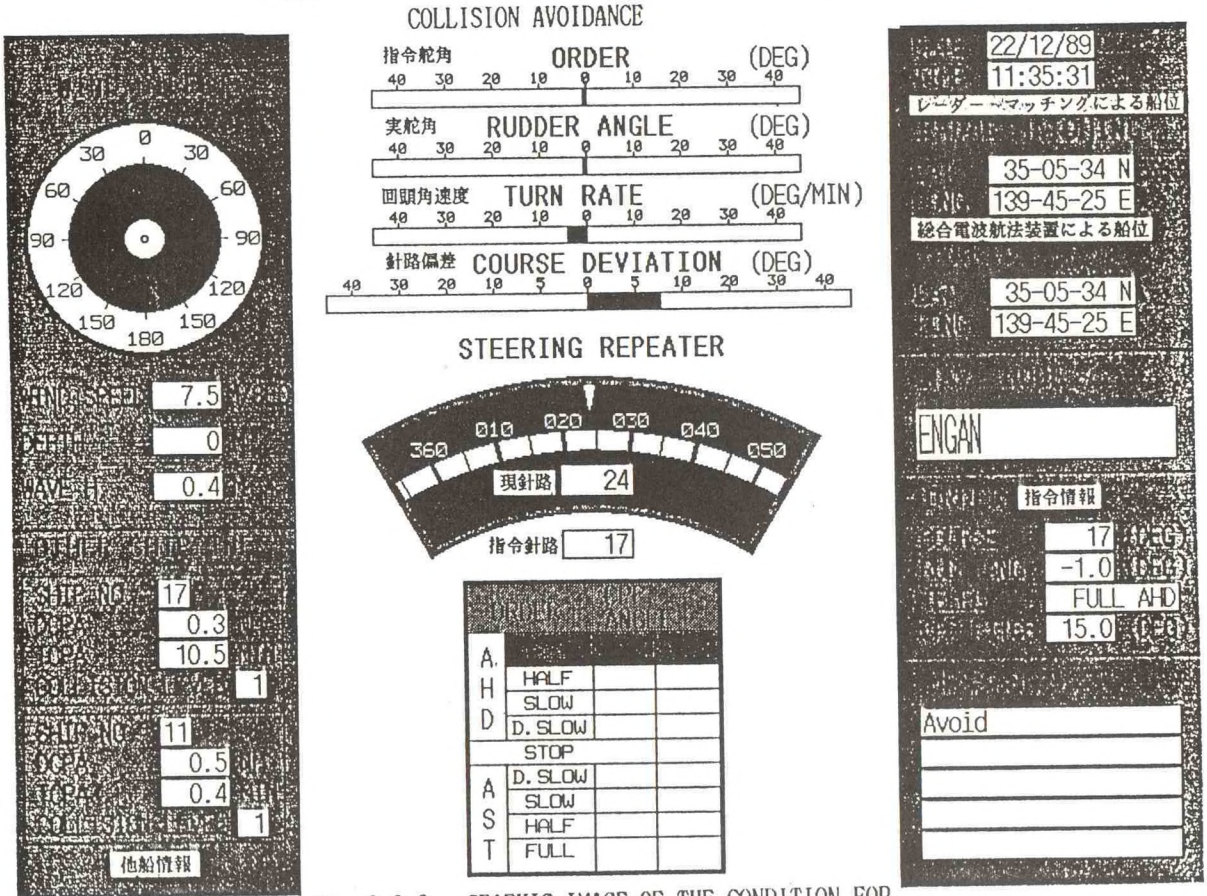

Fig.3.3.3 GRAPHIC IMAGE OF THE CONDITION FOR NAVIGATION

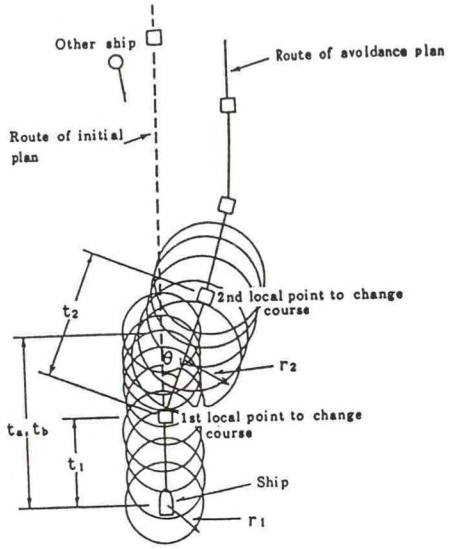

Fig.3.3.1 CRITERIA OF AVOIDANCE PLAN

It was confirmed that the judgment, based on the reasoning at the time of the route planning for the collision avoidance was applied in succession with the knowledge which was compatible with the surrounding conditions, and search for the veering point where no risk of collision might be expected was made. As a result, the planning performed by the system was found to be very close to the judgment of a captain if he were in command of the ship.
Also, the actually make (track) by the automatic maneuvering as per the collision avoiding course coincided with the planned route and, thereby verifying the practicality of the automatic maneuvering function.

The results of the experiment were discussed for evaluation on the following points.

① Display of operating conditions: Information on the ship's position itself, and other and the meteorological and sea state conditions are to be shown and updated at predetermined intervals regularly.
② Planning and change of collision avoidance route: At any time, the appropriate collision avoidance route is to be planned to avoid risk of collision. And in further accordance with the changing surrounding conditon and consequently the changing degree of risk, the collision avoidance route should be altered accordingly.
③ Display of collision avoidance route: The collision avoidance route should be clearly illustrated on the display graphically.
④ Guidance of collision avoidance: Operation guidance which is based on a planned or modified collision prevention course should be indicated by telegraph speed (pitch angle of CPP) and course (rudder angle) successively.
⑤ Automatic collision avoidance maneuvering: In accordance with the maneuvering guidance (pitch angle of CPP and rudder angle), automatic maneuvering should be continued on line.

After the evaluation, the collision avoidance system was confirmed that in view of anticipated development of sensors in the future, in due to the progress of the associated technique, the results of the test were generally satisfactory. Further it was confirmed that, although in case of Automatic Radar Plotting Aids (ARPA), it was very difficult to catch up small fishing boats as well as to identify the kind and size of ships, if manual acquisition might have been taken for the supplementary action of catching up other ships, the effectiveness of the system would be expected as a supporting system.

The themes to be studied in due course of practical application in the future are as follows.

1) Regarding the knowledge base, further amplification and brushup will be necessary.

2) The supporting system should be as follows.

① As an experiment, the format and quality of the displays has been fully satisfactory , but it seems that further improvement will be necessary for practical use.
② Knowledge base of collision avoidance should be improved by the adoption of conversation communication system.
③ Then the AI system might be coming in an unstable condition, it should be explanation and/or indication on the CRT display.

4. Overall evaluation

The following comments were given on the overall evaluation by the members of the evaluation committee.

"After the verification and evaluation of the system functions as found by the experiment on board the Shioji Maru, it has been confirmed that those systems providing the development of the sensors, etc. in the future would be taken into consideration, and brushup of the software and/or knowledge base might be achieved, are appropriate enough to be used aboard actual ships and useful as supporting system. In conclusion, the Shioji Maru experiment has been a fruitful success, and the target has been achieved."

5. Conclusion

It is a great pleasure that, by virtue of endeavors and efforts exerted by development staffs of the abovementioned companies, and under the guidance and assistance of men of knowledge and experience from universities, shipping companies and the crew of "SHIOJI MARU", the experiment to operate an actual ship with three representative items from the highly advanced automatic ship operating system, using artificial intelligence technology, has been completed with a great success.

DEVELOPMENT OF THE MHD SHIP YAMATO-1

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Ship and Ocean Foundation
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ABSTRACT

Since 1985, the Ship and Ocean Foundation has conducted an extensive research and development project in Magnetohydrodynamic (MHD) ship propulsion, resulting in the design and construction of a prototype experimental ship, YAMATO-1. To accommodate two large MHD thrusters under the waterline, a special ship form (which could be called a semi-catamaran) was adopted. To give the ship a futuristic image, the ship's hull consists of a three dimensional complex curvature. The ship displaces 185 tons, with an overall length of 30 meters and design speed of 8 knots. Subsystem testing is underway. Details of the YAMATO-1 system design will be presented at the MHDS '91 Symposium to be held in Kobe, October 28-31, 1991.

INTRODUCTION

An experimental MHD ship has been constructed at the Kobe Shipyard of Mitsubishi Heavy Industries, Ltd (MHI). The ship, YAMATO-1, is now at the final stage of fitting and adjusting of the equipment. To be more specific, MHD thruster No. 2 for starboard was constructed and successfully tested as a complete thruster unit at Toshiba Corporation and then installed in the ship. MHD thruster No. 1 for portside was completed and is being tested at the Kobe Shipyard, MHI.

All other equipment such as main engines, generators, helium refrigerators, etc., were already installed in the ship. The supporting system on land (including a large capacity helium refrigerator, power source for exciting magnets, etc.) was also completed at a pier where YAMATO-1 will be cooled down and excited on land prior to launch. Subsystem testing of major components, including thrusters, is underway.

An International Symposium on Magnetohydrodynamic Ship Propulsion (MHDS '91) is planned to be held October 28-31, 1991 at the Kobe Portpia Hotel. The analysis of subsystem test results is expected to be reported at the symposium.

SYSTEM DESCRIPTION

The major components and subsystems are described as follows.

Superconducting Coils

An MHD thruster unit consists of six superconducting coils. Since the ship is equipped with twin thrusters, twelve superconducting coils were manufactured. The particulars of the unit coil are listed below:

Inner diameter of coils	0.360m
Inner diameter of duct	0.240m
Length of coil (total)	3.70m
Length of coil (parallel part)	3.00m
Number of turns	220 x 2 layers x 2 poles
Normal Electric Current	4,600 amp
Magnetic Flux Density at Center (for single unit)	3.5T

Each coil was tested and attained the design magnetic flux density after experiencing some quenches. Test results of coils for thruster No. 1 are shown in Figure 1. A photo of a superconducting coil is shown in Figure 2.

MHD Thruster Sets

An MHD thruster set consists of six dipole superconducting coils as shown in Figure 3 where thruster No. 2 is shown as an example. A completed thruster set is shown in Figure 4. Figure 5 shows the thruster No. 2 being installed in the ship. The actual weight after completion was 18 tons for thruster No. 1 and 15.8 tons for thruster No. 2. An example of test results after thruster No. 2 completion is shown in Figure 6.

Persistent Current Switch (PCS)

The characteristics of the PCS are listed below:

Operating Current	3900 at Ot
Switch-off Resistance	9 ohms
Heater Resistance (approx)	40 ohms
Weight (approx)	60 kg

Electrodes

Electrodes of titanium coated by Ruthenium oxide were used and fitted in the water duct (see Figure 7). Bus bars were connected to the electrodes.

Helium Refrigerator

Helium refrigerators using a high revolution expansion turbine were completed and tested, applying a thermal load of 10 watts. Characteristics of the helium refrigerator are listed below:

Diameter of Rotor	6.00mm
RPM of Rotor	636.000
Refrigeration Capacity	10W (st 4.4k)
Weight	100 kg

Ship Hull

To contain two large MHD thrusters under the waterline, a special ship form (which could be called a "semi-catamaran") was adopted. To give the ship an image of a "ship of the future," the ship-hull configuration is a three dimensional complex curvature. Although the ship may be maneuvered by adjusting or reversing the thrust of the twin thrusters, twin rudders were fitted for redundancy. Figures 9, 10, and 11 show duct inlet, duct outlet, and control rooms.

Supporting Facility

The supporting facility consists of a large capacity helium refrigerator, compressor, and power source for energizing superconducting coils, etc. (see Table 1 and Figure 11). The supporting facility is situated near a pier where YAMATO-1 will be prepared for sea trials.

The preparation procedures are as follows:

1) YAMATO-1 is placed on a cradle on land near the facility and coils are cooled down, using a large capacity helium refrigerator to provide helium through insulated flexible pipes.

2) After the coils are cooled down to 4k, they are excited by an electric source until the design current is attained.

3) The coil current becomes the persistent current by a persistent current switch, and the electric source will then be shut off.

4) The helium refrigerators on board the ship will then be actuated and the helium line from the land facility will be shut off.

5) The ship will then be launched and ready for operation at sea.

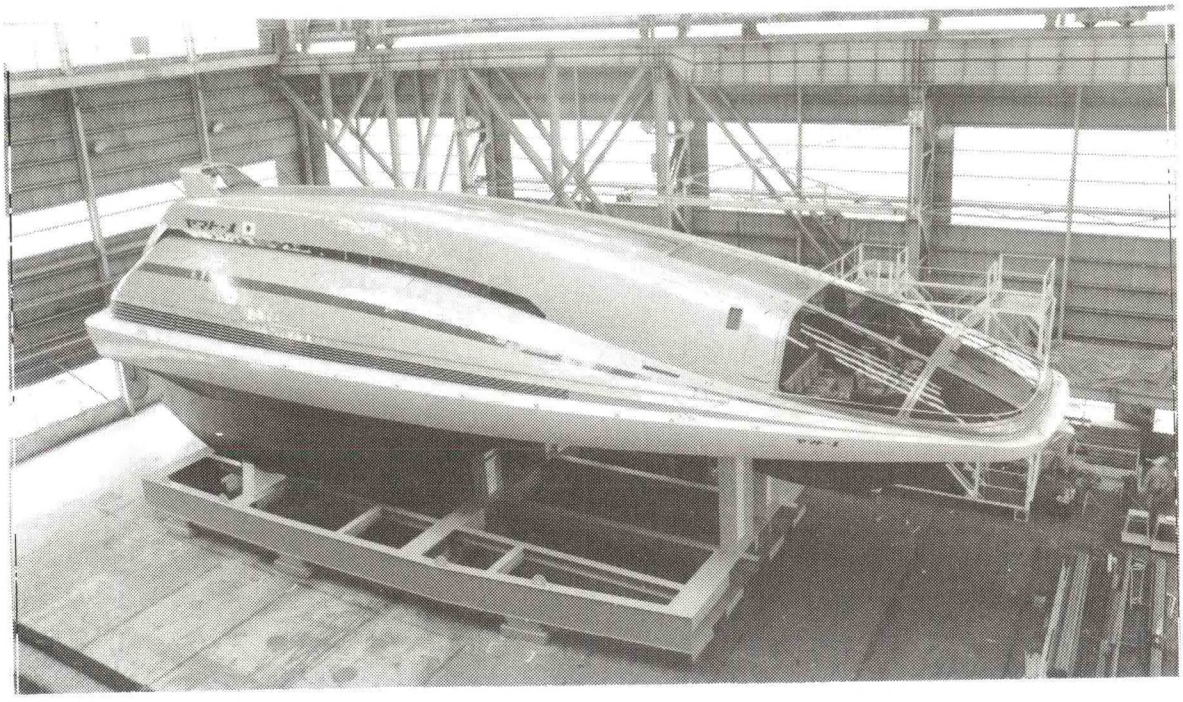
SUMMARY

The experimental MHD Ship YAMATO-1 has been under development by the Ship and Ocean Foundation for 5 years. It is the first ship of this type to demonstrate MHD propulsion. Sea trials will be performed after completion of thruster subsystem testing.

A report on the MHD system design of YAMATO-1 and subsystem testing (completed to date) will be presented October 28-31 at the MHDS '91 Symposium in Kobe, Japan.

Table 1. Supporting Facility

Helium Refrigerator		
Liquefaction Capacity	:	100*L*/hr(at 4.4k)
Refrigeration Capacity	:	300W(at 4.4k)
Helium Compressor	:	Oil cooling type,output pressure 15.5kg/cm^{2}G
Recovery Apparatus		
Ballast Tank	:	5m^3
Recovery Tank	:	10m^3
Gas Bag	:	Made of synthetic rubber, 75m^3
Recovery Gas Compressor	:	Recipro. type, output pressure 150kg/cm^{2}G
Liquid Nitrogen Tank	:	Capacity 20,000*L*
Energizing Power Source		
Rated Output	:	DC 10V, 4800A
Sweep Speed	:	5000A/1~60 min



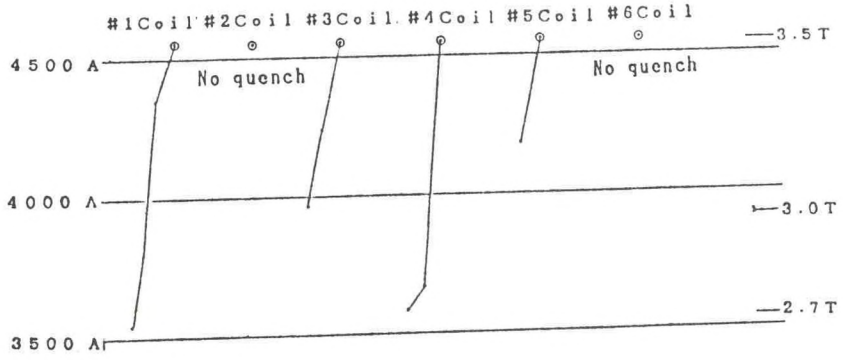


Fig.1 Result training of the unit coils

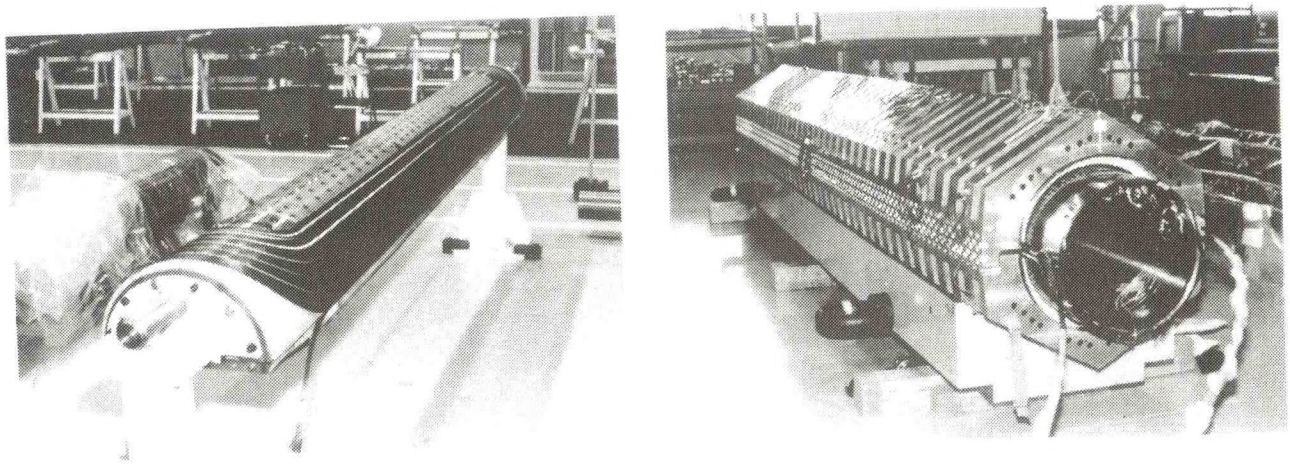


Fig.2 Superconducting coil

NO	ITEM
①	Superconducting coil
②	Coil suppresser
③	Helium vessel
④	80K shield
⑤	Vacuum vessel
⑥	LHe reservoir
⑦	Persistent current switch
⑧	Protective resistance
⑨	Refrigerator

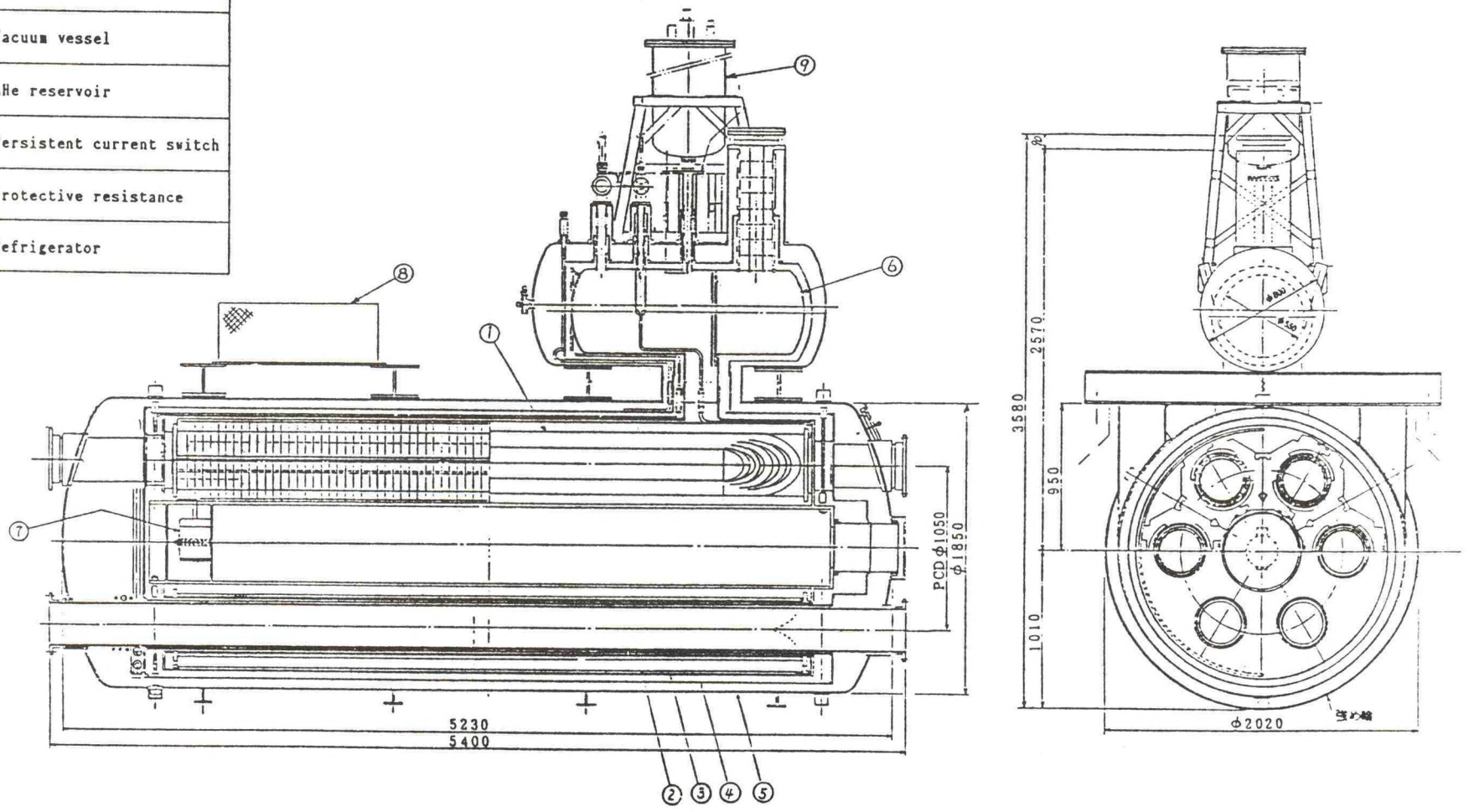


Fig.3 MHD thruster set

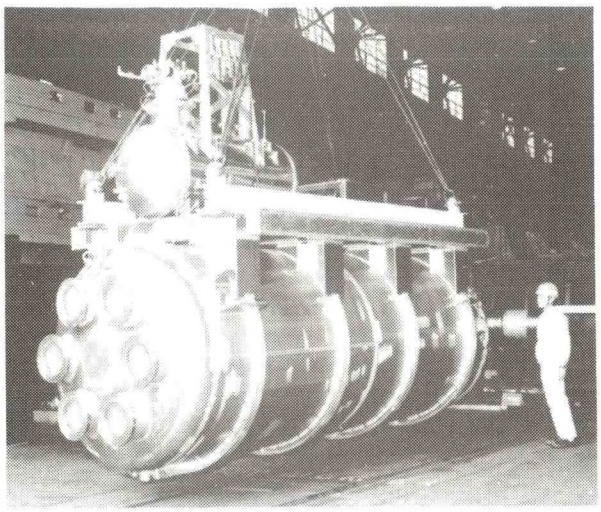


Fig.4 Completed thruster NO.2

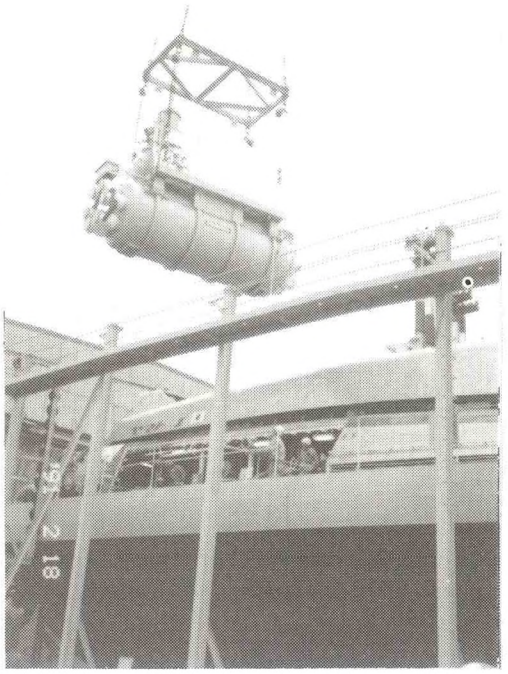
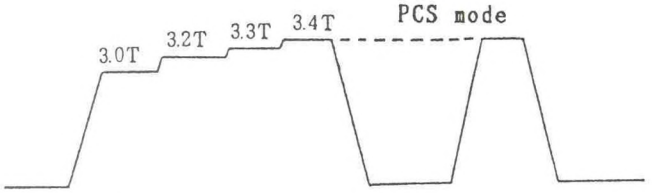


Fig.5 Fitting of thruster NO.2



Magnetic field test

Fig.6 Test results of thruster NO.2

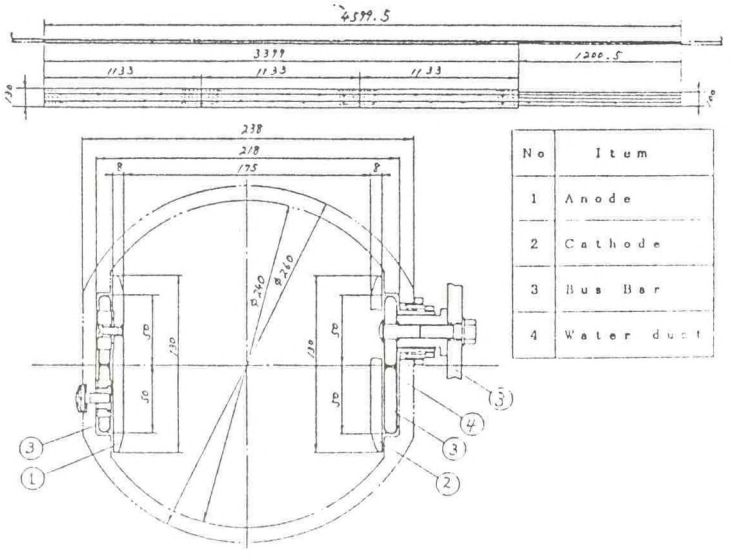


Fig.7 Sectional views of sea water duct and electrodes

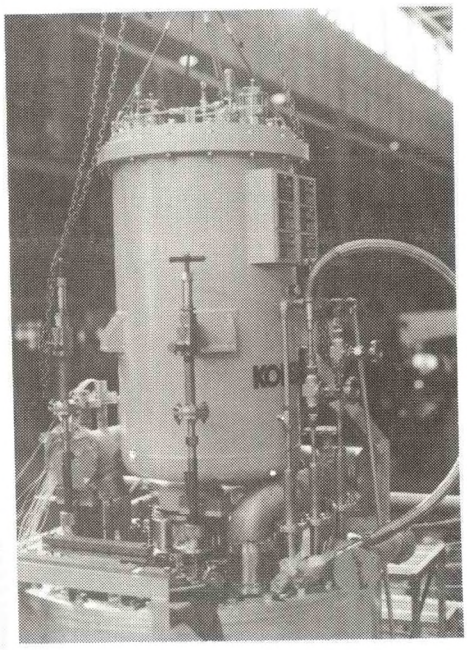


Fig.8 shows the completed refrigerator.

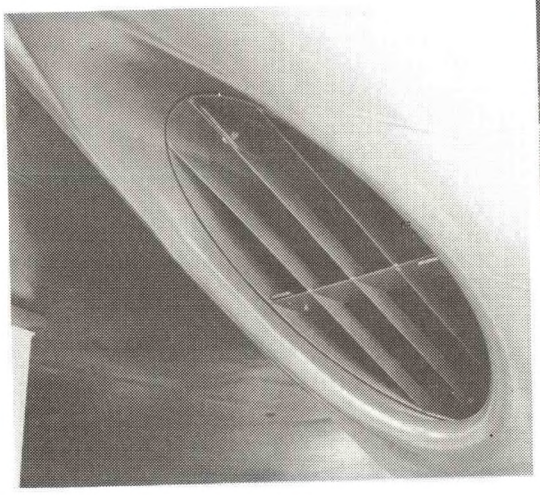


Fig.9 Duct inlet

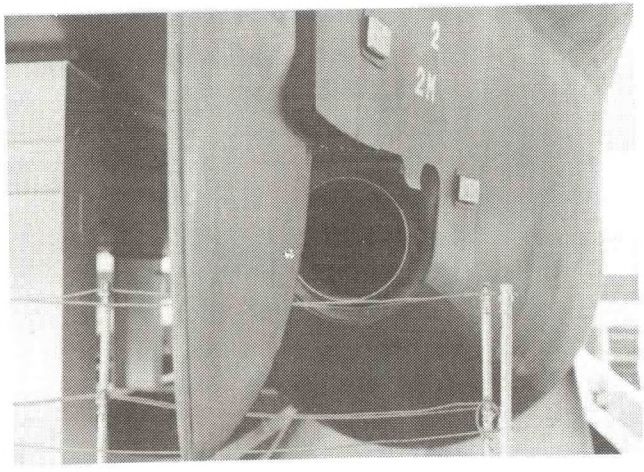


Fig.10 Duct outlet

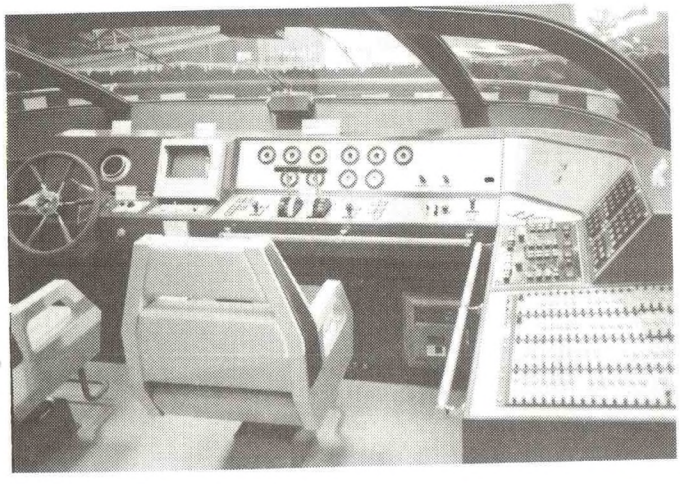
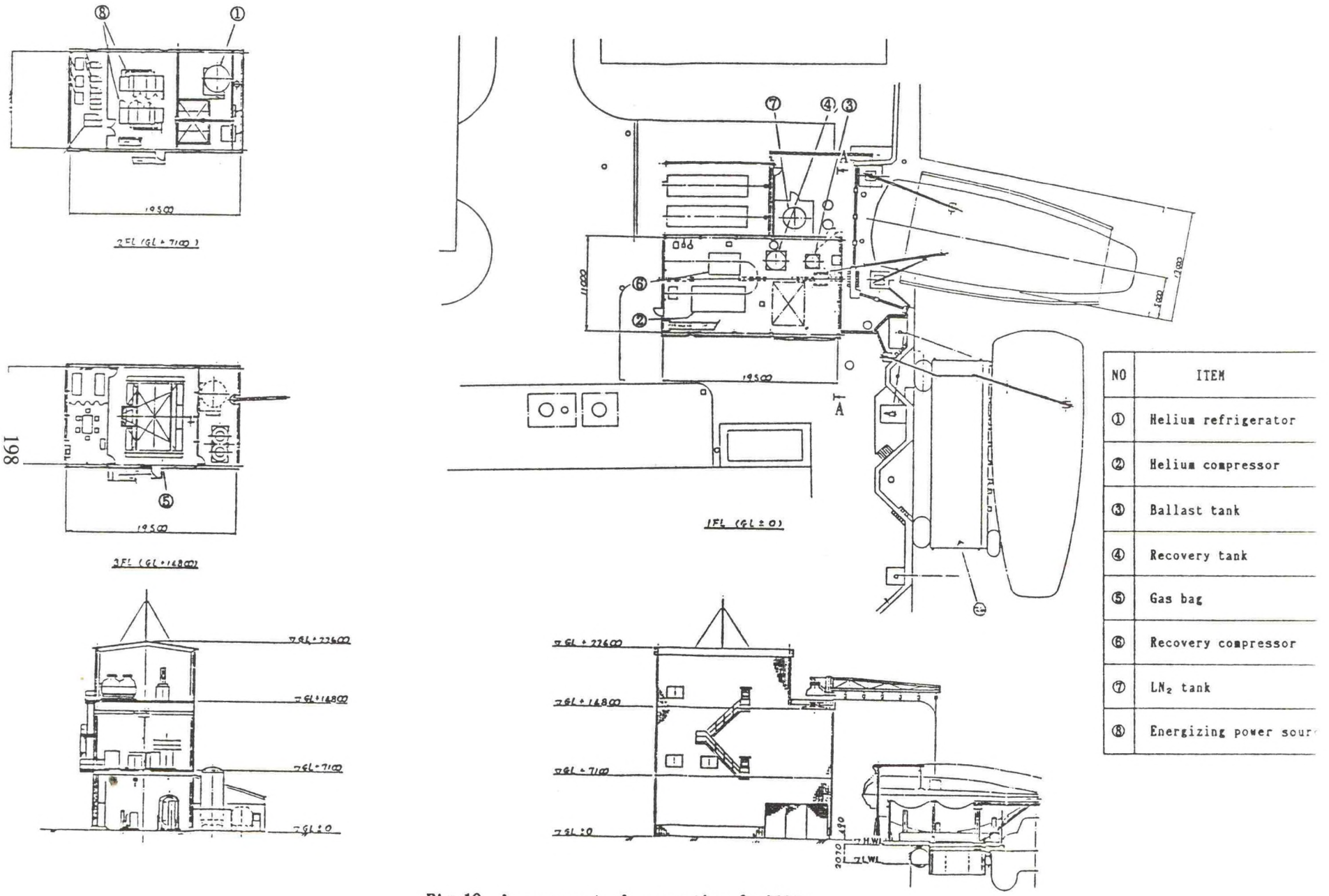


Fig.11 Control room



NO	ITEM
①	Helium refrigerator
②	Helium compressor
③	Ballast tank
④	Recovery tank
⑤	Gas bag
⑥	Recovery compressor
⑦	LN_2 tank
⑧	Energizing power sour

Fig.12 Arrangement of supporting facility

Offshore and Undersea Technology Systems

SENSOR DEVELOPMENTS FOR DEEP-OCEAN AND COASTAL STATIONS

Jerry C. McCall
Director
National Data Buoy Center

Introduction

The National Data Buoy Center (NDBC) operates over 100 moored buoy and coastal observation stations for the purpose of acquiring environmental data for weather analyses and forecasts and other uses. Each station is equipped with a baseline suite of sensors to measure a core set of surface meteorological parameters; among these are wind speed and direction, barometric pressure, air temperature, sea-surface temperature, and, for buoys, nondirectional waves (significant wave height, peak modal period, and the nondirectional wave energy spectrum). In normal operations, these data are collected hourly by low-power electronic payloads at the station and transmitted via the Geostationary Operational Environmental Satellite (GOES) to satellite receivers on shore. The messages are then relayed to the National Weather Service Telecommunications Gateway (NWSTG) from which they are disseminated in real time to the user community.

Over the last decade, as the NDBC network has expanded, a great deal of effort has gone into improving systems reliability and performance. As a result, NDBC has consistently achieved very high data performance rates for its standard observational systems. At the same time, NDBC has undertaken buoy and coastal projects with requirements well beyond the standard set of measurements. The growing significance of oceanography has, in part, led to this change. Enhanced observations at NDBC stations now or will soon include directional waves from buoys; waves from offshore platforms; relative humidity and solar radiation; precipitation; and subsurface oceanographic measurements such as current profiles, salinity, and light. Additionally, as a result of this proven capability, NDBC has expanded its role beyond the marine arena into the systems engineering of automated environmental data acquisition systems. A prime example is the upper-air wind profiler project.

This paper provides a snapshot of several of the more interesting sensor development activities under way at NDBC. While not exhaustive, it does provide a good overview of the broad range of NDBC's technology advancement and application endeavors. The following sensor developments are described:

- Acoustic Doppler Current Profiler
- New Methods for Directional Wave Measurement
- New Ways to Measure Winds from a Directional Waves Buoy
- Coastal Buoy
- Infrared Laser Wave Height Sensor
- Upper-Air Wind Profilers
- Upper-Air Temperature Profilers

Acoustic Doppler Current Profiler

On behalf of the United States Department of Interior (Minerals Management Service),

NDBC will be deploying two buoys off the southern California coast that will be equipped with Acoustic Doppler Current Profilers (ADCP). The ADCP units are commercially available from RD Instruments and have been used aboard ship with success. However, the NDBC activity is the first application of ADCP's for remote, unattended operations on moored buoys, with data relayed via the GOES.

The ADCP systems, which will operate at an acoustic frequency of 75 kHz, have four transducers that project four acoustic beams oriented downward at 30 degrees off-vertical and arranged in 90-degree horizontai azimuth increments (Figure 1). This configuration, with beams at 0°, 90°, 180°, and 270° relative to a horizontal buoy reference line, is designed to prevent interference with the mooring system. The ADCP subsystem is operated in conjunction with a dedicated NDBC data acquisition and telemetry "payload." An independent power system, composed of batteries, solar panels, and voltage regulators, will supply the electrical power to the ADCP, to the payload, and to the specially configured microprocessor interface between the payload and the ADCP. A second data collection system (i.e., payload), independent of the ADCP portion, will be used to report the routinely measured environmental variables (atmospheric pressure, wind speed, wind direction, air temperature, sea surface temperature, and waves).

The ADCP data collection system will measure and report the current vector in 16-meter-thick layers (or depth cells) from 16 meters below the surface to a depth of 336 meters. The surface layer cannot be measured, due to the interference between the transmitted signal and the almost immediate initial return from this layer. Additionally, there will be no flow measurements within a 60-meter-thick layer adjacent to the bottom due to the strong acoustic wave reflections from the hard ocean floor. For each 16-meter-thick layer of the water column for which a flow determination can be made by measuring the Doppler shift of the returned acoustic echo, the eastward flow velocity component (U), the northward flow velocity component (V), and the upward flow velocity component (W) will be reported. These profile-type data sets will be obtained on a measurement interval of 1 hour by the ADCP system on the buoys. Telemetry of the current profile data, so that they are available at NDBC for archival purposes, will also be performed every hour by the NDBC payload via the GOES satellite. No long-term recording of profile data will be done on the buoys.

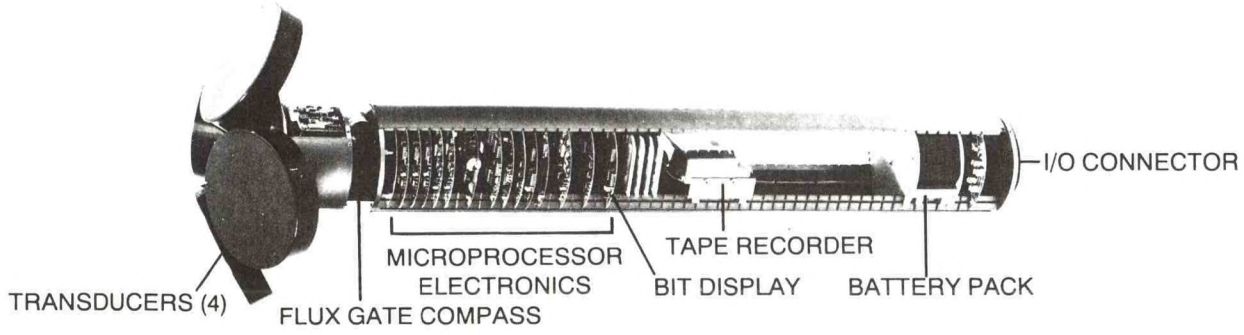


Figure 1. ADCP Physical Configuration

The results of a theoretical analysis of the functional relations between the vertical measuring resolution (bin size or depth cell length), the operating acoustic frequency, and the duration of the sampling period indicate a standard deviation of 1 cm/sec for the current measurements made by the ADCP. For the selected depth cell length of 16 meters and acoustic operating frequency of 75 kHz, a sampling period of approximately 5 minutes duration is necessary. Increasing the duration of the sampling period reduces the value of the standard deviation of the measurement (greater measurement accuracy). Because the effect of some factors that can degrade the measurement accuracy are not yet known, for these initial deployments a sampling period of 20 minutes will be selected for obtaining one profile data set. This sampling period will be centered on the hour. Profile measurements will start at 10 minutes before the hour and end at 10 minutes after the hour. Only one water current profile will be reported for each hour. The values of U, V, and W given for each depth cell will be the average magnitude corresponding to all the individual profile values for that depth obtained during the entire 20-minute duration of the sampling period. The velocity magnitude reporting resolution of the system is 0.5 cm/sec. It is expected that the total system measurement accuracy for the ADCP/VEEP (Value Engineered Environmental Payload) current profiling systems that will be installed on the NDBC buoys will be between ± 1 cm/sec and ± 2 cm/sec. The total system current flow directional accuracy will be largely a function of the effectiveness of the compensation for the steel hull effects on the ADCP compass.

The measurement accuracy enhancement technique called "bottom tracking" will also be implemented with the ADCP/VEEP system. Since current profile velocity values are measured relative to the vehicle that carries the ADCP, the absolute horizontal translational velocity of the buoy must be added vectorially to the measured current velocity components determined by the ADCP. The 75-kHz ADCP units that will be used have a depth range large enough to cause sound reflection from the ocean bottom. Processing by the ADCP of those echo signals from the bottom reflections will yield the needed horizontal translation velocity vector of the buoy.

An important consideration affecting the installation of the ADCP on NDBC buoys is the prevention of biological fouling on the ADCP transducers, which will degrade the system's acoustic performance. In order to allow inspection and cleaning of the ADCP without divers or buoy drydocking, a mechanism has been designed to raise the entire ADCP assembly up through the buoy hull. Technicians can then work on the system from the weather deck of the buoy. Additionally, NDBC is sponsoring research into organic (i.e., nonmetallic) anti-fouling coatings, specifically directed toward the prevention of marine growth on stationary objects (such as buoys).

New Methods for Directional Wave Measurement

The measurement of directional wave spectra using an ordinary slope-following buoy requires the measurement of hull pitch and roll. Although accurate pitch and roll measurements can be made by active sensors based on gyroscopic principles, the energy consumption of such sensors is significant. Their lifetimes, in operating hours, is limited, and they are costly. These disadvantages have led to the use of passive sensors aboard buoys that need to

operate unattended at remote stations for periods measured in years.

Although a number of vendors purport to offer sensors that measure pitch and roll with passive sensors that are small and inexpensive, usually one will find that the measurements are only valid for static conditions. To our knowledge, no small, inexpensive sensors are available on the market that can provide accurate measurements of pitch and roll in the presence of horizontal acceleration.

The lack of such a sensor largely accounts for the fact that almost all (if not all) pitch-roll directional wave measuring buoys in the world make use of one of the "HIPPY" heave, pitch, roll sensors. Datawell, in Holland, has been building these sensors for many years. They are accurate, consume little power, and are quite reliable when handled properly. On the other hand, they are quite heavy and bulky, placing a lower limit on the size of the buoy aboard which they may be used. In recent years, the cost of these sensors has also represented a substantial percentage of the total cost of a buoy payload.

For several years, NDBC has investigated possibilities for new, low-cost methods for measuring pitch and roll aboard buoys measuring directional wave spectra. We are now experimenting with a method that, for lack of a better name, is called the magnetometer-only (MO) method for measuring directional wave spectra. It is so called because our standard buoy for measuring directional wave spectra uses a HIPPY 40 and a triaxial magnetometer to measure pitch and roll, and the MO system requires only the magnetometer. The MO method takes advantage of the usual response characteristics of an axially symmetric discus-like hull, wherein the motions around the mast axis are low frequency and not much affected by waves. The pitch-roll motions caused by waves are at higher frequencies. This frequency separation of the two motions allows the pitch and roll angles each to be uniquely related to the magnetometer outputs. The theory has been tested successfully aboard several hull types. Further tests are being conducted in the U.S. coastal Pacific and U.S. coastal Atlantic to confirm that the method will work when low-frequency, very long waves are being measured. Such waves produce very small slope changes, and thus very small magnetic changes, that might not be detectable.

The MO system, if proven accurate under all sea conditions, promises to reduce the initial cost of a directional wave measuring buoy by the price of the HIPPY sensor plus whatever cost reductions in the hull can be achieved by not having to use the HIPPY. Additional benefits include reduced system complexity, which should improve reliability.

New Ways to Measure Winds from a Directional Wave Buoy

A key observation made by NDBC buoys is ocean surface wind. On each buoy, wind speed and direction are measured by two duplicate anemometers. In this way two objectives are achieved: (1) reliability is improved through the installation of redundant wind sensors; and (2) data quality is enhanced, since the winds from the two sensors may be intercompared. These objectives are important because the anemometers are the only buoy sensors with moving parts that are exposed to the marine environment.

In the last year, NDBC has demonstrated the feasibility of measuring ocean surface

wind speed and direction from by-products of the NDBC directional wave measurement system. The technique to perform this measurement requires no additional sensors and, consequently, is very cost effective. Field tests have proven the accuracy and reliability of the technique. As a result, NDBC now has a method, independent of the standard anemometer wind sensors, to obtain ocean surface winds. The resulting data may be employed routinely for wind sensor data quality assurance.

Recently, a vertical, flat fin was attached to one leg of the mast of a 3-meter discus buoy used for directional wave measurements (Figure 2). The fin provides the restoring torque to force the designated bow of the buoy hull to face the wind and to dampen yawing oscillations of the buoy. As a result, a rather stationary buoy hull condition can be provided during data acquisition. Therefore, the wind direction can be estimated from the direction of the buoy bow, which is expressed by buoy magnetic azimuth produced from an onboard magnetometer that is a part of the directional wave measurement system. Furthermore, the wind will generate drag on the buoy mast that, in conjunction with the mooring force holding the buoy on station, will cause the buoy to tilt in the fore and aft direction (pitch). Ocean waves and other environmental forces also affect buoy dynamics, causing pitch (and other buoy motions) to continuously vary. However, over the period of wave measurement sampling (20 minutes), wave-induced pitch will theoretically have a mean of zero. If the wind is relatively steady over the 20-minute period, then the azimuth (mean of maximum and minimum value) and the mean pitch that are produced by the directional wave measurement system



Figure 2. 3-Meter SWADE Buoy with a Fin

can be used to estimate wind direction and speed, respectively.

Three months of data collected at several NDBC directional wave buoy stations were used to verify the technique. Scatterplots were made between the measured wind directions and the estimated wind directions from the buoy azimuths. For wind speed, an empirical equation relating wind speed to mean pitch angle was derived for each station. The form of this relationship was based on a theoretical analysis of the aerodynamic drag on the

buoy superstructure. Using empirical formulae, wind speeds from buoy pitch were estimated and compared to anemometer-produced wind speeds. The effects of the steadiness of the wind on the difference between the winds from the wind sensors and the winds estimated from buoy pitch and azimuth were studied. For wind speed, variations in the length of the upper mooring chain, which affects the restoring moment of the buoy, were also analyzed.

For the wind direction study, field data were obtained from two directional wave buoy stations (stations 45005 and 46042). Station 45005 was the first NDBC directional wave buoy station established in the Great Lakes area. The station is located at the southwest end of Lake Erie. The water depth at the deployment site is about 15 meters. Station 46042 is located outside of Monterey Bay, California, at a water depth of 2103 meters. For the wind speed analysis, data were used from station 46042 and from station 41008 located in 18 meters of water off St. Mary's Entrance, Florida.

Based on the results of these studies, about 85 percent of the estimated wind directions (from mean buoy azimuth over a 20-minute data acquisition period) differed no more than 20 degrees from the wind sensor directions. Under steady conditions in both wind speed and direction, 96 percent of estimated mean buoy azimuths were less than 20 degrees from the measured wind directions. Using the mean pitch technique, more than 94 percent of estimated wind speeds were within 2 m/s of the wind sensor measured wind speeds, irrespective of wind steadiness. Therefore, the estimating techniques for both wind speed and wind direction have been demonstrated to work quite well.

As an example, Figure 3 is a time series plot showing wind speed for station 46042 as measured by the wind sensor and as estimated from buoy mean pitch. The agreement is quite good. Figure 4 shows a similar time series for wind direction for station 45005. In this figure, the estimated wind direction is labeled BUOYAZ. Note that the directions of the two anemometers (WDIR1 and WDIR2) disagreed, but that the BUOYAZ showed WDIR2 to be correct.

Additional theoretical work has been done in an effort to improve the aerodynamics of the buoy mast-fin configuration. As a result, it is believed that new mast-fin arrangements could yield even better wind speed and direction accuracies. The next step will be to field test the most promising of the new mast-fin designs.

Coastal Buoy

The Coastal Buoy project was initiated to develop a low-cost, lightweight, reliable, moored buoy for use in the coastal environment. Although not a sensor system per se, the Coastal Buoy is an important recent development at NDBC, and holds promise for significant improvements in the sensing of coastal and near-shore regions. A photograph of the Coastal Buoy is shown in Figure 5.

The Coastal Buoy is suitable for meteorological, oceanographic, and directional wave measurements. The meteorological package includes two barometers, two anemometers (for wind speed and direction), an air temperature sensor, and an ocean temperature sensor. The anemometers and air temperature sensor are mounted on the mast at 5.0 and 4.5 meters, respectively. The Coastal Buoy has a fin to orient the hull into the wind so that there is no obstruction to the

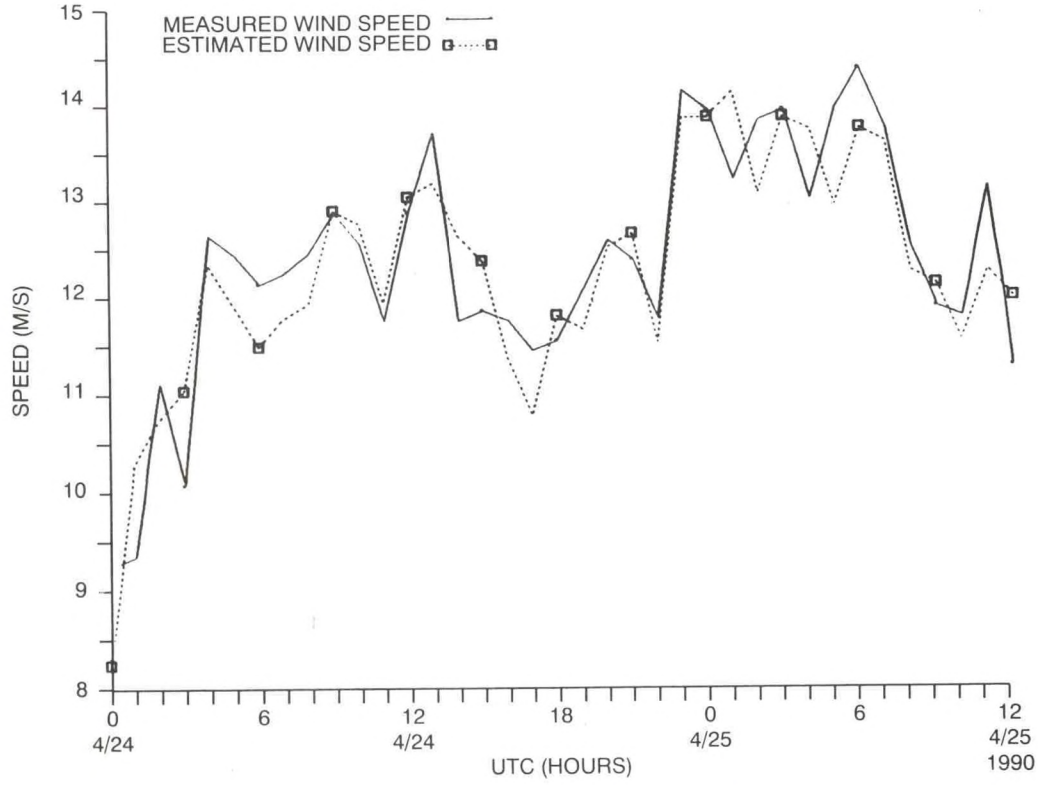


Figure 3. Time Series Plot Showing Wind Speed for Station 46042 as Measured by an Anemometer and as Estimated from Buoy Mean Pitch

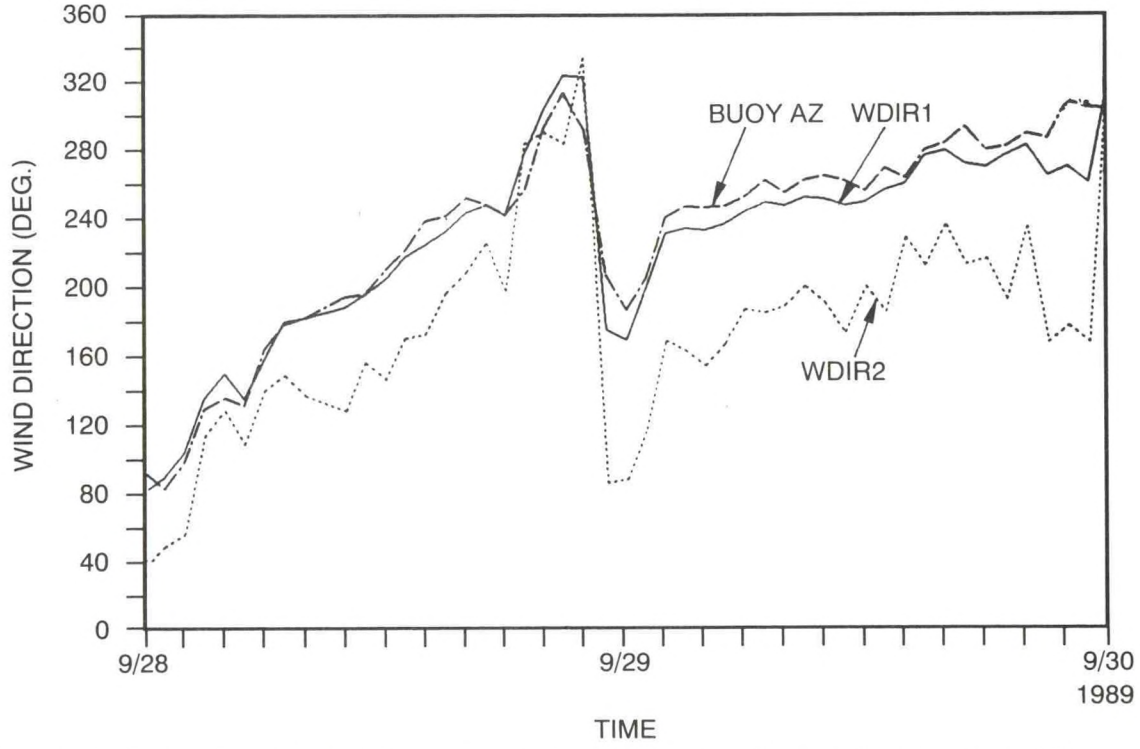


Figure 4. Time Series Plot Showing Wind Direction for Station 45005 as Measured by the Wind Sensors and as Estimated from Buoy Mean Azimuth Angle

anemometers. Any of NDBC's operational payload configurations will fit into the payload compartment, which is a cylinder 0.91 meter in diameter and 0.82 meter tall. Because magnetometers and magnetic compasses will be part of the payloads, the Coastal Buoy is being fabricated of nonmagnetic materials. Other design features are: (1) a truck can transport the buoy without special routing or permits; (2) the buoy can be easily and safely handled without special equipment or procedures; (3) completely outfitted, the buoy weighs less than 820 kg; and (4) buoy hull life is in excess of 6 years.

The hull structure is marine-grade aluminum with a resilient closed-cell foam flotation collar closely fitted around the payload compartment. The central hull structural component is the payload compartment shell. The subsurface structure also has two significant variations. The first subsurface structure uses a pendulum arm mooring attachment within a fixed hoop to optimize wave-following characteristics for directional wave measurements.

The second subsurface structure is designed to reduce pitch-roll motions to best support the meteorological measurements. A traditional counterweighted center pipe design is used with its primary mooring attachment at the base of the center pipe. This approach uses the mooring loads to increase stability and provide increased damping in pitch and roll.

NDBC's Coastal Buoy prototypes have been deployed at special locations in the Atlantic and Pacific Oceans and Gulf of Mexico for engineering testing and observational performance evaluation. Preliminary results look very promising.

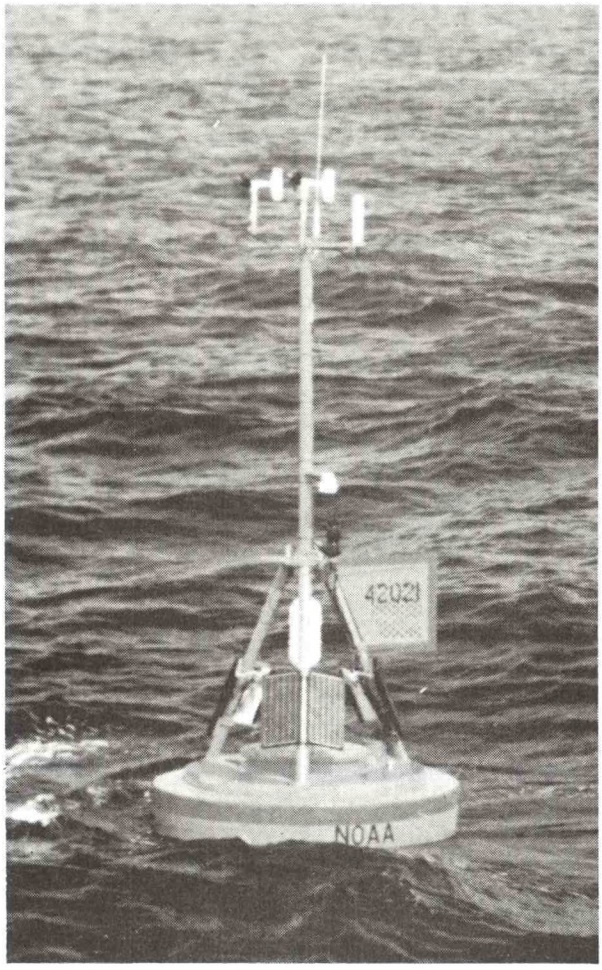


Figure 5. Coastal Buoy Deployed

Infrared Laser Wave Height Sensor

Coastal-Marine Automated Network (C-MAN) stations located on offshore platforms or other suitable structures have the capability of obtaining nondirectional wave data using the Infrared Laser Wave Height Sensor (IRLWHS).

The IRLWHS, which is enclosed in a hermetically sealed, stainless steel enclosure compatible with the marine environment, is installed above the water at a distance between 6 and 50 m. The system transmits a narrow laser pulse at the rate of 1500 pps and measures the time of round

trip pulse flight, which is proportional to the distance from the sensor to the water's surface. In order to ensure accurate measurements, the IRLWHS must have a down-look angle within approximately 15 degrees of the vertical. The sensor output is processed by the C-MAN payload, where the three elementary sea state parameters, significant wave height, the period of the spectral peak, and probable maximum wave height, are calculated. These data are incorporated into the C-MAN message for transmission via GOES.

In addition to fixed platforms, the IRLWHS is also suitable for use on semi-submersible platforms, spar buoys, and other movable structures that remain relatively stationary with respect to the action of the water.

The IRLWHS is a low-cost, accurate, and reliable sensor. Figure 6 compares the spectral plot for a 20-minute data period from the IRLWHS and a wavestaff, a device which is immersed in the water. The two sensors were monitoring the same surface water area. Figure 7 shows a comparison of significant wave height data obtained by the same two sensors over a 72-hour period. These data were taken at the Chesapeake Light Platform.

Upper Air Wind Profilers

NDBC is engaged in a cooperative agreement with the National Oceanic and Atmospheric Administration's (NOAA's) Environmental Research Laboratories (ERL) in Boulder, Colorado, to design, procure, and install a field demonstration network of 30 upper air wind profilers. This project is well under way, and at present, two prototypes and over 10 production units have been built, were installed, and are successfully operating.

The NDBC/ERL upper air wind profiler is a pulsed-Doppler radar operating at a frequency of 404.37 MHz. It produces a true vertical wind profile at an altitude of 0.5 to 16.25 km, with a vertical resolution of 250 m. The radar has sufficient sensitivity to

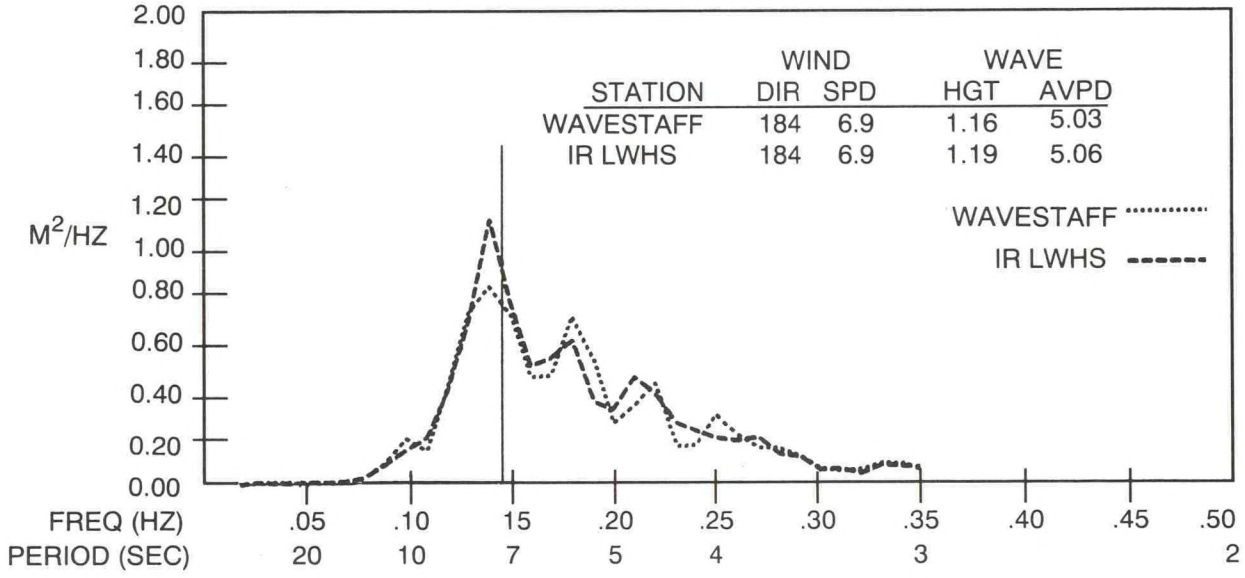


Figure 6. Comparison of Spectral Plot for a 20-Minute Data Period from the IRLWHS and a Wavestaff (6/7/89, 2000Z)

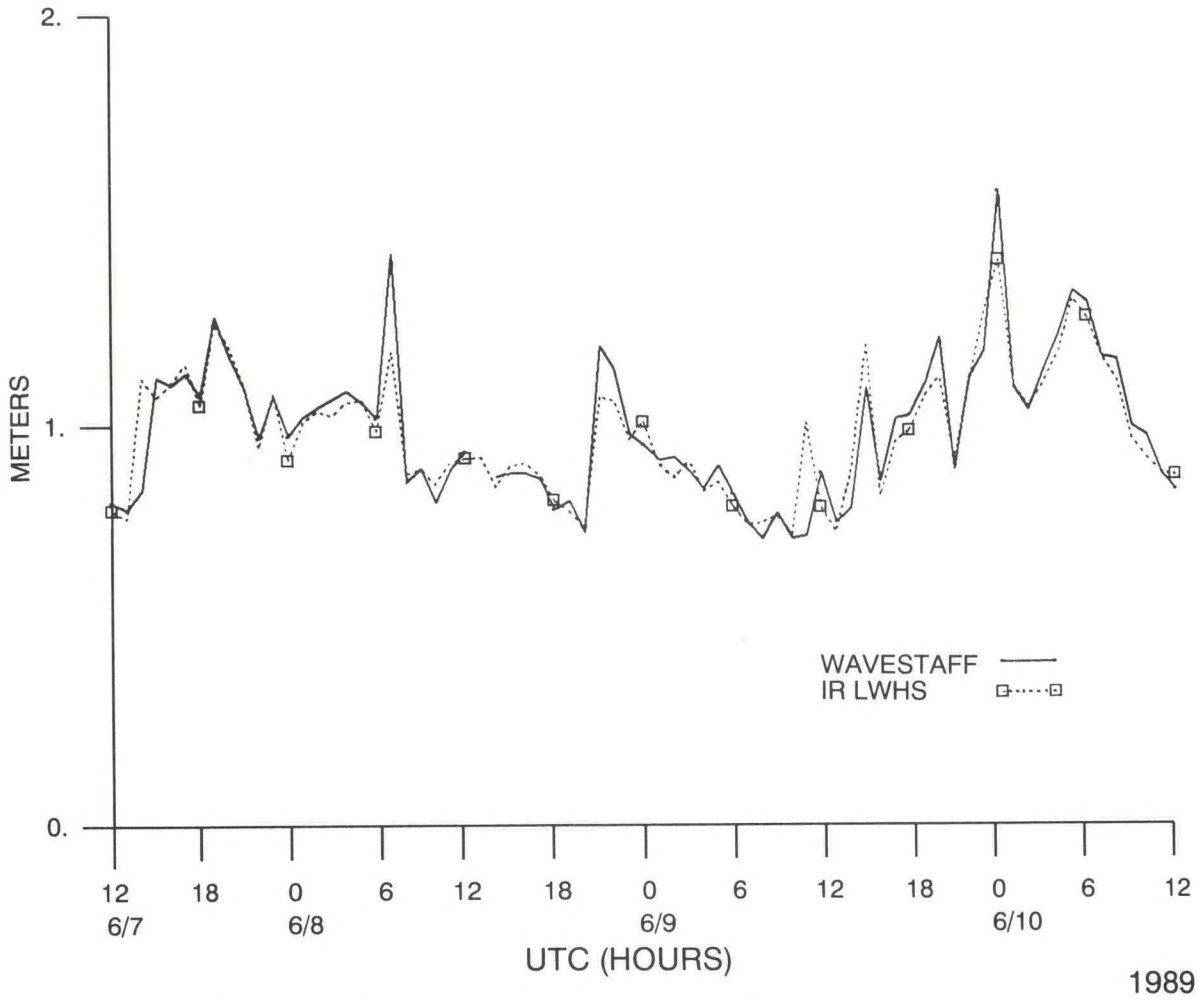


Figure 7. Time Series Plot of Significant Wave Height

detect the signal backscatter from radio refractive-index irregularities caused by atmospheric turbulence. The radial velocity of the wind is determined by measuring the Doppler frequency of the backscattered signal. Wind speed and direction is then determined by processing the data obtained from one vertical and two oblique radar beams. The system transmits for a period of 2 minutes in each beam, producing one vertical wind profile every 6 minutes. At present, data are being released for meteorological applications in the form of 1-hour averaged wind profiles. Wind speed and direction for a 12-hour period is shown in Figure 8. These data are like those obtained by the prototype profiler installed at Platteville, Colorado.

The NDBC/ERL profiler is designed to operate in the most stringent of environmental conditions. All equipment, with the exception of the antenna, is housed in an equipment shelter that maintains the profiler electronics at a constant temperature and humidity through a wide range (-40 °C to 50 °C, 0-100% humidity) of outside environmental conditions. The system is designed for remote, unmanned operation and has a mean-time-between-failure of 6 months. Data are transmitted to a central location every 6 minutes via

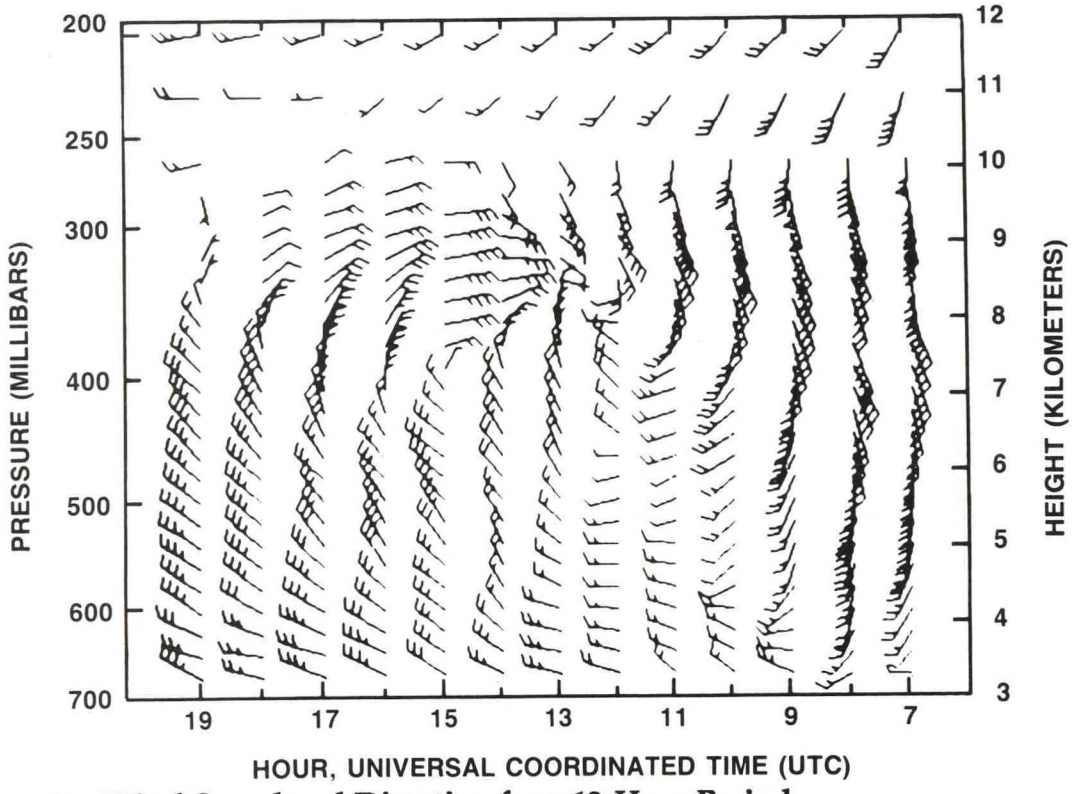


Figure 8. Wind Speed and Direction for a 12-Hour Period

commercial telecommunications facilities, and every hour via the GOES system.

A cut-away view of the NDBC/ERL profiler shelter is shown in Figure 9. Figure 10 shows the whole profiler. The fenced enclosure is 50 feet by 63 feet. The antenna pictured is a coaxial-collinear design. Also shown are the relative positions of the radar beams. The beam positions are electronically switched. The radar is of solid-state electronic construction, and the only moving parts are 10 relays and the air circulation fans located in the electronic bays.

Upper air wind profiler data have numerous applications. Continuous wind data over a wide range of altitudes will greatly improve meteorological forecasts.

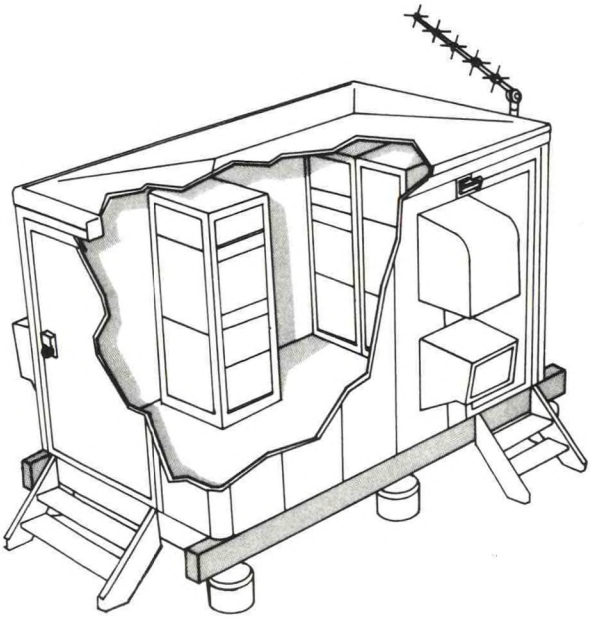


Figure 9. Cut-Away View of the NDBC/ERL Profiler Shelter

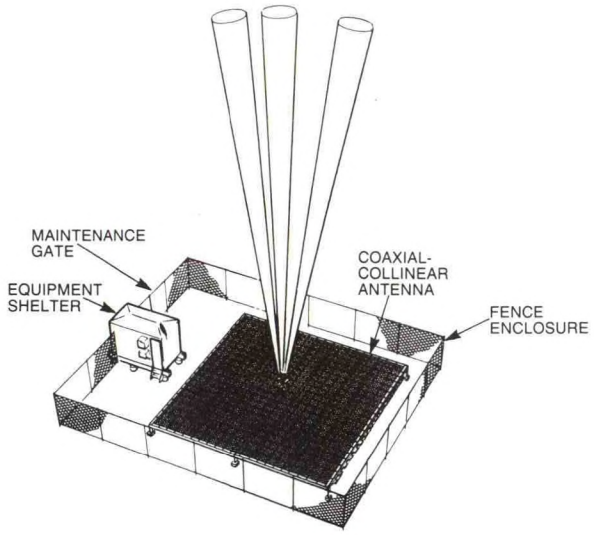


Figure 10. Profiler Layout

More accurate forecasts will be very useful to the agricultural sector, and, in the case of severe weather conditions, will enhance the protection of lives and property. The vertical wind profiles will be especially useful to aviation, and large savings in fuel costs will be obtained by routing aircraft at altitudes where the most favorable winds prevail.

Although wind profilers were originally designed for land-based operation, thereby limiting the ocean data collection to coastal installations and those on offshore fixed platforms and islands, studies have shown that wind profilers can be used effectively on moving, ocean-going structures, such as ships or semi-submersible platforms. Data processing algorithms taking into consideration both vertical and horizontal movements of the antenna will result in accurate wind speed and direction data. In installations where space is limited and the coaxial-collinear antenna cannot be used, a smaller antenna, such as a parabolic reflector, can be installed.

The wind profiler radar is also capable, with the addition of acoustic transducers, of obtaining the data required for the calculation of an upper air temperature profile. This application is discussed in the next section.

Upper Air Temperature Profilers

Radio Acoustic Sounding Systems (RASS) are a method of remotely sensing temperature profiles by combining radar and acoustic sounding techniques. The radar detects backscattered radiation from fluctuations in the refractive index of the air caused by the almost spherical acoustic wavefronts resulting from a sound wave. The Doppler shift of the backscattered signal gives an estimate of the speed of sound through the air, and therefore, of the virtual temperature, which is related to the speed of sound through the air. Virtual temperature, in turn, can be converted to a common temperature scale, such as Celsius or Fahrenheit.

Wind profiler radars are easily adapted to the RASS technique. The addition of acoustic transducers, along with the additional software and a limited amount of hardware required to control the acoustic equipment and process the data, is all that is required. Upper air wind and temperature profiles can then be obtained simultaneously.

A requirement of the RASS technique is that the wavelength of the acoustic signal must be equal to one half of the radar frequency wavelength. If this condition, known as the Bragg condition, is not met, system sensitivity decreases dramatically. The required acoustic frequency for a 404.37 MHz radar is approximately 900 Hz. The attenuation of acoustic signals in the atmosphere, like radar signals, increases as

the frequency is increased. Lower frequencies result in greater altitude coverage. However, because of the Bragg condition requirements, the acoustic frequency of the RASS operating with a given radar cannot be varied (lowered) to obtain data from higher altitudes.

Research in the RASS technique, using experimental equipment, has been conducted for some time in various parts of the world. Figure 11 shows a comparison of a temperature profile measured by a 404.37 MHz wind profiler radar enhanced with a RASS, and a temperature profile obtained by a radiosonde launched from Brighton, Colorado, a location about 24 km from the radar. The radar and RASS were located in Erie, Colorado.

Tests using experimental RASS equipment with the NDBC/ERL prototype wind profiler at Platteville, Colorado, were conducted in the summer of 1990. The data obtained exceeded expectations, and indicate that temperature profiles can be consistently obtained up to an altitude of 5 km using this radar. It is expected that the RASS capability will be implemented at several wind profiler production unit sites. Upper air wind profilers enhanced with the RASS, like the wind profilers described in the previous section, can be installed on moving platforms, such as ships and semi-submersible platforms, so long as data processing algorithms taking into account the platform motion. An unattended system capable of obtaining accurate, reliable, and continuous upper air wind and temperature profiles is especially significant in view of the increasing requirements for on- and offshore meteorological data in an era of declining monetary resources.

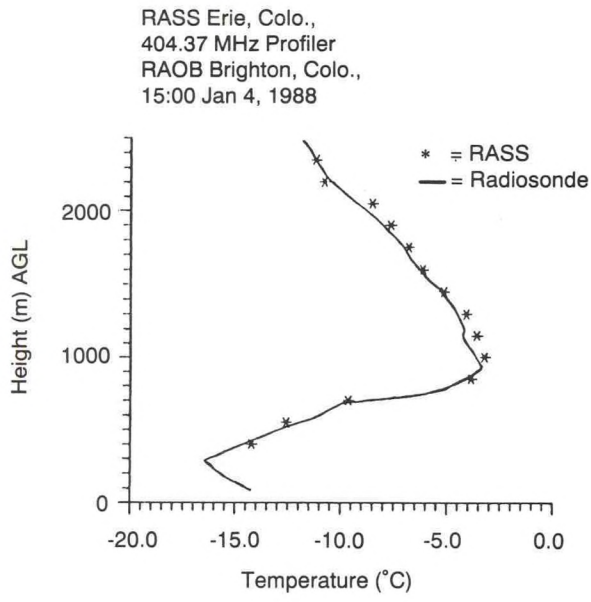


Figure 11. Comparison of a Temperature Profile

Summary

This paper is an overview of several of the more significant sensor system development projects under way at the National Data Buoy Center. Some of the examples are enhancements to existing capabilities and others are entirely new systems with the potential for radically improving our understanding of the oceans and atmosphere. At NDBC, we are dedicated to deploying automated observational stations in the deep ocean and in the coastal zone and operating those stations such that they provide the highest quality data possible at a low cost. This means that performance and reliability are at a premium. As NDBC enters the 1990's, we are continually investigating technological advancements that will enable us to better and more cost-effectively serve the national and world meteorological and oceanographic community.

TOURIST SUBMERSIBLE SAFETY

by
John A. Pritzlaff
Westinghouse Electric Corporation
Chairman SNAME / MTS Tourist Submersible
Operational Safety Guideline Workshop and Book Project

In recent years there has been a significant increase in the world wide operations of tourist submersibles. For those tourist submersibles operating in U.S. waters, the U.S.Coast Guard has the legal responsibility for inspection and regulation. For all of the other tourist submersible operations, there are no specific operational or safety requirements.

Most tourist submersibles and their support craft have been built and are being built under the design, fabrication and test cognizance of one of the major ship classification societies. As such, the physical equipment (submersible - ferry boat - surface support boat etc.) is quite safe. The maintenance of that original safe construction and the day to day tourist dive operations are not covered by any type of safety standard or guideline.

The Society of Naval Architects and Marine Engineers (SNAME) and The Marine Technology Society (MTS) have undertaken a joint Safety Guideline book project in order to provide a basic safety document that can be used on an industry wide basis to ensure a reasonable level of safety for current and future submersible operations.

With the legal requirement to have the responsibility for U.S. tourist submersible operations, the U.S.Coast Guard undertook several initiatives to increase their knowledge and support of tourist submersible safety and operations.

1. Generation of a Navigation and Vessel Inspection Circular covering Guidance for Certification of Passenger Carrying Submersibles. (See Ref. I)
2. Initiation of a task with the Department of Transportation, Transportation System Center, for the generation of a System Safety Analysis for Passenger Carrying Submersibles.(See Ref. II)
3. Initiation of a task with the Marine Board of the National Research Council, for the assessment of Passenger Submersible Safety. (See Ref. III)
4. Support for a SNAME / MTS Tourist Submersible Safety Workshop and the generation of a Safety Guideline book.

The SNAME / MTS Tourist Submersible Safety Workshop was held in Monte Carlo, Monanco on 8 Oct. 1990, as part of the Tourist Oceanology International '90 that was held there on 9 - 11 Oct. 1990. The workshop was focused on the three major sections of the International Safety Standard Guidelines for the Operation of Undersea Vehicles book published by MTS in 1979. The three sections of that book addressed the safety related aspects of operating Personnel, operational Plans and Procedures and operational Equipment. In looking at these three topics the workshop activity asked the question, "What is different now that Tourists are being carried as paying passangers - in some numbers (5 to50) and that these

passengers will come in all ages and in all degrees of health, agility and knowledge of the marine environment.

Many key factors came out of this review and questioning process that formed the basis for the workshop discussions and will make up much of the content of the forthcoming SNAME / MTS book "Safety and Operational Guidelines for the Operation of Tourist Submersibles"

• Tourists are paying for a fun type / entertainment ride. They have a right to expect it to be safe and comfortable.

• The submersible operating company is providing this entertainment experience in order to make money.

• One operator's accident or bad entrapment incident will get world wide publicity and would hurt business for all operators.

These factors combine to point up the interest that the owners and operators of tourist submersibles showed in the safety workshop and their support of the SNAME / MTS safety effort. The owners and operators are indeed interested in safety - as long as it does not cost too much. The major issues involved in operational safety are: How much money should be spent on safety and how safe is safe. Neither of these questions have an easy answer, but the both can be answered with the generalized point of - "enough to be acceptable." Each operational activity will have a slightly different point of view to this depending on the physical type of operation and the particular finances of the owner. The goal of the SNAME / MTS safety guideline effort is to document what is considered by reasonable people to be "acceptable" levels of operational safety.

If a particular tourist submersible operation cannot afford this " reasonable" level of safety or allows the activity to fall below what's considered to be "reasonable", then they should not operate.

With the safety workshop and safety documentation effort focused on the Personnel - Plans and Procedures - Equipment areas, the following topical safety generalities can be made.

• Personnel must have the qualifications and the training to do the job that they are assigned to do. Working with numbers of tourists, they should have additional training or experience in handling numbers of people under stressful conditions.

• All operations need to have various plans and procedures that document how people will be handled throughout the diving operation, how the various vessels will be handled, how maintenance will be done, how emergency situations will be handled etc. Planning and documentation of the plans and procedures is done before the activity is undertaken so that everything can thought out properly and safely.

• With respect to the differences between safety equipment needed for a work submersible and a tourist submersible, there probably is not too much difference in equipment - just more of it. Since more people are involved, more emergency life support consumables are needed ie. food, water, oxygen, carbon dioxide removal chemicals. Since most all of the tourist submersible dive activity is done in relatively shallow water, (80ft. - 125ft. ie.

scuba depth) and it is done adjacent to populated sea side areas where construction type (rescue) equipment is usually available, an emergency life support time duration of 72 hours has been considered to be adequate. If tourist dives are to be done in deeper water or in areas where rescue gear is not readily available, then longer emergency life support time durations must be considered.

• In most large tourist submersibles, the main battery is inside the pressure hull with the passengers. This means that the battery disconnect equipment, safety monitoring gear and fire protection equipment will have to be selected to meet the specific safety needs of the operation.

The SNAME / MTS Safety Book Committee generated a draft copy of the Safety Guideline Text based on the information obtained at the Safety Workshop. This draft was sent out to the Workshop Review Committee and to other interested parties (including most of the workshop attendees). At this time (May - June) the draft is being reworked and it is expected that it will be ready for publication and/or presentation in the Fall of 1991. Presentation of the book material is planned for the Tourist Oceanology International '91 conference being held in Miami Fla., 22 - 24 October, 1991.

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NVIC -

NAVIGATION AND VESSEL INSPECTION CIRCULAR NO.

Subj: Guidance for Certification of Passenger Carrying Submersibles

1. PURPOSE. This circular provides guidance for certification of passenger carrying submersibles under Title 46, Code of Federal Regulations, Subchapter T - Small Passenger Vessels (under 100 Gross Tons) (46 CFR Parts 175-187).

2. DISCUSSION.

   a. Non-military submersibles have been used for several decades in the industrial, experimental and research fields. Submersibles had not been used in any commercial service for which the existing inspection statutes and regulations would apply until 1987 when the first passenger carrying submersible to be certificated by the U.S. Coast Guard went into operation in St. Thomas, U.S. Virgin Islands. Two other passenger submersibles had already been operating in the Cayman Islands and Barbados (outside U.S. jurisdiction) beginning in 1986.

   b. For operations under U.S. jurisdiction, the inspection statutes of U.S. Code Title 46 - Shipping (46 USC) and the regulations in 46 CFR Subchapter T - Small Passenger Vessels (46 CFR Parts 175-187) apply to any submersible less than 100 gross tons carrying more than six passengers. Since the regulations were developed primarily with surface craft in mind, many of the requirements cannot be applied to or may otherwise be inappropriate for submersibles. Additionally, there are many measures not in the regulations which must be applied to attain an equivalent level of safety to that of surface craft and otherwise minimize any inherent hazards of underwater operation.

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2. c. There has also been much interest regarding the operation of smaller submersibles carrying six or fewer passengers. To date, only a few such operations exist. Such vessels are not subject to present inspection laws. However, they are subject to regulation as uninspected vessels under 46 CFR Subchapter C - Uninspected Vessels (46 CFR Parts 24-26). These submersibles must also be designed and constructed to a recognized industry standard for safe underwater operation. Additionally, they may be subject to special local operating restrictions as may be imposed by the Captain of the Port (COTP) relative to navigation safety, port safety and security, and vessel traffic considerations.

d. Recreational submersibles must comply with 33 CFR, Subchapter S (Boating Safety). Undocumented submersibles (i.e., those not having federal documentation) with propulsion equipment, must be numbered in accordance with the federal numbering system or the numbering system of the state in which the submersible will be principally operated. When a submersible is involved in a collision, accident, or casualty, the operator is required to report such occurrences to the appropriate OCMI or state authorities, and to render all possible assistance to others involved in such incidents. 33 CFR 155 (Oil Pollution Prevention Regulations for Vessels) and 33 CFR 159 (Marine Sanitation Devices) also apply to recreational submersibles. Voluntary reports of submersible operations in or near U.S. waters may be made to the nearest Coast Guard Operations Center. Inquiries about the extent of such reports and other questions that cannot be resolved locally should be directed to Commandant (G-NRS) at (commercial/FTS) 202/8-267-1948. These reports are intended for informative use in search and rescue (SAR) activities only.

e. Enclosure (1) to this circular provides general guidance relative to the inspection and certification requirements for submersibles, primarily those carrying more than six passengers. This document does not stand alone, i.e., it makes reference to the applicable regulations and to the appropriate industry standards. Designers, builders and operators must also be familiar with and use the referenced materials.

f. Submersible technology is not new, but its application in the passenger carrying industry is still very much under study. Although we have established a safe baseline, as this industry grows we will see many technological advances which will have to be carefully considered in view of safety. We have initiated a number of studies from which we are likely to gain some insights that may impact on these guidelines, the regulations and the referenced industry standards. Eventually, we plan to establish specific regulations for this class of vessels. In the meantime, enclosure (1) is considered to be the best available approach to facilitating this industry while ensuring passenger safety.

3. IMPLEMENTATION. Coast Guard plan review, inspection, and certification will be based on the guidance contained in this circular. Owners, operators, designers and builders of passenger carrying submersibles must become familiar with the applicable regulations and standards. To facilitate a timely inspection for certification, they are also urged to follow the guidelines of enclosure (1) closely.

Encl: (1) Small Passenger Submersible Guidance

(2) Guidelines for Stability of Small Passenger Submersibles

(3) References

(4) Addresses

(5) Urban Mass Transportation Adminstration (UMTA) Recommended Fire Safety Practices for Rail Transit Materials Selection

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GUIDANCE FOR CERTIFICATION OF PASSENGER CARRYING SUBMERSIBLES

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Encl: (2) Guidelines for Stability of Small Passenger Submersibles
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(5) Urban Mass Transportation Adminstration (UMTA) Recommended Fire Safety Practices for Rail Transit Materials Selection

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15 Supplementary Notes

16 Abstract

During the past few years, several private companies have been using passenger carrying submersibles to conduct underwater sightseeing tours for tourists. For submersible operations under U.S. jurisdiction, the Coast Guard is required by law to establish and enforce a certain minimum level of safety for vessels. The existing Coast Guard statutes and regulations were developed primarily for surface craft; many of the requirements cannot be applied to or are inappropriate for application to submersibles. Furthermore, for passenger carrying submersibles, the complexity and new concepts employed require that the Coast Guard develop methods to adequately evaluate their safety. This report presents the results of the system safety analysis conducted to identify and assess the hazards associated with the operation of passenger carrying submersibles. Included in this analysis is the definition of the submersible system in terms of the basic system elements: equipment and facilities, procedures, people, and the environment in which the submersible system operates. Hazard identification is accomplished through the creation of accident scenarios, the conduct of a Preliminary Hazard Analysis, and the development of Fault Trees. Finally, undesired events resulting from the hazards are assessed for event severity and the probability of event occurrence. General countermeasures to mitigate the undesired events are presented and the factors to be considered in the evaluation of the countermeasures are delineated.

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SAFETY OF TOURIST SUBMERSIBLES

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Commission on Engineering and Technical Systems
National Research Council

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ADVANCES AND EXPERIENCE WITH TELEOPERATED SYSTEMS INCORPORATING REMOTE PRESENCE

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INTRODUCTION

The Naval Ocean Systems Center (NOSC) Hawaii Laboratory has a long standing program in research and development on teleoperated systems. Recent work is summarized in the literature [1, 2, 3]. Our interest in teleoperated systems is removing the human from hazardous environments. Our research and development in this area has the objective of maximizing system capabilities and minimizing operator work load and training by providing the system operator with a sense of remote presence. Remote presence can be described as:

"..the perception of actually being at the remote location."

The degree of 'presence' achieved is determined by: (1) the fidelity and/or richness of the sensory information, (2) the ability to control the relation of the sensors to the remote environment, and (3) the ability to physically interact with the remote environment.

The cost of teleoperation in a system is increased complexity and, based on present technology, a reduced capability for action. Complexity arises from the requirement to provide the remote operator with sensory and control interfaces. Reduced capability for action is a result of the reduced information to the operator resulting from the limitations of the sensors, displays, and control mechanisms. One focus of our research is to improve these technologies.

This paper discusses progress at the Hawaii Laboratory over the past three years in the development of three teleoperated systems: the Advanced Tethered Vehicle (ATV), the TeleOperated Vehicle (TOV) and the TeleOperator/telePresence System (TOPS). We will comment on experience to date with these systems, pointing to the need for additional sensory information by the remote system operator to achieve increased performance. Each of these systems addresses a different mission, but all share common approaches to subsystem design and to various degrees incorporate remote presence. ATV and TOV utilize a fiber optic data link for high band width, small size, ruggedness, and in the case of the TOV, jam resistance and covertness.

DISCUSSION

Advanced Tethered Vehicle (ATV)

The objective of the ATV is to provide the Navy with the capability to perform work to ocean depths of 20,000 feet. ATV is a self-contained, remotely operated undersea system [4]. Since ATV will be operated and maintained by Navy personnel the design was based on mature technology to insure a high level of system reliability and availability. The ATV system, figure 1, consists of five main components: a neutrally buoyant submersible vehicle, tether cable, handling system, control station and auxiliary equipment.

The vehicle work package, figure 2, consists of two manipulators, four television (TV) cameras, a 35-mm film camera and strobe light, and a variety of tools and lights. The manipulators are identical master-slave units incorporating force feedback. Of the four TV cameras, two are used in a stereo pair, one has a zoom lens, and one acts as a view finder for the film camera. The stereo pair and zoom cameras are mounted on pan and tilt units. A suite of hydraulically powered tools is mounted on the support tray below the manipulators and includes a rotary drive to which an abrasive cutoff wheel, drill, or impact wrench can be attached and independent linear tools consisting of a spreader, cable cutter, jack and grabber.

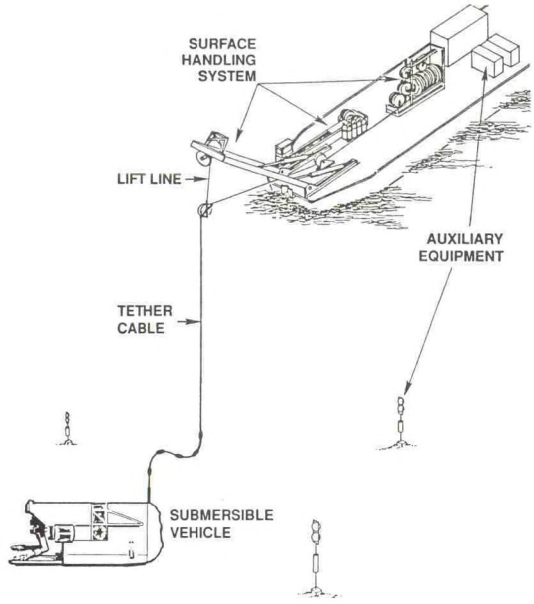

Fig. 1 ATV System Configuration

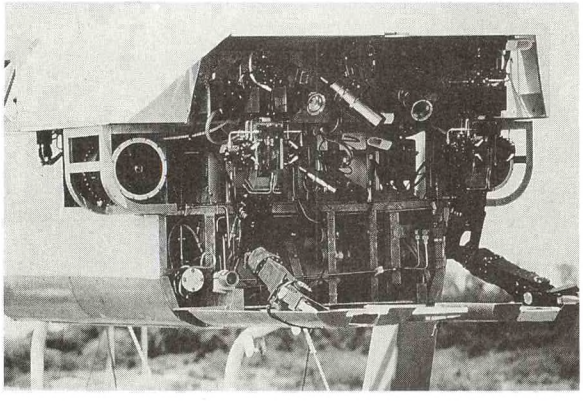

Fig. 2 ATV Work Package



Fig. 3 TOV and Control Van

The subsystems supporting teleoperation, i.e. sensors, displays, telemetry, and control interfaces are summarized in Table 1. The primary control interface with the vehicle are through its joy-stick propulsion control and the dual, force feedback manipulator controllers. The primary sensory displays include the flat panel stereo TV display, the sonar display , the navigation display and force feedback from the manipulator controllers. Over 240 hours of operation at depths to 20,600 ft have been logged on the system during test and evaluation. Experience to date has demonstrated that the system meets its reliability and effectiveness objectives. Operations with the work system have demonstrated that the operators can effectively perform the types of tasks required for deep ocean work, e.g. attachment, object manipulation, tool operation,etc.

TeleOperated Vehicle (TOV)

The objective of the TOV is to provide Marine Corps and Army personnel with a prototype unmanned ground vehicle (UGV) system which can be used in training exercises and operations to assess UGV systems' military worth, develop concepts of employment, and develop an experience base to guide future development.

The TOV is a remotely operated system which permits an operator to extend his sensory, motor function, and problem-solving skills to a vehicle located up to 30 kilometers away [5, 6]. The TOV system consists of a Remote Vehicle and a Control Station, figure 3. An operator controls the TOV system using displays and controls located in the Control Station. Visual and auditory displays have been designed to facilitate understanding of the vehicle's situation. Hand and foot operated controls, analogous to automotive vehicle controls, are used to control vehicle functions. A fiber optic data link allows physical separation of the operator from hazards encountered by the remote vehicle. Based on the High Mobility Multi-Wheeled Vehicle (HMMWV), TOV is capable of high transit speeds and can traverse severe off-road terrain. A mission-specific, add-on

subsystem for Reconnaissance, Surveillance, and Target Acquisition (RSTA) has been developed.

The subsystems supporting teleoperation of TOV are summarized in Table 1. The control station specified in the table provides an interface similar to what is provided in the actual vehicle, i.e. steering wheel, throttle, gear shift, and seat. These controls are presented to the operator in the same relative position they occupy in the HMMWV, figure 4. An alternate controller has been developed which fits in several man portable containers and is easily set up and operated in the field, figure 5. Driving controls are presented to the operator using a motorcycle type controller that integrates the throttle, brakes, gear shift, ignition and starting controls. This design was selected after extensive field testing which considered joy-stick steering, steering wheel, and the motorcycle handle bar like steering. The integrated motorcycle-like system was selected based on performance, compactness and ease of use in the field. Both control approaches use a helmet mounted, stereo display. This display is described extensively in references [7, 8, 9].

NOSC has constructed three TOV systems. Two systems are operated in support of military exercises and demonstrations while the third remains at the NOSC Hawaii Laboratory where it supports further research and development. As a result of operation of these systems an extensive experience base has been developed.

Vision is the primary sensory mode for remote driving. Extensive research has been performed to evaluate various types of displays and to determine their influence on vehicle operation [8, 9]. Field testing with the vehicles has provided additional insight into vision system performance and requirements. For effective high speed driving in rough terrain, head coupled stereo vision is important to performance for recognition of terrain features, such as rocks, depressions and ditches [8, 9]. Field of view (FOV) is also important since we obtain most of our navigation cues from peripheral vision. For existing sensors and

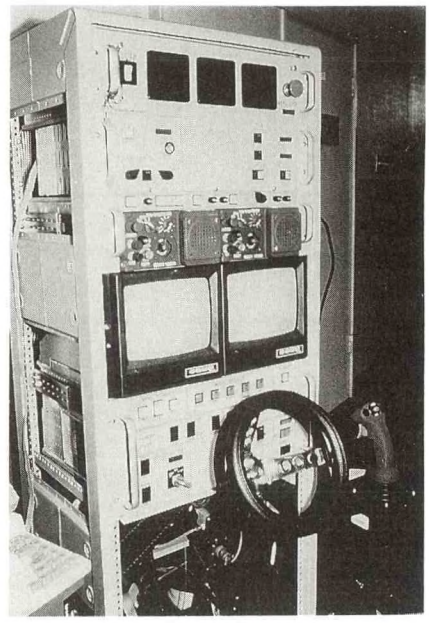

Fig. 4 TOV Control Station



Fig. 5 TOV Portable Control Station

displays, FOV is a trade-off for display resolution. Experience at NOSC indicates that if offered a 40^0 FOV with relatively high resolution or a 55^0 FOV with lower resolution a vehicle operator will select the higher resolution display if head coupling is incorporated. Our experience and that of others [10] indicates that for a fixed viewing system, a 40^0 FOV is inadequate for driving in complex environments. With a head-coupled system operators typically pan the viewing system to get a higher effective FOV. Head coupling appears to provide the required spatial awareness. Color vision is also preferred over monochrome when driving in rough terrain [8, 10] because it

provides increased information to the operator allowing discrimination of objects in grass, depressions, shadows, etc. It is important that sensory displays be in one to one correspondence with what is sensed on the vehicle. This is especially true for the display system magnification and head motion.

Experience gained with these systems indicates that for performance and safety the operators require additional sensory data on the remote vehicles' roll and pitch orientation (situational awareness). An intuitive display of vehicle attitude is required to allow the operator to perceive vehicle attitude on hills and side slopes. TOV operators have experienced several near accidents because they were not aware of the vehicle being on a steep grade. Experience at Sandia National Laboratory also indicates that the majority of accidents with teleoperated vehicles can be attributed to a lack of situational awareness [10].

TeleOperator/telePresence System (TOPS)

The objective of the TOPS project is to develop an anthropomorphic manipulator system and a high resolution stereo vision system to provide a remote work capability equivalent to an undersea diver. The manipulator system has been developed by a team made up of SARCOS Research Corp. and the Center for Engineering Design at the University of Utah. The helmet-mounted display system was produced by Wright-Patterson Air Force Base based on their work in the LHX Helicopter program. Figure 6 shows the master and slave system with the operator using the exoskeletal controller and the helmet mounted display. The manipulator system includes a 16 degree of freedom (DOF) hand/arm, a three DOF torso and a three DOF neck to provide the telerobot with the job site mobility to perform effective work.

Teleoperation subsystems are summarized in Table 1. The remote manipulator (slave) is kinematically equivalent to a human. The manipulator and exoskeletal controller incorporate bilateral force and position feedback, i.e. the force and position of one are reflected at the other. Force and position sensors are mounted at all the joints.

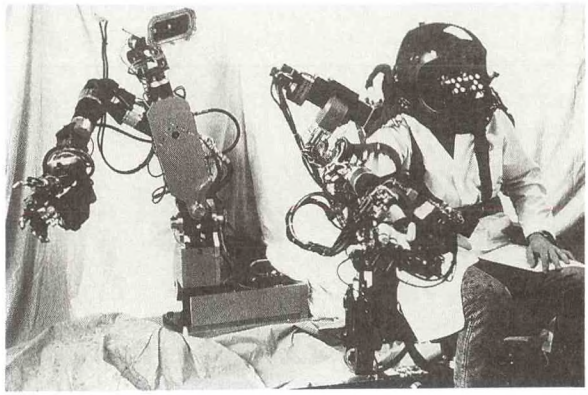

Fig. 6 TOPS manipulator and controller

The manipulator system is presently in the refinement and tuning stage after which a full range of laboratory testing is planned. Anecdotal information from initial testing of the display system with a seven DOF manipulator available at the Hawaii Laboratory indicates that it provides the operator with a sense of remote presence. For these tests, the stereo camera pair was mounted on a simple pan and tilt unit that followed the operator's head motions. Insights gained to date include: (1) the operators would prefer a manipulator with an additional degree of freedom at the shoulder (abduction/adduction), (2) the operators desired the ability to move the camera laterally and fore and aft (torso motion) to get differing perspectives on the task, and (3) the tests demonstrated that the high resolution stereo display significantly enhanced the ability to perform some tasks.

SUMMARY AND FUTURE DIRECTION

The level of presence required in a teleoperated system is a function of its intended use. It has been shown that through inclusion of remote presence technology the task of operating a telerobot can be simplified and made more efficient. We have found that remote ground vehicle operators require additional sensory information, particularly in the area of attitude and location. Operators easily get lost, and have no feeling for vehicle attitude or location.

There is a need for improved vision technology. Remote work requires good resolution and can accept a limited field of view. High speed driving of remote vehicles requires high central resolution and a wide FOV. TOV system drivers have the equivalent of 20/95 vision. Visual acuity of 20/40 is the minimum required by many U.S. driving laws [8]. Small, high resolution, low cost, color displays are required.

NOSC will continue to develop teleoperators for the U.S. Department of Defense. Our experience has shown that the design of the operator interface is critical to the success and performance of these systems. One approach we wish to investigate is the use of 'Virtual World' technology to fuse sensory data and present it to the operator in an integrated context that is natural for the task. The first application under consideration for this approach is in integrating the information available to undersea teleoperated vehicle operators from their sonar, navigation and video sensors. Conceptually this information would be presented to the operator through a head mounted display system, such as is used in TOPS, but the scene would be computer generated. The scene presented to the wearer would be a graphical representation of the world model derived from the combined sensor inputs. Since the operator would be looking into the model from a computer generated vantage point he could choose his point of view to be on the vehicle or outside of it to navigate and maintain an intuitive sense of where the vehicle is and has been. This ability to select a view point should aid in mission planning and route planning.

TABLE 1
SUBSYSTEM SPECIFICATIONS

SUBSYSTEM	ATV	TOV	TOPS
MOBILITY			
CONTROL	Joy Stick - 4 DOF	HMMWV Replica	Exoskeletal
NAVIGATION	Long Base Line	SatNav	None
Display	Graphic - Plan view	Graphic	
SENSORY DISPLAY			
VISION	Monochrome, 512 lines	Monochrome, 512 lines	Monochrome, 1023 ln.
Display	Flat Panel Stereo	Helmet Mounted Stereo	Helmet Mounted Stereo
FOV	60 Degrees	40 Degrees	70 Degrees
Direction	Joy Stick Directed	Helmet Tracking	Helmet Tracking
AUDIO	Monaural	Binaural	Binaural
MANIPULATION	Terminus Control Force feedback 5 lb resolution	None	Exoskeletal Control Force & Position 1.5 oz resolution
MANIPULATION			
MANUFACTURER	Western Space & Marine	NONE	SARCOS
DEGREES OF FREEDOM	7 Total		22 Total
Neck	–		3
Torso	–		3
Arm	6		7
Hand	1		9
DATA LINK			
TYPE	Fiber Optic	Fiber Optic	Analog Cable
DATA RATE	200 Mbs Bidirectional	200 Mbs Bidirectional	800 Mbs Equivalent
LENGTH	23000 ft	30 Km	50 ft

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DEVELOPMENT OF NON-METALLIC MATERIALS FOR DEEP SEA SYSTEMS

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Introduction

Deep-diving, unmanned submersible systems require pressure-resistant capsules with low weight-to-displacement ratios for the successful performance of their missions. These capsules, which house pressure-sensitive electronic and mechanical equipment, provide positive buoyancy to the vehicle. The few materials with the required strength-to-weight ratio able to serve as construction material for a buoyant, pressure-resistant capsule with operational depth of 20,000 feet or beyond are massive glass, massive ceramics, ceramic composites, cermets, and plastic laminates incorporating glass, boron, or graphite fibers.

Solid ceramics and graphite fibers in plastic matrices show the greatest short-term potential for achieving a low weight-to-displacement ratio required by high-performance remotely operated vehicles (ROVs) and autonomous unmanned vehicles (AUVs). Massive ceramics lend themselves best to immediate fabrication of small and medium-size inexpensive capsules, while the fiber-reinforced plastic (FRP) composites exhibit a great long-range potential for development of large pressure hulls with displacement measured in thousands of pounds. But even in such fiber-reinforced composite pressure hulls, transparent ceramics may serve as windows or as bow windows with panoramic visibility.

Current Developments

The present thrust in development of non-metallic materials for deep sea systems is in the fabrication technology for medium-size (i.e., diameter ≤ 1 meter) alumina ceramic cylinders and hemispheres with a proven service rating of 6000 meters and 0.5 weight-to-displacement ratio. Housings with diameters of 56 cm are being produced routinely, and housings with 127-cm diameters are being produced on an experimental basis.

Some attention is also being devoted to medium-size plastic composite cylindrical pressure hulls reinforced with graphite fibers. Because of the technical problems associated with winding of large, thick cylinders free of wrinkles and residual stresses, very little progress has been made in this area. The largest successful pressure housing of graphite fiber reinforced plastic is the 78-cm diameter by 6.35-cm thick by 165-cm long cylindrical pressure hull of the Naval Ocean Systems Center's advanced unmanned search system (AUSS) for deep sea operations. The major thrust in the area of plastic composite pressure hulls is the development of radial fiber reinforcement that would prevent delaminations in thick walled pressure housings under compression loading.

Future Plans

Work is in progress to develop ceramic composite technology for fabrication of large housings by the directed metal oxidation process from alumina ceramic filled with silicon carbide particulate. This process promises to deliver large net-shaped housings with improved impact resistance and lower weight at lower cost.

Another ceramic composite being developed for this application is an aluminum matrix cermet with 80-percent boron carbide particulate loading. Because of this composite's outstanding structural properties (compressive strength ≥ 4 GPa, flexure strength ≥ 450 MPa, Young's Modulus ≥ 350 GPa, density 2.6 g/cc) the weight-to-displacement ratio of housings for 6000-meter service will be reduced from 0.5, achievable presently with alumina ceramic and graphite fiber reinforced plastic, to 0.25.

So far only model scale housings with 15.25-cm diameter have been fabricated from these materials and pressure tested. The results of the tests with model scale housings support the high hopes that the Naval Ocean Systems Center places in these materials.

Summary

Ceramic materials hold out the promise for economical construction of small and medium-size corrosion-resistant, external pressure housings for deep sea systems. The development of aluminum matrix boron carbide particulate composite will, if successful, increase the payload capability of housings and/or pressure hulls for deep submergence vehicles by 50 percent. This, in turn, will result in additional payload or a significant increase in speed and/or range of autonomous deep submergence vehicles.

AN INTRODUCTION TO THE RESEARCH ACTIVITIES OF HARBOR BRANCH

RADM J.Mooney, Jr. USN(Ret.)
President and Managing Director
Harbor Branch Oceanographic Institution

Ever wonder how some marine scientists go to work? ... If it's beneath the surface of the ocean to depths as great as 3,000 feet, and the researchers happen to be with Harbor Branch Oceanographic Institution, we delve into the mysteries of the sea aboard underwater vessels resembling helicopters. With a highly trained aquatic pilot at the controls, we ultimately go to work by riding down the water column in one of our two, four-man, JOHNSON-SEA-LINK lockout submersibles.

.... From within the submersible, underwater aquanauts have the options of hovering in the water column, traveling up and down the face of underwater cliffs ....

.... or sitting directly on the sea floor to observe, photograph, and collect marine organisms

.... even in this exotic and fascinating world of the deep, the view can at times be as barren as a moonscape.

.... Having left the comfort of shore-based laboratories in Florida for a closer look at marine plans and animals in their own environment, Harbor Branch scientists take advantage of the forward acrylic sphere's panoramic visibility.

.... And what do researchers see in the ocean depths? Zooplankton ecologists look at clouds of underwater debris, called marine snow, and at other, more organized congregations.

They see mucous houses that have been built by tiny larvaceans as traps for food. Once one of these little creatures has dined, he avoids cleaning house by moving out and building another one, and this goes on at least several times a day. Environmental researchers want to know if these large, tenuous traps, which are found in great numbers, might trap other debris and thereby serve as sinks for pollutants that could work their way through the food chain.

.... They see jellyfish reaching up to eight feet in diameter.

.... One team of Harbor Branch ecologists is interested in the larvae of these animals, while another investigator studies their life histories. Echinoderms are found in great abundance the world over, and include such well known species as star fish, sea urchins, and sea cucumbers.

.... Fish biologists prefer to fish from the bottom up, using the Johnson-Sea-Link which can at times be even more frustrating than blindly fishing from the surface.

Both Sea Links are equipped with a sampling device nicknamed the "critter gitter". It works like an underwater vacuum cleaner. Fish are drawn into the sampler and contribute to scientific research by becoming the subject of laboratory studies.

Highly specialized equipment, systems and tools needed to conduct underwater research are often designed and built at Harbor Branch, in the Division of Ocean Engineering Research and Development.

The Division of Marine Sciences is composed of an interdisciplinary research team. Its primary goal is to use manned submersibles to conduct basic research on the biology of oceanic and deep sea animals and their role in the ocean food chain and global change. The animals being studied range from abundant bottom dwelling star fishes and sea urchins to numerous pelagic animals that spend their entire life cycle swimming in the midwater regions of the world's oceans. These include large numbers of species such as jellyfish, ctenophores and many other spectacular creatures that are common inhabitants of the oceans which are rarely

seen by marine biologists and oceanographers. Five interrelated research programs are addressing fundamental questions about how these organisms live, feed, reproduce, behave, and contribute to the complex ocean food chain. The importance of this research is indicated by a substantial research support that has been granted by such federal agencies as the National Science Foundation, the Office of Naval Research and the National oceanic and Atmospheric Administration. Our research has also attracted the attention of scientists from other universities and research institutions within the United States and from around the world. Our scientists routinely invite foreign and domestic colleagues to collaborate in our research because the questions being addressed have universal applications. In an effort to further promote this research, a unique laboratory is being developed within the Division of Marine Sciences that will simulate light, temperature and pressure conditions encountered in the deep sea. The laboratory will enable investigators to conduct long-term studies of living organisms collected by our submersibles and transported to Harbor Branch by our research ships. Scientists of other institutions will be encouraged too use this facility and it will become the major focus of our teaching program which began in 1990. A variety of specialized courses for undergraduate and graduate students will be offered each summer and are taught by both resident and outside faculty.

Not all marine studies are conducted at sea.

.... The Division of Coastal Environmental and Aquacultural Sciences, also known as CEAS, consists of scientists and a variety of disciplines such as marine botany, fish biology, physical oceanography, chemical and environmental engineering, and also the culture of molluscs, crustaceans, and fish. This interdisciplinary group conducts research in a complimentary manner, and it is pursued under a basic philosophy, and this is to improve man's understanding of the world's oceans; not just for civilization's impact on the marine environment or full habitation or utilization of marine resources, but to give us a basic understanding of marine and physical processes in natural ecosystems. This is necessary, and improvement of this comprehension is necessary for us to logically utilize our marine resources for it to protect natural marine ecosystems or preserve their integrity. This is a vital community, a submerged community. Fishes that are active in lagoon waters and marginal plant communities among other things are also vital to this ecosystem. We also encourage development of new technologies, both in the study of natural ecosystems and captive ecosystems such as would be utilized here to raise Florida spiny lobsters for food. The spiny lobsters are collected as post larvae in a natural ecosystem and brought into the tanks here at Harbor Branch and raised to marketable size in record time on nutritional sources developed here at Harbor Branch. We also have similar programs with the Nassau grouper, in raising marine fishes, and algae, and oysters, and clam culture. Our oyster, clam culture process has developed sufficiently to go large scale into estuaries around the State of Florida.

A third scientific research division seeks to derive chemical extracts from marine organisms to treat such human ills as cancer, viral infections, fungal diseases, and disorders of the immune system.

.... The Division of Biomedical Marine Research, which began in 1984, consists of twenty-five scientists.

The mission is to address human health problems through chemical and biological research of marine organisms and their chemical constituents. The mission is achieved through chemists and biologists working together as a team to collect, taxonomically identify, culture, and genetically engineer marine organisms. These scientists then perform chemical and biological studies of chemical compounds derived from these organisms which show potential as new therapeutic agents or biomedical research tools.

Currently, one compound with immunosuppressive activity, one compound with antitumor activity, and six antiviral compounds that were discovered at Harbor Branch are being tested further by several different pharmaceutical companies. The division receives research funding from major U.S. pharmaceutical companies, and other industrial and government funding.

Since 1984, division scientists and collaborators have published over 50 high quality manuscripts and have achieved 35 patents. The research team has

collected over 17,000 marine macroorganisms and has isolated over 3,000 microorganisms for biological evaluation by division biologists and collaborating industrial scientists. Approximately 25% of the macroorganisms have been collected from depths down to 3000' using the Harbor Branch Johnson-Sea-Link manned submersibles. These submersibles are the best deep water collection tools in the world.

Division scientists have extended international scientific ties by establishment of a collaboration with a team of Soviet scientists at the Pacific Institute of Bioorganic Chemistry in Vladivostok. This collaboration extends the range of geographical locations open to division scientists for the collection of marine organisms. It also provides a framework for a scientist-exchange program and collaborative research projects between our two institutions.

Although the focus of the research in the Division of Biomedical Marine Research has been on biologically active compounds from marine organisms, research has also been conducted in the collaboration with other divisions at Harbor Branch and with other institutions in the areas of chemical ecology, nuclear magnetic resonance studies of polymers from marine algae, and sponge taxonomy. The division looks forward to continuing these important collaborations, and to pursuing our primary mission.

As the name implies, the Division of Ocean Engineering Research and Development has a dual mission
of both research and development. Although by far the majority of our work may most accurately be characterized as development, our group is comprised of engineers and technicians representing such diverse disciplines as mechanical, electrical and optical engineering, computer science, and machine design. Over the years we have successfully anticipated the technological needs of oceanographic research by developing methods and systems which enable man to conduct work or to make measurements in the sea. Examples of this are found in the myriad of biological and geological sampling devices, data acquisition systems, and laser-aimed optical systems on our own Johnson-Sea-Link manned submersibles and remotely operated vehicles.

The fact that our ultimate laboratory, the place where our creations and ideas must be proven, is frequently the bottom of the ocean, has made simulation an important aspect of our work. Today's high-speed computer work stations enable us to simulate the actions and reaction of such complex systems as the sub's robotic arm without having to go to sea. Such a sophisticated simulator enables engineers to experiment with a concept prior to committing it to hardware. Physical parameters of the ocean itself must also be simulated. We have designed specialized systems to recreate the near-freezing temperatures, suspended nonorganic matter and crushing pressures of the deep ocean. Our research also involves characterizing the ocean's optical properties, requiring yet another sort of laboratory simulation.

In addition to fostering Harbor Branch's own research efforts, the Ocean Engineering R&D Division has been called upon for our expertise in developing oceanographic instrumentation by NOAA, the Naval Research Laboratory, Naval Coastal Systems Center, the Naval Ship Research & Development Center, Naval Surface Weapons Center as well as a number of firms in the private sector.

Our relatively small group compliment our research capabilities through close interaction and affiliation with Engineering colleges at various universities. Our resident staff is augmented by postdoctoral fellows and visiting professors.

Similarly, members of our own staff serve as adjunct professors at these universities, enabling graduate students to conduct their research here at Harbor Branch under the guidance of our own engineers.

The Johnson-Sea-Link submersibles as tools for science have gone through a series of evolutions since the first commissioning in 1971 thereby maintaining a constant state-of-the-art status for continuing to increase efficiency. Thanks to Harbor Branch ocean mechanics and engineers, the Johnson-Sea-Link submersibles operated by specialized pilots can now do almost any underwater work that was once done only by human hands. These submersibles for science have at times played roles in matters of national interest, such as the CHALLENGER debris search and recovery mission

conducted for NASA off the coast of Cape Canaveral.

Investigations conducted with the use of manned as well as unmanned submersibles are vital to the understanding of the oceans delicate balance. .... As one Harbor Branch scientist points out, the real world in terms of density of creatures inhabiting the earth, is underneath the oceans where, for the most part, mankind has never been. The earth is, after all, largely covered by water to an average depth of over two miles, and all this space serves as a habitat for life. In other words, in terms of real estate, mankind occupies less than one percent of the world's living space.

.... Realizing the living ocean's inestimable value, Harbor Branch remains dedicated to acquiring a better scientific understanding of this vast underwater world and to finding ways to use it for the benefit of mankind without adversely affecting it.

The Influence of Thruster Dynamics on Underwater Vehicle Behavior and Their Incorporation Into Control System Design

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Abstract—**The system dynamics of underwater vehicles can be greatly influenced by the dynamics of the vehicle thrusters. In this paper a nonlinear parametric model of a torque-controlled thruster is developed and experimentally confirmed. The model shows that the thruster behaves like a sluggish nonlinear filter, where the speed of response depends on the commanded thrust level. A quasi-linear analysis utilizing describing functions shows that the dynamics of the thruster produce a strong bandwidth constraint and a limit cycle, both of which are commonly seen in practice. Three forms of compensation are tested, utilizing a hybrid simulation which combined an instrumented thruster with a real-time mathematical vehicle model. The first compensator, a linear lead network, is easy to implement and greatly improves performance over the uncompensated system, but does not perform uniformly over the entire operating range. The second compensator, which attempts to cancel the nonlinear filtering effect of the thruster, is effective over the entire operating range but depends on an accurate thruster model. The final compensator, an adaptive sliding controller, is effective over the entire operating range and can compensate for uncertainties or the degradation of the thruster.**

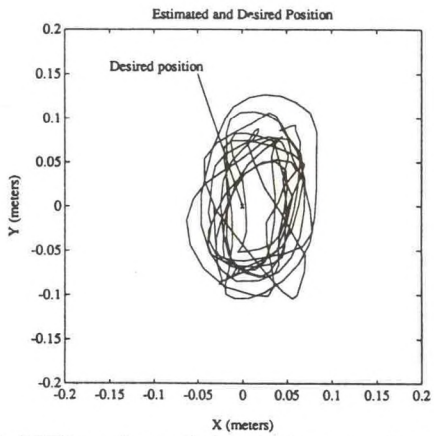

Fig. 1. The ROV Jason shows a limit cycle when in the closed-loop position control.

I. INTRODUCTION

THE AUTOMATIC control of underwater vehicles represents a difficult design problem due to the nature of the dynamics of the system to be controlled. Controllers based on simple models of vehicle mass and drag usually yield disappointing performance. In this paper, it is shown that for a wide class of vehicles, the dynamics of the thrusters dominate the control problem and must be properly considered to obtain good results.

The general underwater vehicle control system design problem includes a variety of nonlinearities and modeling uncertainties. These include hydrodynamic nonlinearities, inertial nonlinearities, and problems related to coupling between the degrees of freedom [1], [2]. Additionally, the ability of thrusters to produce force is greatly influenced by axial- and cross-flow effects. These types of nonlinearities are especially prominent at high speed.

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Good control of a vehicle at low speed is also an important design problem which must be solved to permit important operations like automatic docking and combined vehicle–manipulator control. In this regime, nonlinearities related to thruster dynamic behavior can be very important and influence overall system behavior in a manner fundamentally different from most hydrodynamic and inertial nonlinearities.

This paper focuses specifically on the dynamic behavior of thrusters and its implication for control. The dynamics of an electrically powered thruster are modeled, and the model verified in a tank test. It is shown that the dynamics of the thruster dominate behavior of the vehicle by restricting the maximum closed-loop bandwidth and creating a limit cycle.

Such limit cycles are commonly seen in most closed-loop marine vehicles, ranging from dynamically positioned ships to small servo-controlled remotely operated vehicles (ROV's). Fig. 1 shows the closed-loop positioning performance of Jason, a 1200-kg ROV, during a dockside test in calm water. With no compensation for thruster dynamics, the system shows a stable oscillation about the desired position with a fixed frequency and a magnitude of about 10 cm. Fig. 2 shows similar behavior for the RV *Knorr*, and 1800-ton oceanographic research ship, while under control of its dynamic positioning system in calm water. As in the case of the ROV, the oscillation is of fixed magnitude and frequency and is not caused by a forced input, such as waves. For a simple controller without an integral term or outside disturbances, such

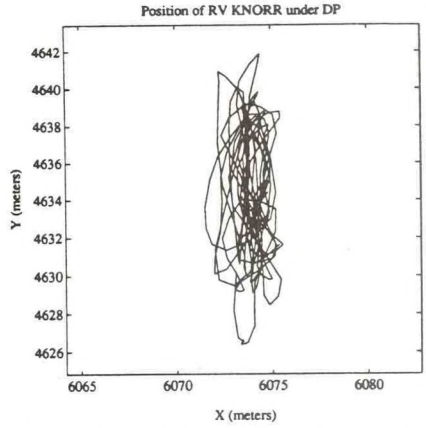

Fig. 2. RV *Knorr*, an 1800 ton research vessel, shows a prominent limit cycle when under closed-loop position control.

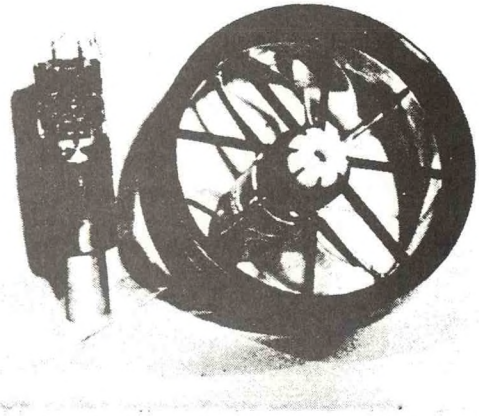

Fig. 3. Jason's thrusters consist of a pressure-compensated brushless dc motor and controller driving a propeller mounted in a shroud.

limit cycles cannot be produced by simple nonlinearities like stiction, deadband, or pure delays. For the Jason example, it is shown that such behavior is produced by the nonlinear response of a torque-controlled thruster.

A series of control system design procedures are outlined that reduce the effects of the thruster dynamics. First, a linear compensation scheme is shown to improve performance compared to the uncompensated system, but it results in nonuniform behavior over the entire operating regime. Nonlinear compensation techniques are shown to improve the overall system performance over the entire vehicle operating range. Finally, the use of a nonlinear adaptive sliding controller is shown to preserve system performance even as the thruster performance degrades or in the presence of significant uncertainties.

II. A Dynamic Thruster Model

A. General Description of a Thruster

Most small-to-medium-sized underwater vehicles are powered by electric motors driving propellers mounted in ducts. Some of these vehicles utilize reduction gears between the motor and propeller, but direct drive is the most common. In virtually all cases, the propeller is mounted in a duct or shroud which increases the static and dynamic efficiency of the thruster.

The thruster unit from the Jason ROV (Fig. 3) will be considered here. These thrusters utilize a 1/3 hp brushless dc motor contained in a pressure compensated oil-filled housing, along with a brushless motor controller. Motor torque is commanded by applying an analog voltage ($\pm$ 10 V) to the motor controller.

These motors have been utilized down to the full operating depth of Jason, 6000 m. They were also used on the Jason Jr. vehicle which explored the *Titanic* and on the Robin ROV, which also operates to 6000 m. Similar motors have been used on the UNH Eave series of autonomous vehicles. Conceptually, these thrusters resemble the electric units on most low-cost ROV's.

These types of thrusters are not ideal force-producing actuators. It is well known that thrusters are subject to serious degradation due to axial- and cross-flow effects. Axial-flow effects can be reasonably approximated by the modeling of the thruster unit alone, the velocity of the fluid entering the thruster shroud effectively changes the angle of attack of the propeller, thus altering the force produced. Cross-flow effects are much more difficult to model and have been shown experimentally to be highly dependent on the position of the thruster on the vehicle [3]. In both cases, the reduced amount of force produced by the thruster will reduce the overall gain of a control system unless these effects are specifically included in the controller design.

Even when a thruster is not moving through the water, its force-producing behavior is not simple. In the rest of this paper it will be shown that these types of thrusters act like nonlinear filters that significantly influence closed-loop behavior at low speeds and hover. This effect is largely responsible for the notoriously poor performance of the automatic heading and depth servoes for most small underwater vehicles.

Torque-controlled thrusters predominate in electrically powered vehicles and will be considered exclusively in this paper. Thrusters with speed-controlled motors have significantly different dynamics, but are less common for several reasons. The steady-state relationship between torque and thrust is nearly linear, while the steady-state relationship between propeller speed and thrust is nonlinear. Additionally, the speed-controlled thruster requires a high-quality angular speed sensor (typically much better than the sensors used to commutate a brushless motor), and the thruster performance is more sensitive to axial flow effects.

B. Lumped Parameter Model Development

A typical thruster, as shown in Fig. 4, consists of a static shroud and a propeller driven by a torque source (τ) at angular velocity (Ω). The thruster shroud has a cross-sectional area (A) and encloses a volume (V). The ambient fluid has a density (ρ) and a volumetric flowrate within the thruster (Q).

The model development is simplified by the following assumptions:

- The energy stored is due solely to the kinetic energy of the fluid in the duct.
- The kinetic energy of the external ambient fluid is negligible.

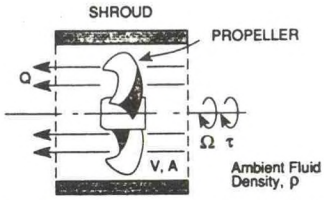

Fig. 4. Schematic of the thruster. The enclosed volume is V, the crosssectional area A, the angular velocity of the propeller is Ω, and the applied torque is τ.

- Friction losses are negligible.
- Ambient fluid is incompressible.
- Fluid flow at the thruster intake and exhaust is parallel, one dimensional, and at ambient pressure. Rotational flow effects are ignored.
- Gravity effects are negligible.
- The thruster is completely symmetric with respect to the flow direction.

The kinetic coenergy T^* of the fluid in the thruster can be expressed as a state function of the volumetric flowrate Q:

$$T^*(Q) = \frac{1}{2}\rho V\left[\frac{Q}{A}\right]^2.$$

A generalized momentum Γ can be defined as

$$\Gamma = \frac{dT^*}{dQ} = \rho V\frac{Q}{A^2}. \tag{1}$$

The above relation is that of an inertia (momentum related by a static constitutive law to the flow [4]) in bond-graph nomenclature with the effort variable Γ and flow variable Q. Γ has units of momentum/area and is referred to as the pressure momentum. Since the energy relations are linear, the coenergy and energy have equal magnitudes [5], and the kinetic energy T can be expressed as a state function of the pressure momentum Γ:

$$T(\Gamma) = \frac{A^2}{2\rho V}\Gamma^2.$$

A power balance yields the following pressure momentum relation;

$$\frac{dT}{dt} = \frac{A^2}{\rho V}\Gamma\dot{\Gamma} = \Omega\tau - KQ \tag{2}$$

where $\Omega\tau$ represents the power input from the thruster propeller, K represents the exiting kinetic energy per volume, and $\dot{\Gamma}$ represents the time rate of change of the pressure momentum.

The exiting kinetic energy per volume K can be expressed as

$$K = \frac{A^2\Gamma^2}{2\rho V^2} = \frac{\gamma^2}{2\rho}$$

where $\gamma \equiv A\Gamma/V$ is the fluid momentum per volume within the thruster.

The thruster and ambient fluid are coupled through the convected linear momentum, which is equal to the thrust developed:

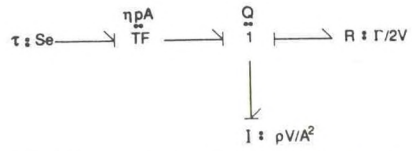

Fig. 5. Bond graph representing thruster dynamics.

$$\text{Thrust} = \gamma Q. \tag{3}$$

Assuming that the propeller does not cavitate, the volumetric flowrate can be related to the thruster/propeller characteristics and angular velocity Ω. The difference between the theoretical and actual advance per revolution of a propeller is referred to as the *slip* and is typically expressed as a ratio σ as follows:

$$\sigma = \frac{\Omega pA - Q}{\Omega pA}$$

where p represents the axial distance traveled by the propeller blades with each unit of rotation (1 rad) and is referred to as the *pitch*.

It follows from the equation above that $Q(\Omega)$ can be expressed as

$$Q = \eta pA\Omega \tag{4}$$

where $\eta \equiv 1-\sigma$ and is referred to as the *propeller efficiency*.

From (1)–(4), the following thruster dynamic state and output equations are formed:

$$\dot{\Gamma} = \frac{\tau}{\eta pA} - K$$

$$\text{Thrust} = \gamma Q.$$

The thruster dynamic state and output equations can be represented topographically in the bond graph of Fig. 5.

If we assume that the propeller efficiency (η), pitch (p), and duct area (A) are constant, the thruster dynamic state and output equations may be expressed with the propeller angular velocity Ω as the thruster dynamic state variable:

$$\dot{\Omega} = \frac{\tau}{\eta^2 p^2\rho V} - \frac{\eta pA}{2V}\Omega|\Omega|$$

$$\text{Thrust} = A\rho\eta^2 p^2\Omega|\Omega|.$$

Note that the steady-state thrust force is proportional to the input torque, as mentioned earlier.

The normalized step response of the thruster model to torques of 2, 1/3, and 1/4 Nm is presented in Fig. 6, graphically emphasizing the nonlinear dynamics. The thruster presents a more complex control problem than the linear first-order lag associated with most actuators. The thruster time response performance actually degrades as the magnitude of the input decreases. This dynamic behavior, when coupled with other dynamic nonidealities such as a pure delay, could result in the limit-cycle behavior associated with underwater vehicle hover control.

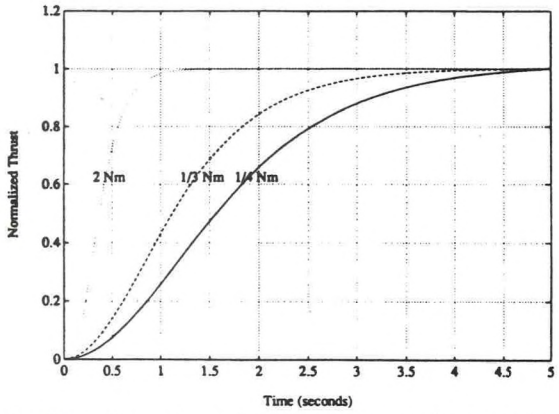

Fig. 6. The nonlinear nature of the thruster response is illustrated in this set of normalized step responses. The larger the input, the more rapid the dynamics of the thruster.

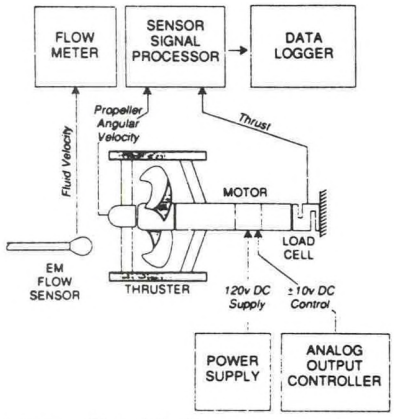

Fig. 7. The test setup allowed the thruster control voltage to be set from a computer, while the thrust force, flow rate, and propeller speed were logged.

C. Model Summary

Using an energy-based physical system approach, a lumped parameter dynamic model of the thruster was developed. With the propeller angular velocity Ω as the thruster dynamic state, the model and the output equation take the form:

$$\dot{\Omega} = \beta\tau - \alpha\Omega|\Omega|$$

$$\text{Thrust} = C_t\Omega|\Omega|$$

where τ is the input torque, α and β are constant model parameters, and C_t is a proportionality constant.

This model will be used subsequently as a dynamic structure of determining the constant model parameters, and ultimately in the design of controller systems to compensate for the thruster dynamics.

III. Model Verification

The model was verified using a thruster mounted in a tank which was instrumented for output force, propeller speed, and output flow velocity. As shown in Fig. 7, the thrust was measured by a load cell, the propeller speed was measured using an electro-optic device similar to a simple optical shaft encoder but suitable for immersion, and the output flow velocity was measured by an analog electromagnetic current meter.

A series of static and dynamic tests were conducted to confirm the model presented earlier and to determine the specific parameter values α, β, and C_t. Given the available measurements, it was possible to confirm that these corresponded to reasonable values for the physical parameters such as the propeller efficiency and involved volume.

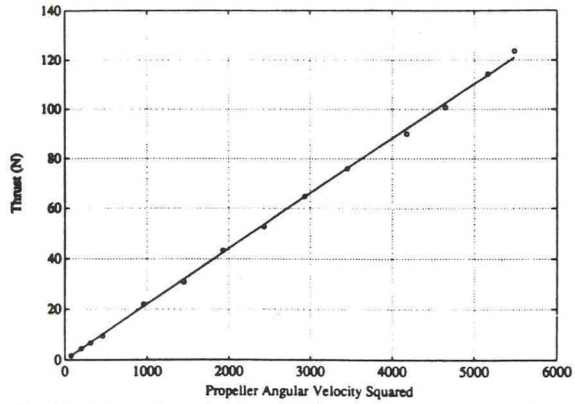

Fig. 8. Experimental results show excellent correlation between the steady-state thrust force and the absolute squared propeller speed.

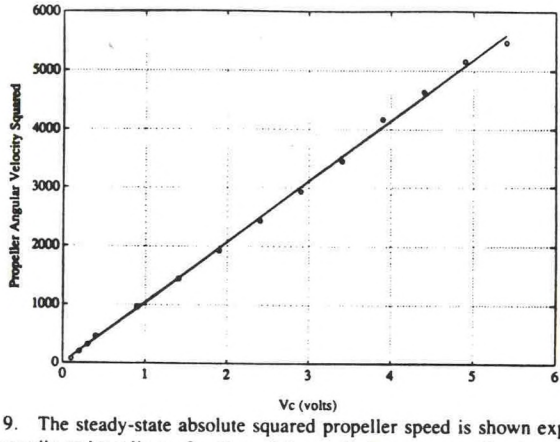

Fig. 9. The steady-state absolute squared propeller speed is shown experimentally to be a linear function of the applied motor control voltage.

Static tests provided values for C_t and the ratio β/α. These tests were conducted for thrust in the forward direction only, ignoring the asymmetry of the thruster. Fig. 8 shows a plot of output force versus the absolute squared propeller speed, yielding a value for C_t. Fig. 9 shows absolute squared propeller velocity as a function of applied motor control voltage, which is proportional to torque. This curve yields the ratio β/α. Both plots show excellent agreement to the model. The identified values were:

$$C_t = 0.022 \text{ Ns}^2$$

$$\beta/\alpha = 1.0 \cdot 10^3 \text{ V}^{-1} \text{ s}^{-2}.$$

A dynamic test was conducted to determine the individual values of the parameters α and β. The thruster was commanded with a random input signal passed through a filter with a 1-hz cutoff. By measuring propeller speed as a function of the applied motor control voltage, least-squares values of α and β were determined:

$$\alpha = 0.037$$

$$\beta = 42 \text{ V}^{-1} \text{ s}^{-2}.$$

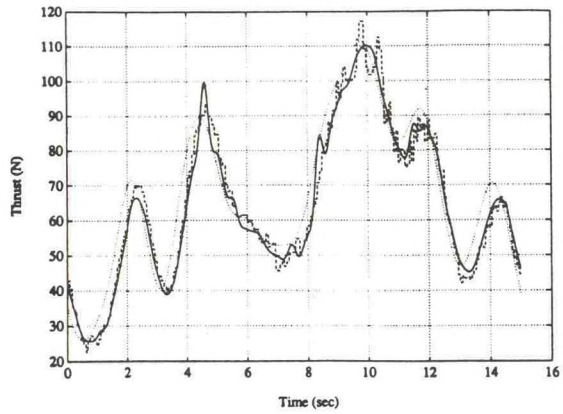

Fig. 10. The measured (dashed line) and simulated thrust force (solid line) responses to a random input (dotted line) are shown. The plot shows good agreement and emphasizes the phase lag exhibited by both the real thruster and model.

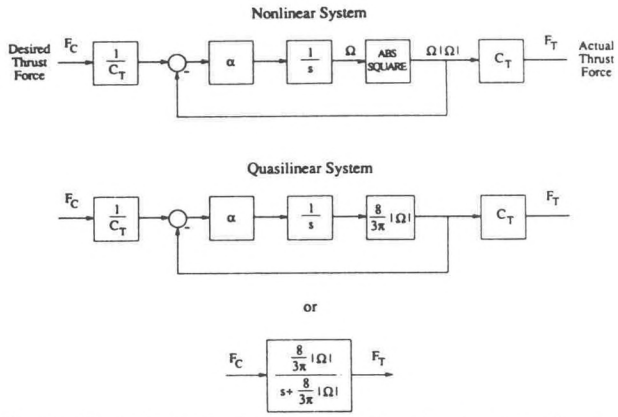

Fig. 11. Replacing the absolute squared nonlinearity with a describing function permits the sinusoidal steady-state response of the system to be analyzed.

Note that the ratio of $(1.1 \cdot 10^3)$ for β/α for the dynamic test matches the results of the static tests, even though the dynamic tests included flow in both directions.

Fig. 10 shows the recorded propeller speed data and the simulated response using the identified parameters.

The ratio of these two numbers ($1.1 \cdot 10^3$ V^{-1} s^{-2}) compared favorably to the statically determined value of $1.0 \cdot 10^3$ V^{-1} s^{-2}). Likewise, a least-squares value for C_t determined from the recorded dynamic output force and propeller speed yielded a value of 0.019 Ns^2, compared to the value 0.022 Ns^2 determined from the static tests.

As all the parameters in the model are based on the physical parameters of the motor, propeller, and duct, it is possible to check the experimentally determined values of α, β, and C_t to see if they make physical sense. The only two physical parameters of the model that are not directly determinable are the involved fluid volume V and the propeller efficiency η. Given the experimentally determined parameters α, β, and C_t as well as the known physical parameters for propeller pitch ($p = 0.101$ m), duct area ($A = 0.0527$ m^2), and fluid density ($\rho = 1000$ kg/m^3), the values of V and η can be implied. The computed value of η is 0.22, which is reasonable for propellers of this type, and the computed involved fluid volume is 0.016 m^3, which is twice the actual volume enclosed by the duct.

In summary, the identification procedure provided good values for the parameters and also supported the basis for the model. Static and dynamic tests were consistent and the identified parameters made physical sense.

IV. Effect of Thruster Dynamics on Closed-Loop Behavior

In this section it will be shown that the thruster dynamic model can be used to explain several difficulties encountered in controlling many types of underwater vehicles. First, a strong constraint on the closed-loop bandwidth is encountered which is much lower than the limit implied by sampling or time delays. Also, the vehicle will exhibit a limit cycle about the desired setpoint.

A quasi-linear approximation of the dynamic model will be used for this analysis. As seen in Fig. 6, the model can be approximated as a first-order system where the time constant is a function of the input magnitude. Describing functions will be used to approximate the behavior of the system by representing it as a first-order filter which is a function of the magnitude and frequency of a steady input sinusoid. Describing functions are ideal for analyzing a limit cycle, as they apply directly to steady-state sinusoidal conditions.

The block diagram in Fig. 11 shows a thruster model which substitutes a describing function [6] for the absolute-square nonlinearity. For this nonlinearity, the describing function has a gain which is a function of only the magnitude of the input, in this case the propeller speed Ω. However, the steady-state sinusoidal relationship between the commanded thrust (F_c) and output thrust force (F_t) is that of a first-order filter for which the break frequency is a function of both the input magnitude and frequency.

Given that the system is first order, the magnitude of the input and output sinusoids are related by

$$\frac{|F_t(j\omega)|}{|F_c(j\omega)|} = \frac{\omega}{(\omega^2 + \lambda_{th}^2)^{1/2}}$$

where the break frequency λ_{th} is a function of the propeller speed Ω,

$$\lambda_{th} = \frac{8\alpha}{3\pi|\Omega|}.$$

Combining these two equations, recalling that the output force $F_t = C_t\Omega|\Omega|$, and solving a quadratic yields the break frequency λ_{th} as a function of the input magnitude $|F_c(j\omega)|$ and frequency ω:

$$\lambda_{th}^2 = \frac{1}{2}\left\{-\omega^2 + \left[\omega^4 + |F_c(j\omega)|^2 \frac{\gamma^4}{C_t^2}\right]^{1/2}\right\}$$

where

$$\gamma = \frac{8\alpha}{3\pi}. \tag{5}$$

Fig. 12 shows a contour plot of the break frequency λ_{th} for a Jason thruster, using the identified values of α and β as a function of the input sinusoid magnitude and frequency ω. The break frequency is strongly dependent on the magnitude of the input sinusoid, and weakly dependent on the frequency of the

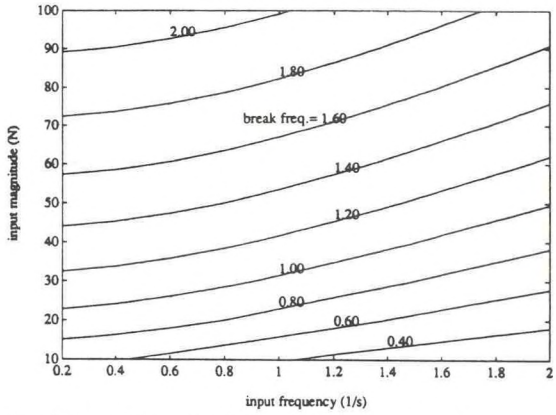

Fig. 12. The quasi-linear break frequency, as determined from the describing function analysis, is a strong function of the magnitude of the input and a weaker function of the input frequency.

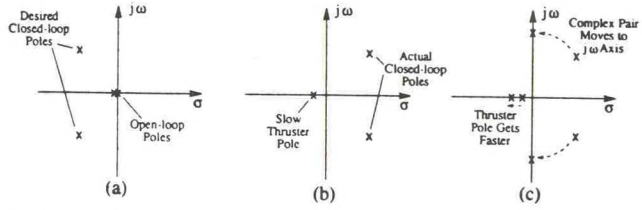

Fig. 13. (a) If no thruster dynamics are present, the open-loop poles are easily placed to produce the desired closed-loop response. (b) The unacknowledged presence of the slow thruster pole results in the actual closed-loop poles moving into the right half plane. (c) The resulting instability causes the thrust level to increase, which speeds up the thruster pole. The thruster pole frequency increases until the pole pair reaches the $j\omega$ axis to form a pure oscillator.

input sinusoid. For the Jason thruster, the value of the thruster break frequency is less than 2 for all magnitudes, which is certain to wreak havoc with any effort to place the closed-loop poles at a reasonable bandwidth, unless specifically factored into the design.

Now the describing function model can be used to analyze the effect of the thruster dynamics on closed-loop performance. In the simplest case, a single degree of freedom of a vehicle can be described as a pure inertia (Fig. 13(a)). Assume that the goal of the control system design is to place the closed-loop poles at a location specified by the natural frequency λ_{cl} with a damping ratio $\zeta = 0.707$. Both position and velocity gains are required to achieve a damped response, and these can be computed algebraically.

However, unless the break frequency of the thruster dynamics is much higher than the desired value of λ_{cl}, the poles will not move as expected. With the system initially at rest, the thruster action will be low, and the filter break frequency, very low. The presence of the low-frequency pole associated with the thruster dynamics will drive the two other poles into the right half plane. The resulting instability will then increase the magnitude of the input to the thrusters until the filter break frequency increases to the point where the poles lie directly on the $j\omega$ axis. This process is illustrated in Fig. 13.

This situation describes a classic limit cycle. The resulting oscillation will be of a specific and constant frequency and magnitude that are independent of the initial conditions. The

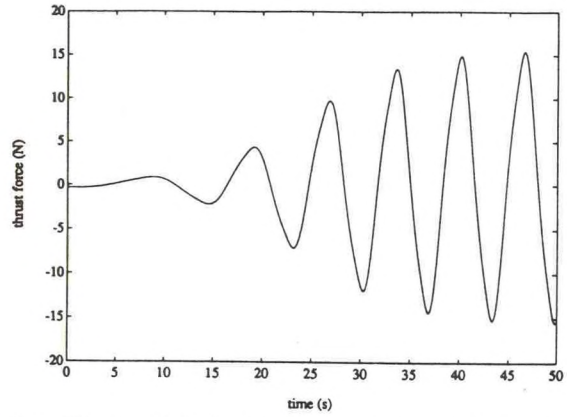

Fig. 14. This plot of simulated thrust is consistent with the movement of the closed-loop poles shown in Fig. 13. Additionally, the magnitude and frequency of the limit cycle are very close to the values predicted by the describing function analysis.

describing function model can be used to compute approximate values for the magnitude and frequency.

The desired closed-loop system transfer function relates the desired position X_d to the actual position X:

$$\frac{X(s)}{X_d(s)} = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

where ω_n is the desired natural frequency, and ζ is the desired damping ratio.

Unfortunately, if the thruster dynamics are ignored when the gains are chosen, the following third-order closed-loop transfer function is obtained for the system, including the thruster pole:

$$\frac{X(s)}{X_d(s)} = \frac{\lambda_{th}\omega_n^2}{s^3 + \lambda_{th}s^2 + 2\zeta\lambda_{th}\omega_n s + \lambda_{th}\omega_n^2}.$$

The value of λ_{th} which puts the two complex poles on the $j\omega$ axis can be computed by substituting $s = j\omega_{lc}$ into the characteristic equation and finding the roots, where ω_{lc} is the frequency of the limit cycle. This calculation yields:

$$\omega_{lc} = \omega_n$$

$$\lambda_{th} = \omega_n/2\zeta.$$

This means that the magnitude of the thruster input will increase until the break frequency of the thruster dynamics reaches a value of $\omega_n/2\zeta$. Recalling (5), the magnitude of the commanded thruster force can be related to the break frequency of the thruster and the thruster command frequency:

$$|F_c(j\omega)|^2 = \frac{C_t^2}{\gamma^4}(\lambda_{th}^4 - \lambda_{th}^2\omega_{lc}^2). \qquad (6)$$

Fig. 14 shows that the limit cycle produced a numerical simulation of a single axis of a vehicle the size of Jason Jr., including the full nonlinear thruster dynamics. The magnitude of the commanded thruster signal during the limit cycle is 15.6 N, which corresponds closely to the value of 15.7 N predicted by (6). Likewise, the frequency of the limit cycle corresponds almost exactly to the desired closed-loop frequency of 1/s (period = 2π s).

V. Compensation for Thruster Dynamics

Several controller structures were investigated to overcome the effects of neglecting the thruster dynamics. Recall that there were two bad effects that resulted from neglecting the thruster dynamics: First, overall system bandwidth was limited, and secondly, a limit cycle was produced.

A. Hybrid Simulation

A hybrid simulation was used to verify the various controller designs. The hybrid simulation was an extension of the test setup used to verify the thruster model (see Fig. 7). Rather than just logging the output of the thruster, the measured value was used to drive a real-time numerical simulation of a single degree of freedom vehicle. This permitted the behavior of the actual thruster and its effect on the control loop to be observed while acting on a "pure" vehicle with well-known characteristics. For the controllers that were implemented digitally, the states of the vehicle simulation (x and $\dot{x}$) were made available to the controllers. Additionally, the adaptive sliding controller required the propeller speed measurement Ω. A more detailed description of the hybrid simulation is given in [7].

An important limitation of the hybrid simulation is that the thruster does not actually move when the simulated vehicle velocity is nonzero. This means that axial-flow effects are ignored. For this reason, the experiments concentrated on hovering and small movements.

The vehicle simulation had the form:

$$M\ddot{x} = \text{thrust} - C_D\dot{x}|\dot{x}|$$

where M is the effective mass (actual mass plus "added mass"), and C_D is the drag parameter. The numerical values used were chosen to represent a single DOF of Jason Jr., $M = 340$ kg, and $C_D = 67\ \text{Ns}^2/\text{m}^2$.

A vehicle position controller was implemented which compensates for the vehicle drag with a nonlinear feed-forward term which would produce first-order tracking behavior:

$$u = C_D\dot{x}|\dot{x}| - 2\lambda\dot{\tilde{x}} - \lambda^2\tilde{x}$$

where $\tilde{x} = x - x_d$ is the tracking error, u is the computed control force, and λ is the desired closed-loop bandwidth.

This control law was used for all the control schemes that follow. However, in each case, a different type of compensation was employed. These compensators operate on the control force u computed by the position controller (which is naive to the existance of the thruster dynamics) to produce an improved overall system response.

B. Lead Compensation

Given the resemblence of the nonlinear thruster dynamics to a first-order system, it is sensible to compensate with a lead network [8]. If the thruster actually behaved like a first-order linear system, a zero could be placed at the frequency of the thruster pole and a complementary pole placed at a higher frequency where it would not interfere with the controller.

Fig. 15 shows the results using a lead compensator compared to the results with no compensation. The lead compensator was implemented in analog form. The time constant

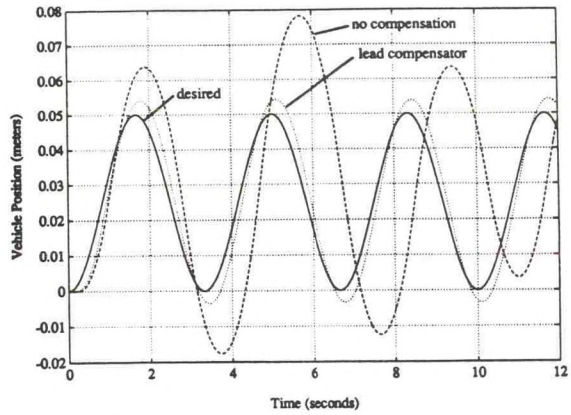

Fig. 15. For a sinusoidal tracking task, the lead compensator improved performance considerably over the uncompensated case, as shown in these hybrid simulation results.

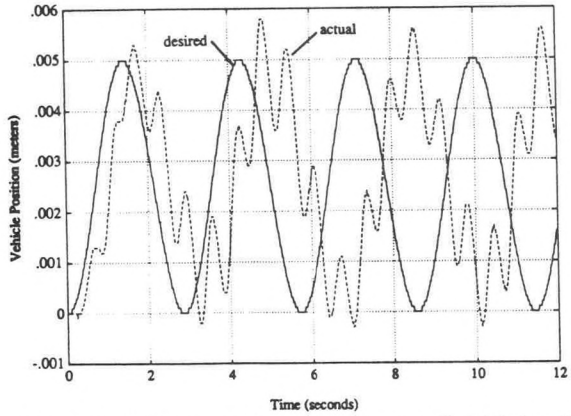

Fig. 16. The effectiveness of the lead compensator diminished as the operation conditions change from those for which the lead compensator was designed. Here, for a low magnitude input, performance has degraded significantly.

selected as representative of the dynamics to be compensated is that observed at low control signals. From Fig. 6, we observe that a 0.75-s time constant matches the observed step response at a 1-V control signal. The lead compensator increases the system order to two, and we select our desired dominant poles with an attenuation twice that of the first-order pole and a damping ratio of 0.707. Following the root locus method of [8], the lead compensation pole and zero are placed at -6.5 and -2.43, respectively. The resulting improvement due to the addition of lead compensation on the closed-loop system response is shown in Fig. 15.

Fig. 16 shows the results for a trajectory which calls for a much lower level of thrust (resembling hover). The closed-loop response is oscillatory and shows a phase lag not seen when the system is operating closer to the design point.

In summary, the lead compensator represents a substantial improvement over no compensator, but performance degrades substantially if the operating conditions vary greatly from the design point.

C. "Pole" Cancellation

The "pole" cancellation controller is so named because it compensates for thruster dynamics by canceling the apparent

lag pole with a corresponding "zero." The corresponding control law which is implemented digitally is of the form:

$$u^* = u + \frac{\dot{u}}{\lambda_v(u)}. \tag{7}$$

where u^* is the compensated thrust command, and $\lambda_v(u)$ is the inverse of the thruster time constant which is chosen as a function of the uncompensated control input u. Note that although the term "pole" us used here loosely, the validity of this time-varying "pole-zero cancellation" can be justified for this first-order system as long as λ_v is bounded away from zero.

The pole cancellation method requires the evaluation of the time derivative of the commanded control signal $\dot{u}$. The value of $\dot{u}$ can be determined explicitly if the commanded control signal for the thruster is known *a priori*, as when there is a predefined force trajectory for the associated vehicle; however, this is not normally the case. The value of $\dot{u}$ may also be determined by differentiating the vehicle control law, resulting in some terms that are known explicitly and some that may be determined by numerical differentiation. For example, the vehicle control law is

$$u = -K_p\tilde{x} - K_d\dot{\tilde{x}}$$
$$\dot{u} = -K_p\dot{\tilde{x}} - K_d\ddot{\tilde{x}}.$$

The velocity error $\dot{\tilde{x}}$ is known from the state measurement, and the acceleration error $\ddot{\tilde{x}}$ may be determined by numerical differentiation with a known error bound taking the form of a disturbance.

$\lambda_v(u)$ represents the location of the apparent first-order thruster "pole" and is considered a function of the magnitude of the commanded input; $\lambda_v(u)$ was determined empirically by matching the step response of a first-order system to the observed thruster step response; $\lambda_v(u)$ was determined for the full range of thruster operation and matched to the functional form:

$$\lambda_v(u) = 0.49\sqrt{u}.$$

In [7], it is shown that this relationship provides a good fit to the observed thruster behavior and that it is consistent with the model identified earlier.

Combining this functional form for $\lambda_v(u)$ with the "pole" cancellation differential equation yields the differential equation for the "pole" compensation:

$$u^* = u + \frac{\dot{u}}{0.49\sqrt{u}}.$$

Fig. 17 shows the hybrid simulation results for the closed-loop system with "pole" compensation. Unlike the lead compensator, the nonlinear compensator provides uniform performance over the entire operating range.

Fig. 18 illustrates a fundamental limitation of the "pole" compensation scheme. In this example, an obstruction was placed in the thruster duct, altering the static and dynamic properties of the thruster. Clearly, the "pole" compensation technique relies on good knowledge of the thruster properties.

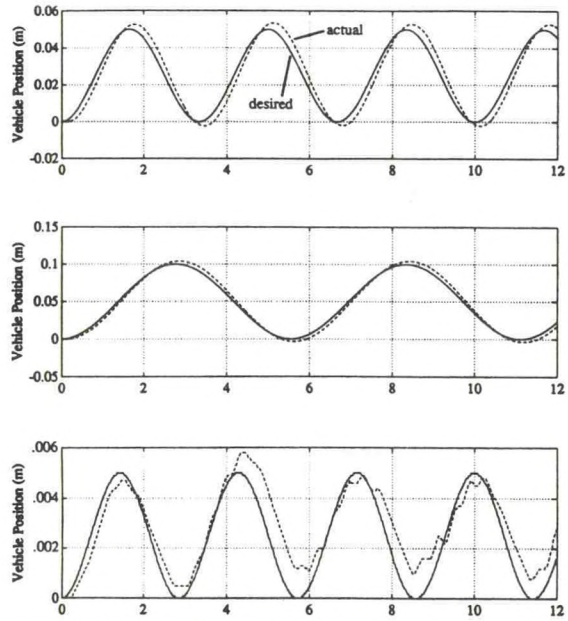

Fig. 17. The "pole" cancellation technique provides good performance over a wide range of operating conditions, as shown in these hybrid simulation results.

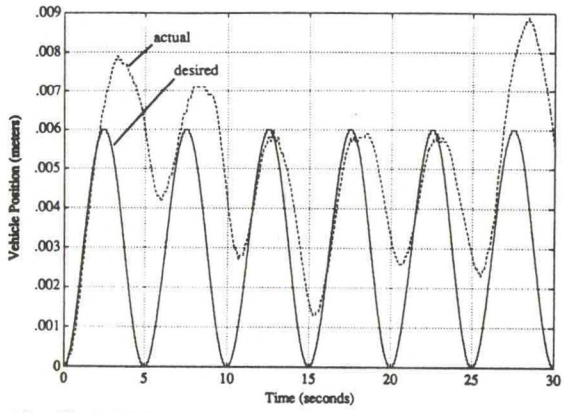

Fig. 18. The "pole" cancellation technique suffers when the actual thruster statics or dynamics differ significantly from the model. Here, a blockage is placed in the flow for the hybrid simulation and control performance degrades significantly.

D. Sliding Controller

Unlike the previous two compensators, a model-based compensator can directly take advantage of the previously identified controller model. Given the perfect measurement of the thruster dynamic state and a perfect model, the input torque can be directly computed and applied; however, this *computed torque* method may quickly fail in the presence of model uncertainty, measurement noise, computational delays, and disturbances.

Analysis of the effects of these nonidealities are further complicated by nonlinear dynamics. The issue becomes one of ensuring that a nonlinear dynamic system remains *robust* to nonidealities while minimizing tracking error.

One method able to deal directly with system uncertainties is referred to as "Sliding Mode Control" and has received considerable attention in the Soviet literature, where it

is applied to the control of linear systems with discontinuous control action. Sliding control theory has been extended to systems with nonlinear systems with continuous control action [9], and has been further extended to included adaptation to system parametric uncertainty [10]. Application of adaptive sliding mode theory permits precise tracking performance while being robust to modeling errors and disturbances. The controller design presented follows closely the development of sliding controllers in [10] and [9].

With the propeller angular velocity Ω as our thruster state measurement, the thruster dynamic model can be written as

$$\dot{\Omega} = \beta\tau - \alpha\Omega|\Omega|$$

or

$$h\dot{\Omega} = \tau - c\Omega|\Omega|$$

where τ is the input torque, while α and β are the thruster parameters.

A sliding surface s (in the example in this paper, a *point*) is selected based on simple linear dynamics:

$$s = \tilde{\Omega} = \Omega - \Omega_d$$

where Ω_d is the desired angular velocity. Perfect tracking is then achieved by the state trajectory remaining at the sliding point ($s = 0$).

Having selected the sliding point, the condition (referred to as the *sliding condition*) necessary to constrain trajectories to be directed toward the sliding point must be determined. The sliding condition is satisfied if a quadratic form of s can be established as an Lyapunov-like function of the closed loop system [9]:

$$V = \frac{1}{2}hs^2$$

$$\dot{V} = sh\dot{s} \leq 0.$$

Imposing the sliding condition on the dynamic model and sliding point yields the control law:

$$s = \tilde{\Omega}$$

$$h\dot{s} = h\dot{\tilde{\Omega}} = h(\dot{\Omega} - \dot{\Omega}_d)$$

and substituting the system dynamics:

$$h\dot{s} = \tau - c\Omega|\Omega| - h\dot{\Omega}_d$$

the best approximation of a continuous control law which would achieve $h\dot{s} = 0$ is

$$\hat{\tau} = \hat{c}\Omega|\Omega| + \hat{h}\dot{\Omega}_d$$

where $\hat{(\ )}$ indicates an estimate.

To satisfy the sliding condition despite model uncertainty, a discontinuous control law is required. This can be achieved by adding a term to the approximately continuous control law which is discontinuous across the sliding point:

$$\tau = \hat{c}\Omega|\Omega| + \hat{h}\{\dot{\Omega}_d - K\,\mathrm{sign}(s)\}$$

where

$$\mathrm{sign}(s) \equiv \begin{cases} 1, & s \geq 0 \\ -1, & s < 0 \end{cases}$$

and K is selected to be large enough to offset the model dynamic uncertainty, ensuring that the sliding condition remains satisfied.

Although the discontinuous control law provides for perfect tracking despite nonidealities, it exhibits undesirable chattering around the sliding point. Chattering can be avoided by smoothing the control law within a thin boundary of the sliding point [9]. This smoothing introduces behavior which departs from the dynamics specified by the sliding surface in the form of a first-order filter in s when inside a region about the sliding surface called the "boundary layer." This can be accomplished by replacing the discontinuous control law term by the continuous term K sat (s/ϕ), where

$$\mathrm{sat}(z) \equiv \begin{cases} \mathrm{sign}(z), & \text{for } |z| \geq 1 \\ z, & \text{otherwise} \end{cases}$$

and ϕ is the boundary layer width.

Inside the boundary layer, the dynamics of s should take the form:

$$\dot{s} + \lambda s = bu$$

where u is the input, b is the input gain, and λ is the bandwidth.

This can be verified by substituting the modified control law inside the boundary layer into the dynamic equation for the sliding point:

$$h\dot{s} = \tau - c\Omega|\Omega| - h\dot{\Omega}_d$$

$$h\dot{s} = \hat{c}\Omega|\Omega| + \hat{h}\dot{\Omega}_d - \hat{h}K\frac{s}{\phi} - c\Omega|\Omega| - h\dot{\Omega}_d$$

$$h\dot{s} = -\hat{h}K\frac{s}{\phi} + \boldsymbol{Y}\tilde{\boldsymbol{a}}$$

where $\boldsymbol{a} = [c\ h]^T$, $\tilde{\boldsymbol{a}} \equiv \hat{\boldsymbol{a}} - \boldsymbol{a}$ is the parametric uncertainty, and $\boldsymbol{Y} = [\Omega|\Omega|\dot{\Omega}_d]$.

The dynamics of s can be seen to be first order:

$$\dot{s} + \frac{K}{\phi}s = \hat{h}^{-1}\boldsymbol{Y}\tilde{\boldsymbol{a}}. \tag{8}$$

This implies that inside the boundary layer the bandwidth is established by

$$\frac{K}{\phi}$$

with s dynamics driven by the dynamic uncertainty, $\hat{h}^{-1}\boldsymbol{Y}\tilde{\boldsymbol{a}}$.

The sliding controller with a boundary layer yields the control law:

$$\tau = \hat{c}\Omega|\Omega| + \hat{h}\dot{\Omega}_d - \hat{h}K\,\mathrm{sat}(s/\phi).$$

E. Adaptive Sliding Controller

The sliding controller design can be made adaptive to parametric uncertainty by coupling it to on-line parameter estima-

tion which is based on the algebraic distance of the current state to the boundary layer [10]. This structure leads naturally to active adaptation only when the system is outside the boundary layer, avoiding the long-term drift frequently experienced in parameter estimation schemes [10]. The developed adaptive controller structure is based on the premise that there be no adaptation to that which can be modeled, but adaptation should occur only in response to complex dynamic effects that cannot be simply modeled. Examples of appropriate triggers to the adaptation mechanism include thruster fouling, motor or propeller degradation, or complex flow effects.

Inside the boundary layer for steady-state conditions, (8) yields:

$$s = \hat{h}^{-1}\frac{\phi}{K}Y\tilde{a}.$$

However, K was selected to be greater than the dynamic uncertainty $\hat{h}^{-1}Y\tilde{a}$, which implies that $s \leq \phi$.

This indicates that once in the boundary layer, s remains there. The value of s will be driven out of the boundary layer *only* when the actual dynamic uncertainty exceeds our current estimate. Therefore we should only adapt when outside the boundary layer and in proportion to the distance to the boundary layer.

To ensure the stability of the adaptive closed-loop system, the parameter estimation scheme must preserve the attractiveness of the boundary layer. With this in mind, a Lyapunov function candidate is selected of the form:

$$V = \frac{1}{2}[s_\Delta h s_\Delta + \tilde{a}^T\Gamma\tilde{a}]$$

and sliding condition:

$$\dot{V} = [s_\Delta h\dot{s}_\Delta + \dot{\tilde{a}}^T\Gamma\tilde{a}] \leq 0$$

where

$$s_\Delta = s - \phi\,\text{sat}\left(\frac{s}{\phi}\right)$$

$$s_\Delta = \begin{cases} 0, & \text{inside the boundary layer} \\ s - \phi\,\text{sign}(s), & \text{outside the boundary layer} \end{cases}$$

$$\dot{s}_\Delta = \begin{cases} 0, & \text{inside the boundary layer} \\ \dot{s}, & \text{outside the boundary layer} \end{cases}$$

$$\dot{\tilde{a}} = \dot{\hat{a}}, \qquad \text{since } \dot{a} \equiv 0$$

and Γ is a symmetric, positive definite matrix.

Imposing the sliding condition outside the boundary layer yields the adaptation recursion relation:

$$\dot{V} = [s_\Delta\{Y\tilde{a} - \hat{h}K\,\text{sign}(s)\} + \dot{\tilde{a}}^T\Gamma\tilde{a}]$$

$$\dot{V} = [\{s_\Delta Y + \dot{\tilde{a}}^T\Gamma\}\tilde{a} - s_\Delta\hat{h}K\,\text{sign}(s)]$$

which satisfies the sliding condition:

$$s_\Delta Y + \dot{\tilde{a}}^T\Gamma = 0$$

and

$$\dot{\hat{a}} = -s_\Delta\Gamma^{-1}Y^T.$$

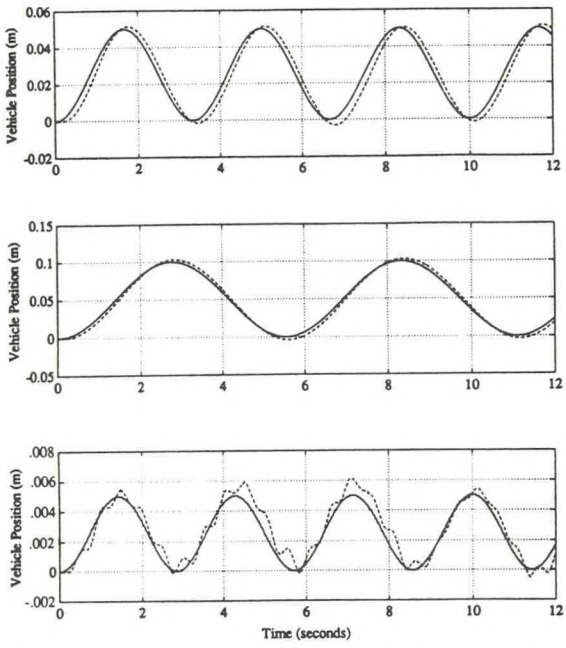

Fig. 19. These hybrid simulation results show that the adaptive sliding controller performs very well over the entire operation range. Here, the thruster parameters are initialized at their proper values and no adaptation takes place.

The model-based adaptive sliding controller was shown to avoid the limitations of the other controllers evaluated through use of the hybrid simulation. Good vehicle-tracking performance over the full range of thruster operation is obtained as shown in Fig. 19. In addition, the adaptive sliding controller is robust to significant parametric uncertainty with the ability to adapt on-line to changes in model parameters.

The ability of the contoller to adapt is best demonstrated by assuming that the model parameters are initially known. As shown in [7], when parameter estimates were initially set to zero, they converge rapidly and directly to the proper values. Fig. 20 shows an example of parameter convergence for the hybrid simulation for a sinusoidal-commanded position input with a magnitude of 0.2 m and a frequency of 0.3 Hz. The parameters do not converge exactly to the actual values, but are estimated only well enough to achieve a tracking error within the specified boundary layer. Adaptation ceases within the boundary layer, preventing long-term drift.

The adaptive sliding controller is also robust to changes in model parameters as demonstrated by the tracking performance achieved when an obstruction is placed in the thruster duct outlet shown in Fig. 21. This is the same desired trajectory and obstruction used in the evaluation of the "pole" cancellation controller shown in Fig. 18. Performance after imposing the obstruction ($t \approx 8$ s) is not quite as good as without the obstruction, but is far superior to the performance of the "pole" cancellation compensator.

VI. Conclusion

The dynamics of underwater vehicles can be dominated by the dynamics of the thrusters, particularly at low speed or hover. Unless compensation for these dynamics is included in

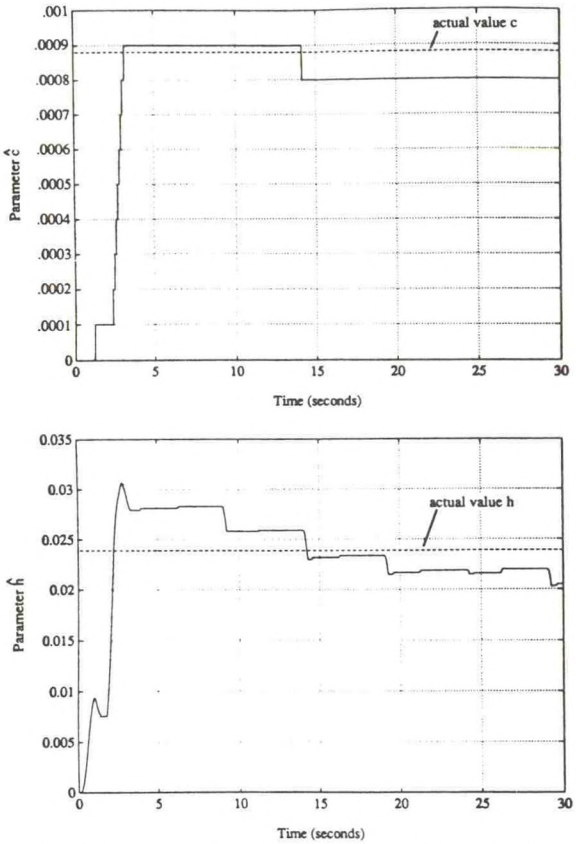

Fig. 20. With the parameters initialized at zero, the adaptive sliding controller shows rapid parameter convergence, after which adaptation ceases.

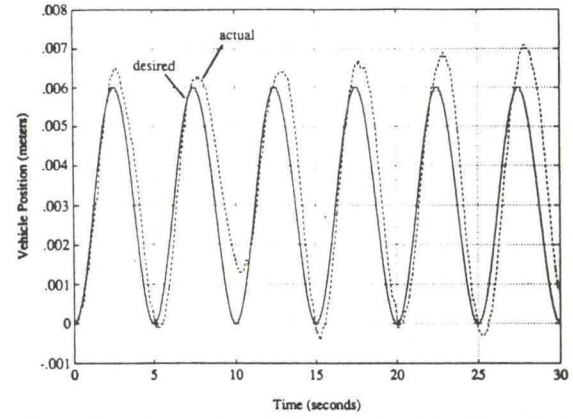

Fig. 21. Unlike the "pole" cancellation technique shown in Fig. 18, the use of an adaptive sliding controller allows the system to maintain performance even when an obstruction is placed in the duct.

the control system, the closed-loop system will be limited in bandwidth and prone to limit cycle. This behavior is seen in the heading and depth control of most commercial ROV's, and also in the position control of advanced ROV's and AUV's.

A lumped parameter model of a torque-controlled thruster shows the dynamics to be nonlinear. The thruster represents a fairly sluggish filter, although the speed of response increases with the magnitude of the thruster input. The lumped parameter model was identified in a test tank using an instrumented thruster from the full ocean depth ROV Jason.

A quasi-linear analysis utilizing describing functions was performed to investigate the influence of the thruster dynamics on the closed-loop system behavior. The analysis reveals that the thruster dynamics place a strong constraint on the closed-loop system bandwidth and produce a limit cycle. Furthermore, the frequency and magnitude of the limit cycle can be precisely predicted.

Three forms of compensation were tested utilizing a hybrid simulation which combined an instrumented thruster with a real-time mathematical vehicle model. The first compensator, a linear lead network, was easy to implement and greatly improved performance over the uncompensated system, but did not perform uniformly over the entire operating range. The second compensator, which attempts to cancel the nonlinear filtering effect of the thruster, was effective over the entire operating range but depends on an accurate thruster model. The final compensator, an adaptive sliding controller, was effective over the entire operating range and can compensate for the uncertainties or degradation of the thruster.

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TOURIST SUBMARINE "MOGLYN"

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1. Introduction

Our company built and delivered the tourist submarine Moglyn which won distinction of being the first such one built in Japan to the order of Japan Submarine Tourism Co., Ltd. in September, 1989, and since December of that year, she is in successful service above coral reef seabeds off Onna Village, Okinawa Prefecture.

The tourist submarine is definitely different from general surface crafts and even from submergence research vehicles in that it will submerge in water with many and unspecified passengers on board, whose design concept is without doubt the first one in Japan. In addition to technical matters as a submergence vehicle, there were many issues to be studied indeed.

How to apply the rules and regulations was one important issue, while the ensuring of safety was another big subject to free prospective passengers from any apprehensions whatever vague about submergence.

In this paper are introduced many points mainly in respect to the safety consideration, and further support systems for and mode of operation of the Moglyn are also referred to.

2. Rules and regulations to be applied to the tourist submarine

Safety rules and regulations to be applied to the submergence vehicles became law in Japan as the Special Applicable Criteria for Submergence Craft. Sometime ago, while similar ones exist in the U.S.A., the U.K., Norway, etc. The Shinkai 2000 and the Shinkai 6500, deep submergence research vehicles, etc. were designed and built in accordance with the above-mentioned criteria.

In case of the Moglyn as a first example of tourist submarines, however, special reference was necessary to the safety rules and regulations then in force with regard to safety of the vehicle and passengers on board. By referring to the applicable rules and regulations in detail, technical verification was made one by one and finally all inspections and tests were completed, always the special features of submergence vehicles for passenger carrying have been taken into consideration.

Simultaneously with the above, inspection by Nippon Kaiji Kyokai was conducted to be issued with a classification certificate on completion of the vehicle.

3. Outline of the Moglyn

3.1 Principal particulars, general arrangement, etc.

Fig 1 & 2 are a picture of outside view and interior of the Moglyn, and Fig. 3 shows the general arrangement.

The full designed as a pressure hull of the Moglyn is subdivied into a cockpit, a passenger cabin and a machinery space from forward to aft, a sound-proof divisional wall being provided between the latter two spaces.

On either side of the passenger cabin are fitted ten viewports, and it is possible for every two persons to enjoy outside view through one viewport in seated condition. The underside of the passenger cabin is allocated to a watertight compartment for the storage of two banks of

batteries each with a capacity of 500 Ah.
Diving of the Moglyn is to be done by ballasting buoyancy tanks fitted in way of shoulders of the pressure hull by means of venting air, while surfacing is by deballasting the same tanks with the supply of high pressure air. At the same time, vertical thrusters fitted to both sides of the hull amidships may also be driven to assist the diving and surfacing. The adjustment of weight distribution and trim is to be made by ballasting and deballasting, including shifting among, weight trimming tanks located forward, amidships and aft by means of a seawater pump. Underwater cruising is made usually at a speed of 0.5 knot with a main propeller, and the change of course is to be made by lateral thrusters fitted forward and aft.

Principal particulars of the Moglyn

(1) Principal particulars

Length overall	:approx. 19m
Max. width	:3.5m
Depth	:3.6m
Pressure hull length	:15.9m
Pressure hull diameter	:2.5 m
Max. diving depth	:50m
Complement	:40 passengers 3 crew
Speed	:2 knots
Lift support	:72 hours

(2) Hull construction
Pressure hull: Cylinder with outer frames
KB, KF, KA steel
Access trunks: Forward 850mm dia.
Aft 1,000mm dia.
Upper structure: FRP

(3) Power Source
Enclosed lead acid battery
2 banks of 500 AH x 224 V
(for 7 voyages and 72 hrs emergency use)
Charge time: Normal 7 hrs

(4) Maneuvering System
Main propeller :11kW AC motor x 1
Lateral thruster :3.7kW AC motor x 2
Vertical thruster:3.7kW AC motor x 2
Vertical rudder :El-Hy driven

(5) Buoyancy and Trim Control System
Main ballast tank: 6.4 m
press. air 24 Cylinders of 50 x 150 kg/cm
Trimming tank: 3.4 t
S.W. pump 150 1/min x 7 kg/cm

(6) Navigation equipment
Gyro compass, depth gauge, sonars for front and upward direction, TV camera for rear monitor, underwater telephone

3.2 Outline of passenger facilities
3.2.1 Outside view of hull
One of the most important points in the design of passenger craft is to create any innovative idea to attract the interest of general public who are always potential passengers, and the Moglyn was not an exception. It was very difficult but interesting job to reconcile both the function and design under the restricted condition of submergence vehicle. Above all, the outside view of the hull is the focal point of interest to be appealed and in cooperation with the Design Center of our company, number of design models were prepared for solid beauty evaluation and also for the getting of opinions of younger people considered to be the principal passengers for the final selection and determination. As seen in Fig. 1, the overall appearance of the Moglyn as completed shows features of its own, and friendly design somewhat simple though matches with the deep blue sea of Okinawa, further being enhanced by a logo of the Moglyn which was chosen and affixed later.

3.2.2 Viewports
The Viewports are the most important features in connection with the

function of and the safety for the tourist submarine.
Made of acrylic resin, the windows for the passengers, 20 in total, are of circular type with a clear diameter of 550 mm, and at the forward end of the hull is provided for the pilot a big viewing window also of acrylic resin and in dome form with a clear diameter of 1,000 mm.
To make free from any distortion in the underwater image through the dome type window, arrangement is made that the eyepoint of the pilot will be positioned at the center of curvature of the window.
In the past, our company had a lot of experience in the design, manufacture and actual use of acrylic resin viewports through the building of the Shinkai 2000, Shinkai 6500, etc., but such a big viewport as to be used for underwater viewing was a first encounter. In view of this, prior to the manufacture of the windows actually to be installed on the vehicle, a full-scale model was prepared to be followed by pressure and impact tests, and finally it was confirmed that the static strength and impact strength was quite satisfactory for the practical use.
During the test, verification of manufacturing technique of the viewports and sealing practice was made to ensure reliability.
The sealing system for viewports in this vehicle is double seal configuration comprising a seal ring and a gasket.
The viewports for passengers are protected from any intentional or accidental damage by the provision of acrylic resin protection covering of 3mm thickness closely attached to the inner surface of the viewports. For the pilot window, a protection covering of 6mm thickness of concentric form is provided on the outer surface to prevent from any damage due to the contact with floating matters.

3.2.3 Layout of the passenger cabin
The passengers sit facing the viewports inside shell and they will continue seating in a sitting posture for about forty minutes during the underwater tour to look through the viewports, no movement being allowed due to safety reasons. For this reason, it was quite necessary to find out the best layout of seat easy for long time sitting from the standpoint of ergonomics. For this purpose, a full-scale model of seat was prepared and actual examination of sitting by men and women of all ages including children was carried out to finally determine the layout of seats in relation to the relative positions of seats, armrests, viewing windows and feet resting positions.

3.2.4 Countermeasures for noise reduction
The sources of noise in the vehicle are an electric motor generator, an air-conditioning unit, a cooling water pump and the main propulsion motor in the machinery space. The effect of these on the passenger cabin was calculated for the prediction, and anti-noise measures was taken accordingly as follows:
The auxiliaries in the machinery space were mounted on anti-vibration foundations to reduce the solid propagation of noise, sound insulation was made on the partition wall all over, and sound absorption measures was taken to reduce the noise transmission from the sound insulated duct.
The noise measurement indicated a level of 50 dB(A) in the cockpit and 56 dB(A) at the center of the passenger cabin, having been proven sufficiently quiet.

3.2.5 Interior finish work
As explained before, the hull is of one compartmentation layout so far as the fire safety is concerned, and if fire occurs during submergence, no refuge can be made. Hence it is

definitely necessary to minimize the risk of fire as far as practicable. Before finally determining what is to be used as incombustible material, a test to check the generation of poisonous gas was conducted, and only selected and approved materials were used for the interior work.

3.3 Inboard environmental control

As the measures for inboard environmental control, the air-conditioning unit, and an oxygen generator and a carbon dioxide absorber to maintain the appropriate composition of the air in the hull are provided.

(1) Air-conditioning unit

Conditioned air in the vehicle is designed to be at 28°C with a relative humidity of 50%. the unit has an enough capacity to cool down air from 35°C at 65% relative humidity to the above condition in only 5 minutes at the time of disembarkation and embarkation offshore when ingress of hot and wet air will be inevitable.

(2) Oxygen generator

During normal submergence, the ordinary use oxygen generator is in service, and oxygen to meet the consumption will be supplied from two small oxygen cylinders of 6.7 liters each at 150kg/cm^{2}g fitted in the vehicle. In case of an emergency, oxygen is to be supplied from 13 oxygen cylinders (50 liters at 150 kg/cm^{2}g) fitted outside the hull. Oxygen piping systems for both are independent each other.

(3) Carbon dioxide absorber

Considering absorbent capacity and cost-effectiveness, absorbent of sodium lime compound (Ca(OH)2) is chosen.

Absorbent was chosen on ground of duration for use which will be longer than another if to be used up to an absorption factor of 60%.

The vehicle is equipped with oxygen reservoirs and carbon dioxide absorbent to correspond to the oxygen decrement and carbon dioxide increment whose data may appear somewhat bigger, as the emergency situation is taken into account here. The design of the carbon dioxide absorber and the exchange frequency of absorbent were determined on the base of the carbon dioxide increment being 22 l/h/man and carbon dioxide content always less than 0.5 percent.

3.4 Safety appliances

In addition to the safety appliances for life-saving, fire-fighting, etc. as required for the surface craft, emergency breathing apparatuses and also provisions and drinking water for emergency use are stowed on board as required for the tourist submarine. In case of the subemergency vehicle, whatever abnormal might happen, the only and first measures to be taken is to surface at all events on quite apparent reasons. For the emergency surfacing, followings are provided on the Moglyn.

i) A deballasting system for the weight trimming tanks.
ii) An emergency air blow system for the buoyancy tanks.
iii) A drop weight jettisoning system through two ways.
iv) In the event of the above all being failed or insufficient, a rescue buoy release system as a last measures.

A support craft can raise the vehicle up to the surface with its emergency lifting appliances.

4. Operation of the Moglyn in service and supporting systems

4.1 Operation

Submergence operation area of the Moglyn is located several kilometers off the base. Between the passenger landing pier and the Moglyn usually positioned in the operation area, passengers will be transported by the

high-speed tender Uruma built exclusively for the purpose, and at the operation area they will embark and disembark the Moglyn via the support vessel in transit. The Moglyn is always operated under the full attendance and watch of the Deigo, an exclusive support craft for her, and during one cycle of voyage offshore up to seven consecutive submergence can be made usually.

4.2 Restriction on the operation
The ensure the safe operation of the Moglyn, it is necessary to pay full attention to weather and sea conditions, etc. and following guidance and/or restriction are established.

(1) Operation to be ceased when one or more of the following conditions is expected or encountered with.
wind speed: 8 meters of more
wave hight: 0.8 meter or more,
visibility at sea: 1km or less,
current: 0.5 knot or more,
visibility through the water:
10 meters or less

(2) Forbidden clauses for passengers
The lighting of fires
Movement inside the hull during submergence.

(3) Operation of the vehicle to be made following underwater nautical marks provided for exclusively.

4.3 Support Systems
4.3.1 Base facilities
(1) An office, a passenger waiting room and the passenger landing pier.

(2) A mooring quay for Moglyn and the support craft:
The charging of batteries, filling up of gas and inspections will be made.

(3) Landing place for the Moglyn:
For the refuge for typhoon, external inspection and maintenance of the Moglyn.

4.4 the support craft
The role of the support craft Deigo is as follows:

(1) Watch of and communication with the Moglyn.

(2) To act as a transition point between the tender and the Moglyn.

(3) Rescue of passengers form the Moglyn in an emergency, and raising of the same in an emergency.

(4) Charging of batteries, filling of oxygen, supply of shore electricity, support of inspection and maintenance.

(5) Other items, if any.

General arrangements of the Deigo and the Uruma are shown in Fig. 4.

5. Concluding remarks
As described above, the Moglyn built in Japan as the first such vehicle to realize people's long cherished dream of underwater tour is a new type of marine vehicle in fact hitherto never have been seen. Now it is possible for everyone to enjoy the sea life easily by boarding the Moglyn, and many more being anticipated to do so to enhance more interest on sea.
It is hoped sincerely that the tourist submarine industry will prosper to enjoy a thriving business by continuing successful operation of the Moglyn.

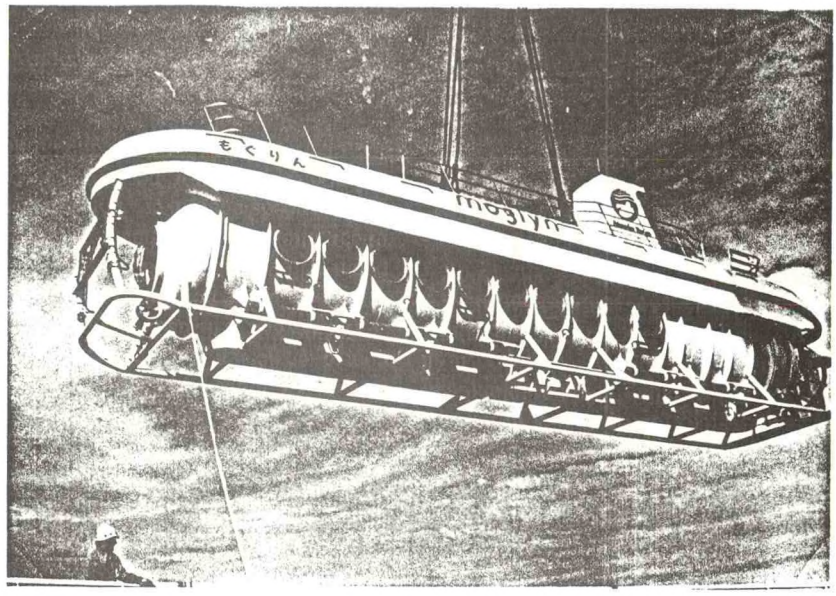

Fig. 1 Outside view of Moglyn

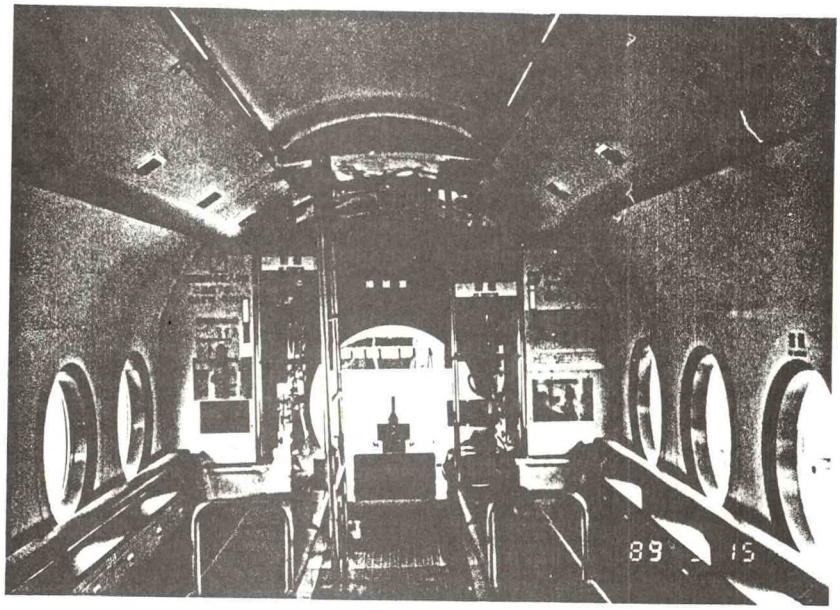

Fig. 2 Interior of Moglyn

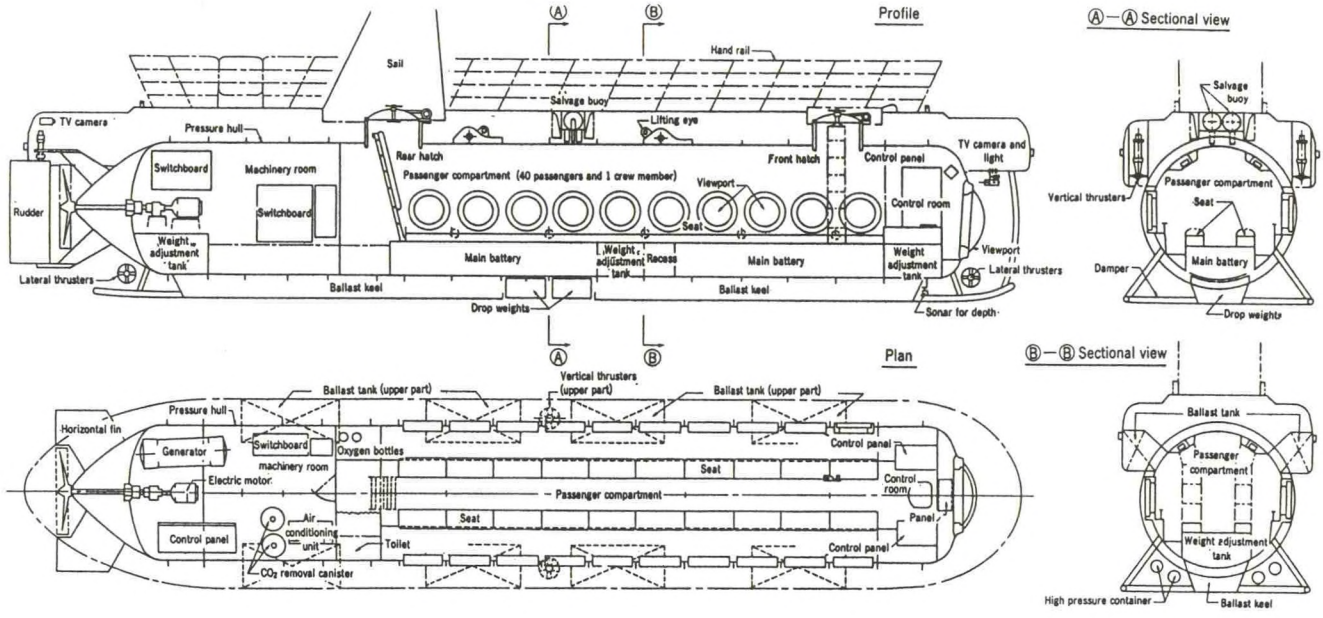

Fig. 3 General Arrangement of Moglyn

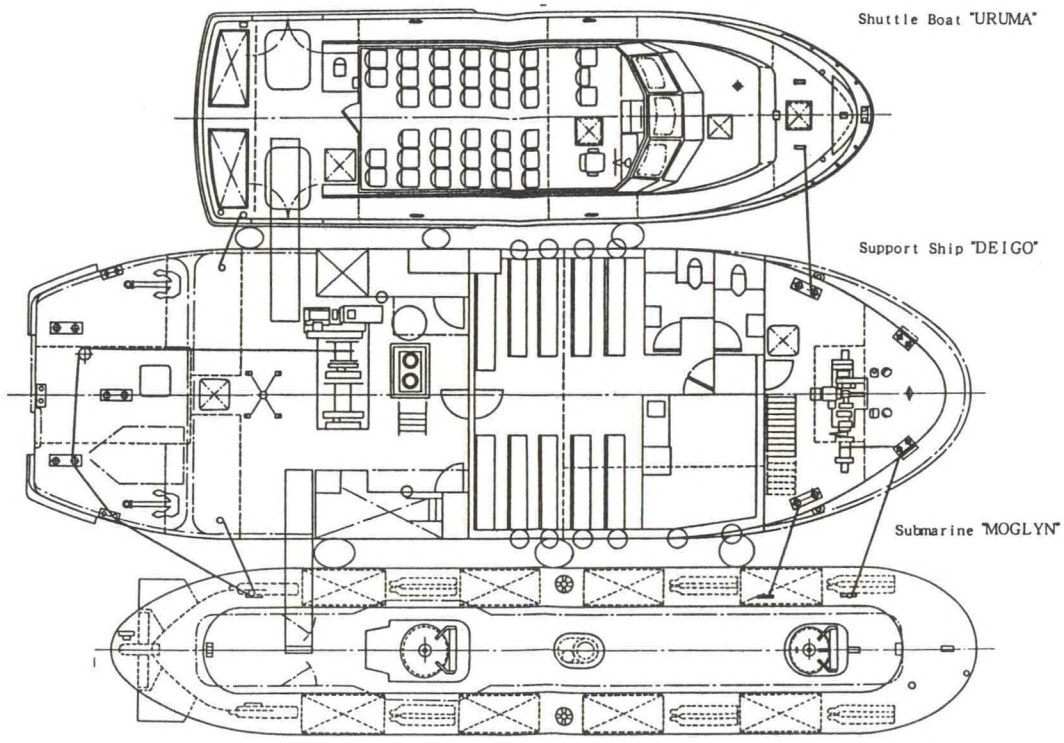

Fig. 4 Moglyn Fleet

ON DEVELOPMENT OF 10,000-M CLASS REMOTELY OPERATED VEHICLE

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Japan Marine Science & Technology Center

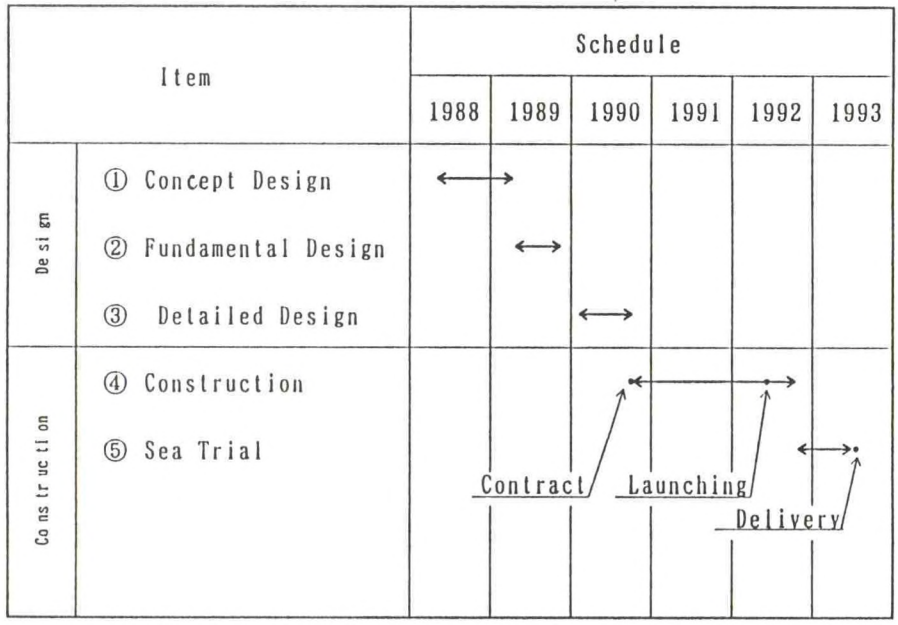
1. INTRODUCTION

The 10,000-m class remotely operated vehicle (10K) is scheduled to be mounted on "Yokosuka", a support vessel put into service in April last year and conduct deep sea research in collaboration with the research submersible "Shinkai 6500".

The contract of 10K construction was carried out in December, 1990. The construction schedule is shown at table 1 and 10K will be completed by March 1993.

10K design is summarized below.

Table 1 Construction Schedule



2. ROLE OF THE 10,000-M CLASS ROV (10K)

Deep-sea research by the "Yokosuka" support svessel and the "Shinkai 6500" research submersible can be divided into wide-area research using a multinarrow beam echo sounder (MNBES) mounted on "Yokosuka" and detailed research done by "Shinkai 6500". MNBES displays the topography of a particular seabed by sending acoustic wave of thin fan beam to the seabed.

Currently, on the basis of wide-area research using thisMNBES, detailed research points using "Shinkai 6500" are planned to be selected. However, wide-area research can provide only an contour map with the difference of elevation of about 50m. This is not helpful enough to select a place of detailed research by "Shinkai 6500". As a result, intermediate research between wide-area research and detailed one is indispensable.

One of the important roles of 10K is to conduct this type of research. More specifically, the launcher is towed by "Yokosuka". A side scan sonar (SSS) and parametric subbottom profiler (SBP) mounted on a launcher are used to investigate the topography or geology of a particular seabed, the results of which are used for selection of a place of detailed research.

10K has two another important roles. One is underwater research to 10,000m depth which cannot be done by "Shinkai 6500". The other is emergency rescue of "Shinkai 6500".

3. CHARACTERISTICS OF 10K

As shown in Fig.1, 10K adopts a launcher system with a towing function and consists of equipments as given below.

- Vehicle
- Launcher
- Primary tether cable
- Secondary tether cable
- Launch and recovery system (Support vessel)
- Deck equipment
  (including a maneuvering and control system)

The functions anb capabilities of 10K can be characterized as follows:

(1) Maximum operating depth: about 10,000m

(2) Submergence support system (acoustic navigation system)

Basically, LBL and SSBL position measurement systems are used in combination. In operating 10K, it is necessary to always grasp the correct relative position of the launcher to the vehicle, so an echo sounder receiver is installed on the launcher for theSSBL position measurement purpose. Furthermore, this relative position is connected with information concerning the position of the launcher obtained byLBL position measurement on the "Yokosuka" support vessel, making indication of the posittion of the vehicle by an earth coordinate system possible. This is the most distinguished characteristic of the submergence support system.

(3) Data transmission system

At this point, the vehicle have five TV cameras and the launcher is equipped with SSS and SBP. They will provide an enormous amount of information obtained from observation. 10K adopts a large-capacity data transmission system of about 1,000 Mbps to transmit this information to the support vessel.

(4) Power supply

Electric motors of the launcher and vehicle will be directly driven by high-voltage power supply of about 3,000V at the receiving end of the launcher. This is intended to minimize power transmission loss in the primary cable.

4. VEHICLE AND LAUNCHER

(1) Vehicle

To operate 10K to 10,000m depth, it must withstand water perssure and must be made light as much as possible to allow it demonstrate maneuverability. To realize this, 10K's vehicle and launcher have structural features as given below.

a. Oil-immersed equalizing devices are employed.

Of devices fitted to the 10K vehicle and launcher, all devices such as the hydraulic pump and electric motor except electronic circuits will be oil-immersed equalizing types.

As a result, the number of necessary pressure containers is three each for the vehicle and the launcher, thus contributing greatly to the reduced weight. The oil-immersed pressure equalizer is a device to protect devices from water pressure by immersing them in oil and controlling the oil pressure to keep it equal to water pressure.

b. Titanium and titanium alloy are adopted.

Titanium or titanium alloy is adopted in the frames and pressure containers of the vehicle and launcher to reduce their weight.

As stated early, both vehicle and launcher are

equipped with many acoustic devices. Control of noise generated from the hydraulic pump and electric motor was an important study subject. The study resulted the adoption of a screw type hydraulic pump producing less noise at a frequency band of 7 to 10kHz in place of an axial plunger type hydraulic pump.

Principal items of the designed vehicle and its side view are shown in Table 2 and Fig. 2, respectively.

Table 2 Principal items of the vehicle

Dimension	Length × width×height; Approx. 3m×2m×2.3m
Weight	Weight in air ; Approx. 5.7tons Weight in water; Approx. -10kg
Hydraulic pump	Tipe; Oil-immersed screw type hydraulic pump
Specific gravity of buoyancy material	0.63
Propeller	7 (4 for the horizontal direction and 3 for the vertical direction); Oil-pump drive
Maximum underwater velocity	Approx. 2knots
Observation devices	TV Camera ; Colour 4, Black & white 1, Still camera 1, CT 1
Navigation devices	Obstacle avoidance sonar 1 Altitude meter 1, Directional gyroscope 1, etc.
Manipulator	7 freedom×2sets

(2) Launcher

The 10K launcher has two important functions, One is a staging base function between the vehicle and the support vessel. When launched from the support vessel, both vehicle and launcher, still in a connected state, sink to a point at a altitude of approx. 200m from the seabed. Then, the vehicle goes out from the launcher and begins to act alone. In the meantime, the launcher supports the act of the vehicle by veering out and taking up the secondary tether cable. For lifting the vehicle up to the support vessel, the vehicle is connected to the launcher and lifted up to the sea surface by the primary tether cable and lifted up to the support vessel.

Another function of the launcher is to conduct tow research. For the launcher to conduct seabed research using SSS and SBP while towed by the support vessel, it is necessary to keep the attitude of the towed launcher stable at all time. For that purpose, the launcher is covered by an FRP outer shell and fitted with vertical and horizontal stabilizing fins on its stern.

The principal items and the side view of the launcher are shown in Table 3 and Fig. 3, respectively.

Table 3 Principal items of the launcher

Dimension	Length, width and height : Approx. 5.2×2.6 ×2.0m
Weight	Weight in air : Approx. 5.0tons Weight in water : Approx. 3.0tons
Research devices	SSS: range of research ; each side maximum 1,000m (altitude ; 200m) SBP: geological research to the depth of 30m under the seabed CT
Maximum tow velocity	1.5knots
Navigation devices	Obstacle avoidance sonar 1, Altitude meter 1, Depth meter 1, etc.,
Secondary Cable Handling System	Secondary cable reel 1, Shock absorber 1,
Acoustic	LBL receiver 1, SSBL receiver 1,

5. CABLE

(1) Primary Cable (Fig. 4)

- Type : Optical fiber · electric power cable, pressure equalized,
- Length & dia meter : 12000m, 44mm
- Breaking Strength : more than 40tf
- Voltage : 3000V AC, 60Hz, 3 ϕ

(2) Secondary Cable (Fig. 5)

- Type : Optical fiber · electric power cable, presuure equalized,
- Length & dia meter : 250m, 28mm
- Breaking Strength : more than 3tf
- Voltage : 3000V AC, 60Hz, 3 ϕ

6. DATA TRANSMISSION

As data transmission, single mode optic fiber for supporting vessel to the launcher, multimode one for launcher to vehicle are adopted. Velocity of data trnsmission is about 840 Mbps for vehicle to support vessel, about 420 Mbps for launcher to support vessel.

7. DECK EQUIPMENTS

Deck Equipments consist of primary cable handling equipments and 10K launch and recovery system.

Primary cable handling equipments consist of as follows as shown Fig. 6 :

(1) Cable store winch
(2) Traction winch
(3) Ram tensionar (heave compensator)

10K launch and recovery system consist of retrieval frame, winch, gimbal shicave, lifting device, trolley.

By these equipments, 10K is lifted up to the support vessel from sea sarface without using the primary cable.

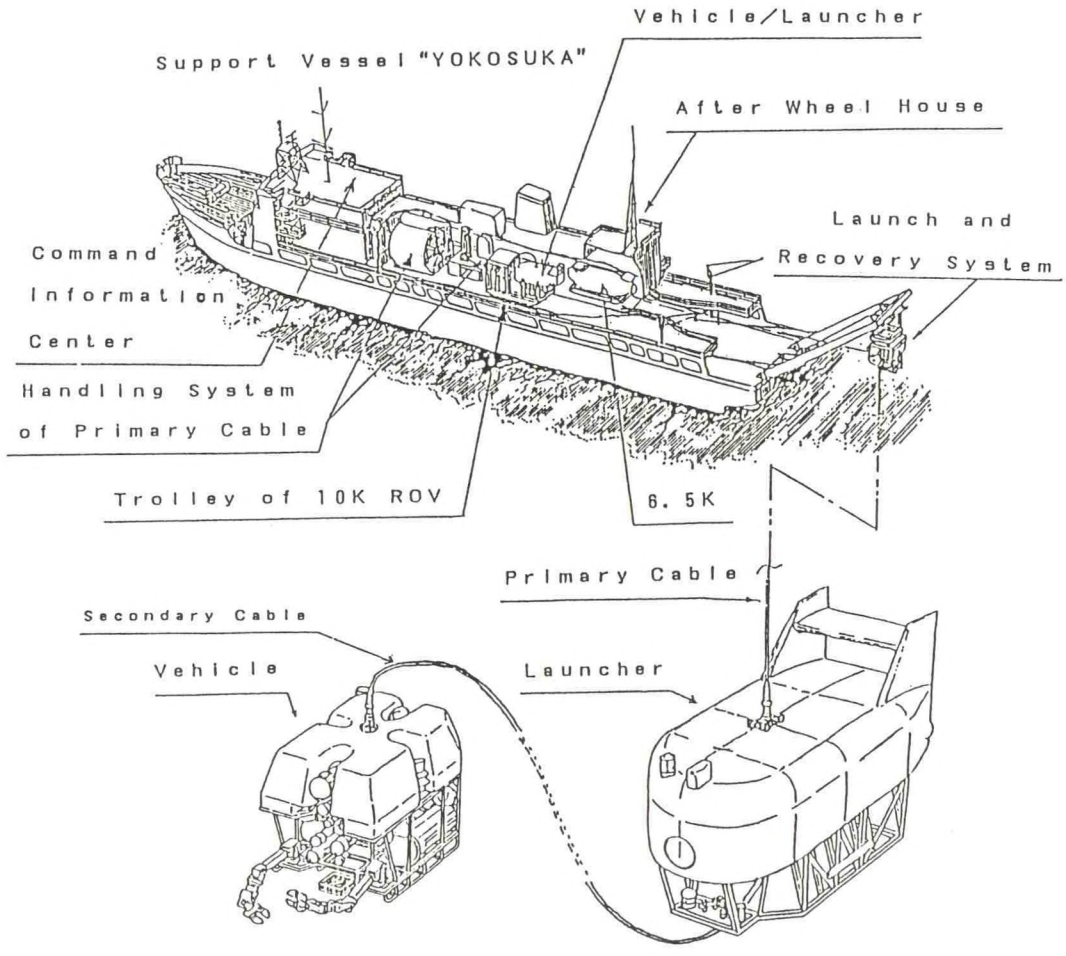


Fig. 1 10K System

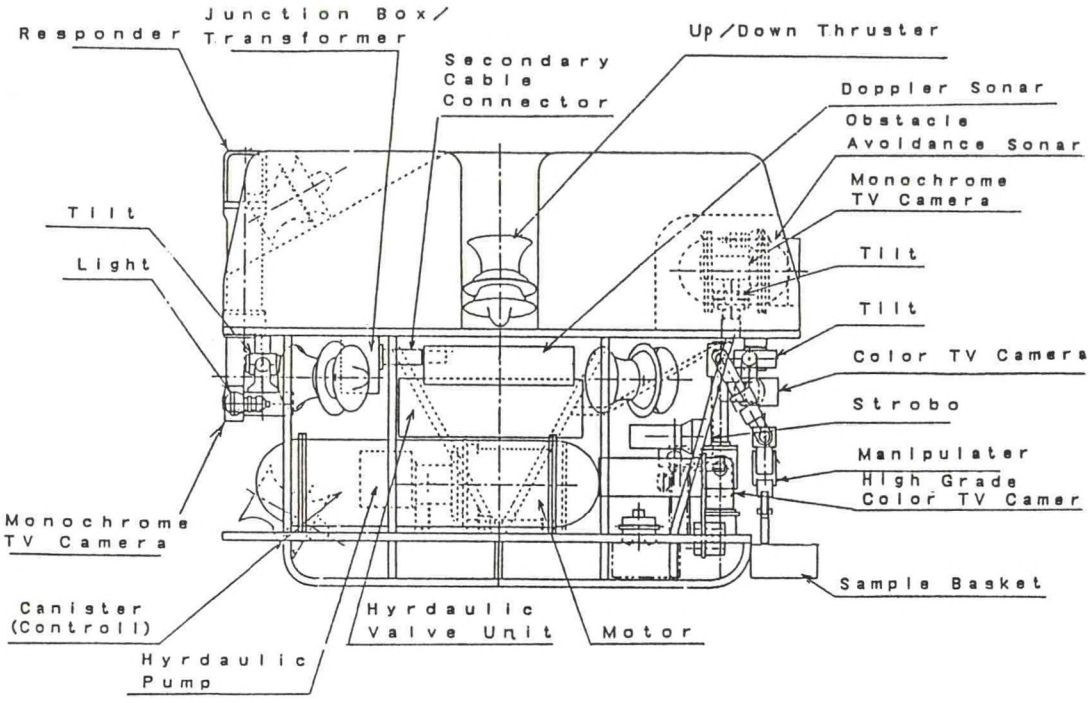


Fig. 2 Vehicle (Side View)

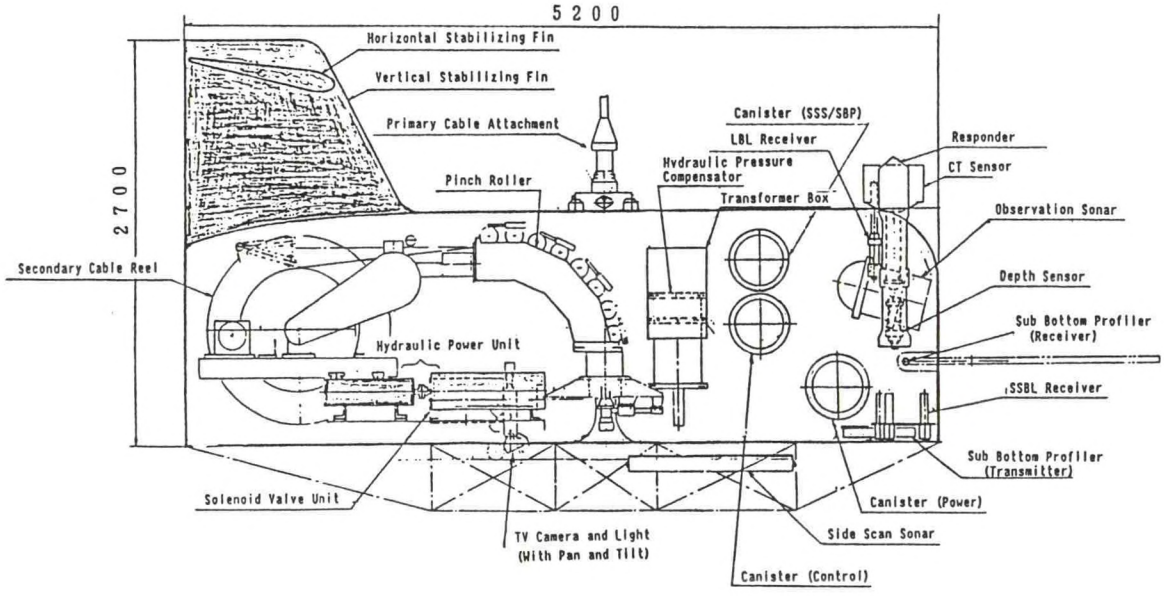


Fig. 3 Launcher (Side View)

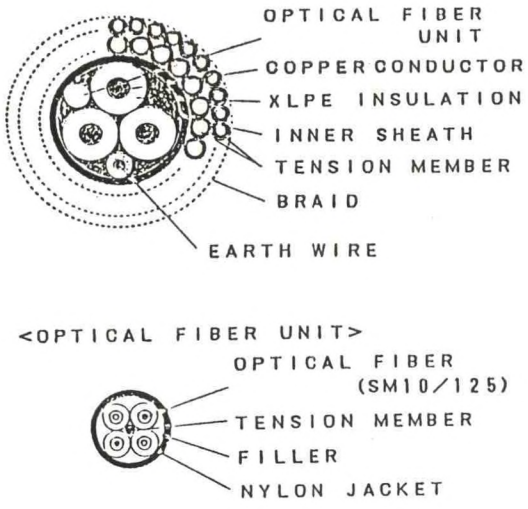


Fig. 4 Primary Cable

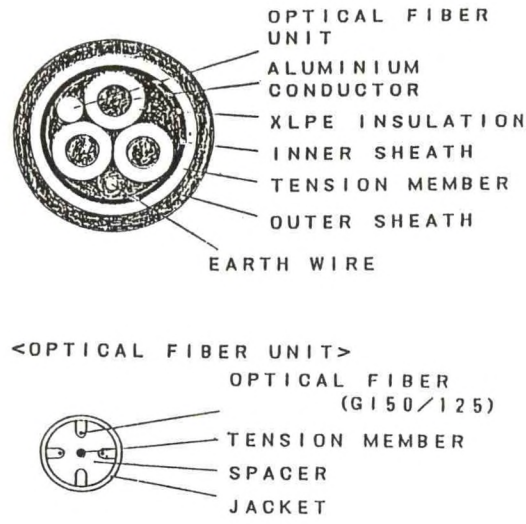


Fig. 5 Secondary Cable

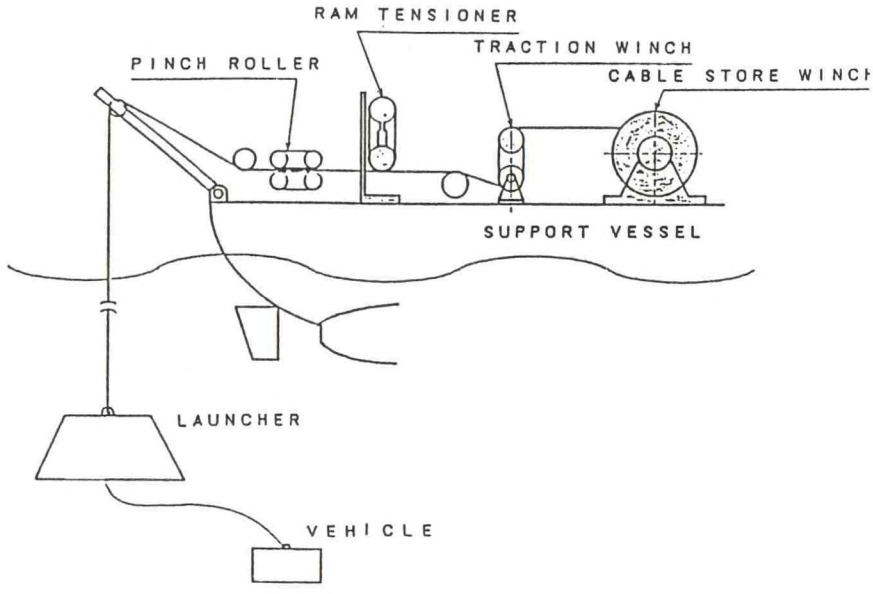


Fig. 6 Primary Cable Handling System

RECOVERY OF AN OBJECT ON THE DEEP SEA FLOOR BY TRAWLING A LONG WIRE WITH GRAPNEL ANCHORS

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INTRODUCTION

Various instruments, settled on or sent to the deep sea floor are used for geological, geophysical and other scientific surveys. Deep sea research vehicles, regardless of whether manned or unmanned, are also included in them. These instruments are usually designed to get enough buoyancy when it jettisons the weight and be able to pop up to the sea surface in the recovery operation. Acoustic link is the most common method to send the pop up commands to the instruments. However, their recovery systems, including both communication links and weight release mechanisms some times don't operate well and the instruments are left on the sea floor to continue their works in vain.

To recover objects on the sea floor, wire trawling method has been used occasionally. In 1981, JAMSTEC's deep sea research group succesfully recovered an acoustic transponder from the depth of 6000m which they could not recover with ordinary procedure because of the weight release trouble. Although this would be a very fortunate case, trawling wire will be a powerfull method to recover objects on the deep sea floor if the dynamics of the trawling wire is well understood to optimize the towing strategy and appropriate instrumentation is done.

METHOD

The concept of our trawling method is shewn in Fig.1. The object lying on the sea floor

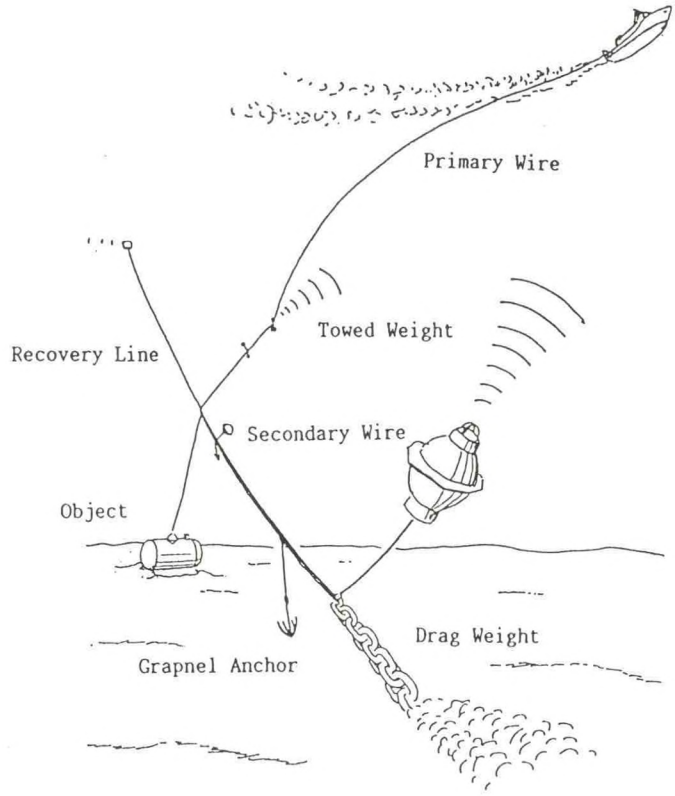

Fig.1 The Concept of the Recovery Method

is assumed to have a recovery line with a float at the top. It is also assumed to have an acoustic transponder or pinger so that the position of the object can be monitored from the towing ship. Then the objective of the operation is to catch this recovery line with grapnel anchors atatched to the secondary wire extended from a towed weight fixed to the lower end of the primary wire.

Now we consider a long wire towed from a towing vessel. The lower end of the towed wire does not respond quickly to the change of the velocity of the towing vessel. This is the principal reason for the difficulty of the path control of the lower wire end at

which various instruments are usually attatched. The delay is caused by the mechanical flexibility and inertia of the wire, and the fluid dynamic drag exerting on the towed wire the magnitude of which is in the same order as the weight of the wire itself in most cases. When a long wire (We call this a primary wire) with a heavy weight attached to the lower end is towed from a towing vessel, and the vessel goes on a circular path with a constant tangential speed relative to the ground, the weight will also move on a circular path but in a smaller diameter, as shewn in Fig. 2. The

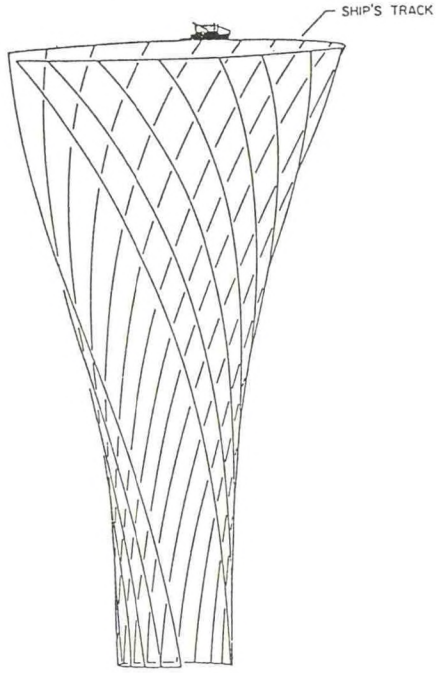

Fig.2 Typical Configuration of a Towed Wire

ratio of the diameters depends upon the length, the specific gravity, the drag area (drag coefficient x diameter for unit length) of the primary wire, and the towing speed. If there exist ocean currents, the center of the circular path of the towed weight will not coincide with that of the towing vessel. Even under such a condition, the path of the weight will still be nearly circular, if the current speed is not extreme such as greater than the towing speed throughout the whole water column. In this case, the wire length control is inevitable if the depth of the weight must be kept constant. For a given towing depth and the specifications of a towed wire and a weight, the radius of the circular path of the weight R_2 is varied by varying the radius of the circular path of the towing vessel R_1 and the tangential speed V_t. As shewn in Fig.3, increasing R_1 or decreasing V_t makes R_2 smaller and vice versa. Fig. 3 also shows the motion of the secondary wire extended several hundred meters from the weight to the drag weight which is towed on the sea floor. The drag weight again moves on the circular path, whose radius R_3 is smaller than R_2. The grapnel anchors for catching the object on the sea floor are attached to the secondary wire at a certain interval together with buoys to neutralize the weight of the anchors. The determination of the number of the grapnel anchors and their attachiment interval are important problems, and will be discussed later. To minimize the probability of cathing the ground instead of the recovery object, the system must be towed so that the grapnel anchors don't toutch the sea floor. It can be assumed that the speed of the towed weight is low and the fluid dynamic drag on

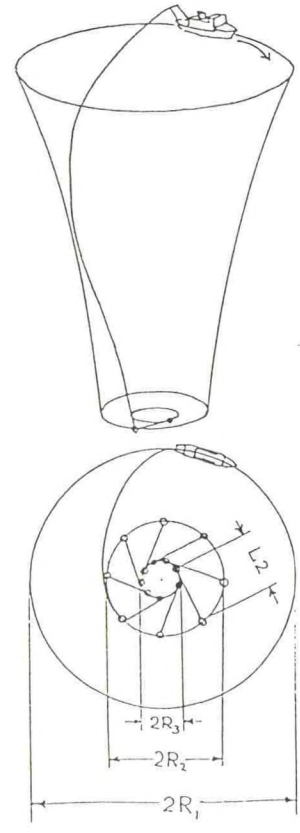

Fig.3 Configuration of the Trawling Wire

the secondary wire is small compared to the friction drag of the drag weight which moves on the sea floor. Therefore the secondary wire can be thought straight, and the following simple relation between R_2 and R_3 is obtained from geometry.

$$\frac{R_2-R_3}{L_2} = \frac{R_2}{L_2}\sqrt{\left(\frac{R_2}{L_2}\right)^2 - 1} \qquad \text{for } \frac{R_2}{L_2} > 1 \qquad \cdots\cdots\cdots(1)$$

where L_2 is the secondary wire length. If R_2 is smaller than L_2, the secondary wire slacks, and the drag weight stays at a certain point. So, $R_3=0$ and,

$$\frac{R_2-R_3}{L_2} = \frac{R_2}{L_2} \qquad \text{for } \frac{R_2}{L_2} \leq 1 \qquad \cdots\cdots\cdots(2)$$

These results are shewn in Fig.3. As the

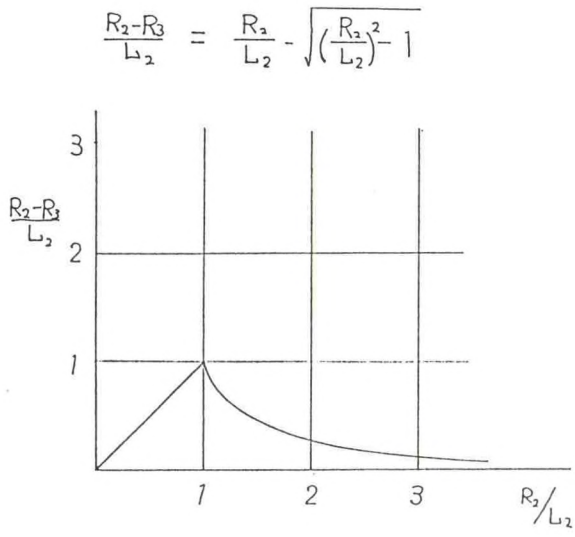

Fig.4 Sweep area of the Secondary Wire

recovery line is to be caught in the area bounded by the circles of radii R_2 and R_3, the operation is optimized when R_2-R_3 takes the maximum value. For given secondary wire lengths L_2, this will be achieved when

$$\left(\frac{R_2-R_3}{L_2}\right) = 1 \qquad \cdots\cdots (3)$$

or, as already described, $R_3=0$. This leads to the simple relation

$$R_2 = L_2 \qquad \cdots\cdots\cdots(4)$$

This corresponds to the upper limit of R_2 where the drag weight on the sea floor can stay at the center of the circular path of the towed weight.

The next step is to optimize the towing condition so that the eq. (4) is satisfied. This will be done by the selection of the radius of the circular motion of the towing vessel R_1 and the tangential speed of the vessel V_t. From the assumption that the fluid dynamic drag on the secondary wire is small, the influence of the secondary wire can also be neglected when we consider the optimization of the towing. Now, we consider the simple steady state towing of a weight. The equilibrium configration of the cable towed in a circular path have been calculated by Skop[1], and Choo[2]. They derived the three dimensional equation of equilibrium for a towed cable element. The equation is in the differential form and can be integrated from the lower end with the given end load condition. Mudie[3] used the quasi- steady model in which the elongation of the cable is neglected and the longitudinal cable motion is determined merely from the geometrical continuity. The method we used in the steady towing analysis is identical to Skops'. The only differences are the difference of the mathematical model of the fluid dynamic force[4] and consideration of the centrifugal force which is not included in their formulation. The specifications of the towed wire used in our experiments are given in Table 1. And the results of the calculations are shewn in Fig.4. In this Fig. the ordinate is the depth, and the abscissa is the radius of the circular path of a point on the towed wire at corresponding depth. Each curve is drawn for different angular velocity of the towing vessel ($\omega=Vt/R_1$). We can determine the

Name	Particulars	
Stock-Drum Winch	Winding Load	:ab. 200kg
	Winding Speed	:ab. 50m/sec
	Operation Method	:Manual Operation at Machine Side
	Brake	:Manual Operation at Machine Side
Friction-Drum Winch	Winding Load	:8/12 ton
	Winding Speed	:46/30 m/min
	Operation Method	:Manual Control at Machine Side or Remote Control
	Brake	:Manual Operation at Machine Side
Towing Cable (Primary Wire)	Classification	:Steel Wire Rope
	Diameter	:16mm
	Length	:ab. 8,000m
	Breaking Strength	:over than 18ton
	Weight/Length	:0.989kg/m
	Weight in Air	:ab. 8ton
Trawl Rope (Secondary Wire)	Classification	:Nylon Rope
	Diameter	:26mm
	Length	:ab. 400m
	Breaking Strength	:12.3ton
	Weight	:162kg
	Accessories	:20 grapnels, 2 transponders, floats as necessary

Table1 Specifications of the Trawling System

optimum ω from this Fig. at which the condition (4) is sutisfied. We also performed the fully dynamic simulation. The mathematical model of the trawling wire system is given in the ref. 4). The strategy of the recovery and the operation program was determined from the results of the dynamic simulation.

EXPERIMENT

A series of recovery experiments were performed in May 1990, at Ensyu-nada where the water depth is 2,600m. An experimental object, illustrated in Fig.6 was thrown from the vessel down to the sea floor. The towing vessel approached the predetermined circular path of 1,200m diameter at very low speed($\simeq$0.5 kts), paying out the trawling wire(Fig.7). The center of the circle was placed just above the object on the sea floor. The positions of the object, the towed weight, and the drag weight were measured by the acoustic navigation system, and monitored on the graphic display on board the towing vessel. Once the towing vessel came on the circle, the vessel was controlled to keep on the circle. When the drag weight reached about 20m above the sea floor, the wire winch control mode was changed to keep the altitde of the drag weight constant, and the towing speed was increased to 2.5 kts. The trajectory of the drag weight came to the steady circular path asymptotically. Because of the existence of

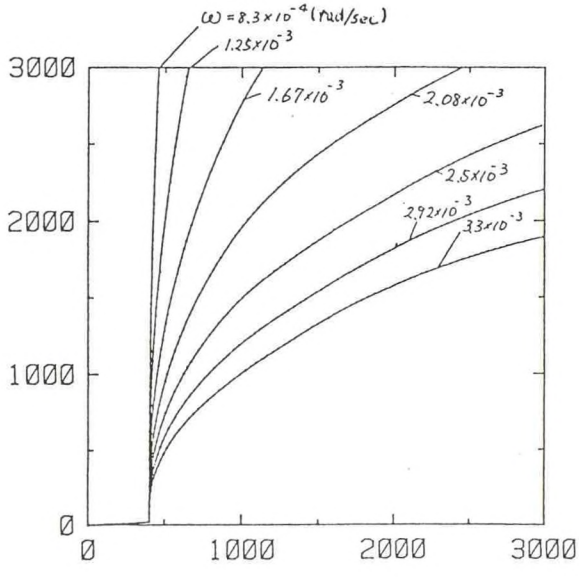

Fig.5 Configuration of the Primary Wire

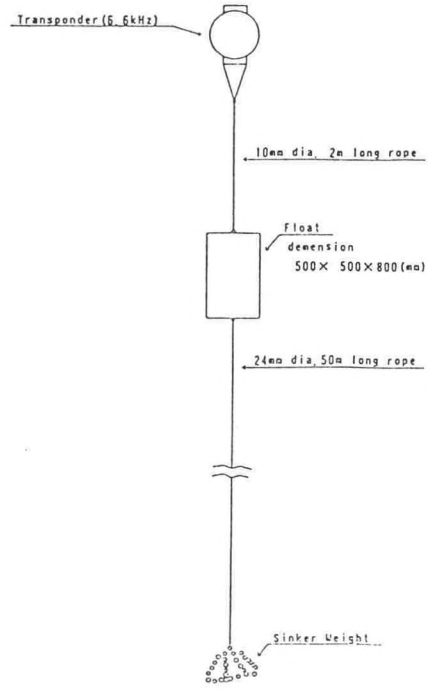

Fig.6 Object for the Recovery Experiment

the underwater current, the center of the circular path of the drag weight slightly shifted from the object. When the horizontal distance between the drag weight and the object became less than the secondary wire length, trawling wire was payed out again at very low winch speed until the drag weight reached the sea floor, and the altitude of

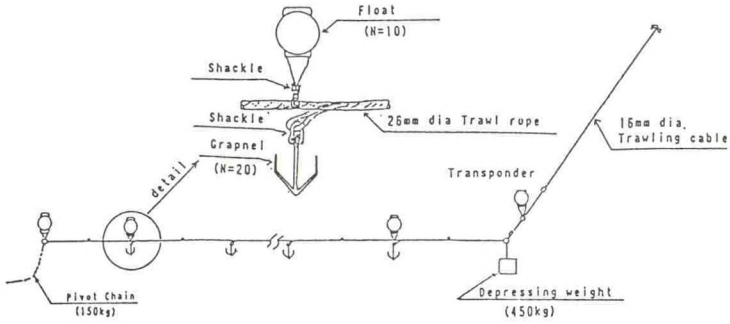

Fig.7 Trawling Wire System

the towed weight from the sea floor came to 50m which corresponded to the length of the recovery line of the object. The altitude of the towed weight was kept constant, and one of the grapnel anchors caught the recovery line. The experiments were done twice, and the object was recovered successfully in the both operations.

DISCUSSION

The most important factor in this recovery operation is the aquisition of the positions of the object, the drag weight, the towed weight and the towing vessel. Although nothing can be done without information of the object position, if the position of the drag weight or the towed weight was not obtained, the dynamic simulation would make up the luck of information on their positions.

In the first experiment, 20 grapnel anchors were attached at the interval of 20m. However, several anchors attached near the drag weight entangled with each other. The excess number of grapnel anchors merely seem to increase the probability of entanglement and to make the on board operation bothersom. Then, 15 grapnel anchors on the towed weight side were removed in the second experiment, and entanglement did not occur. Although we used five anchors in the second experiment, the number of grapnel anchors might be reduced to one.

The motion control of the towing vessel to keep the trajectory on the circle of 1,200m diameter at 2～2.5 kts was almost the limit of the ship control if the vessel does not have bow thrusters. So, if the vessel cannot be controled at such low speeds, the speed together with the rudius of the circular path can be changed without changing the radius of the towed weight path.

CONCLUSION

(1) The trawling a wire in a circular path proved to be a reliable method for the object recovery from the deep sea floor.

(2) Accurate position information of the object, the towed weight, and the drag weight is the most important factor for the successfull operation.

(3) Five grapnel anchors were adequate, and the number of anchors will be reduced further.

It seems very interesting that the poor responce of the motion of a long towed wire to the motion of the towed vessel, which usually makes the towing operation troublesome makes this recovery method highly reliable.

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study on the Solidification of Carbon Dioxide in Deep Sea (Discussions of its Feasibility by Basic Experiment)

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Abstract
The deep sea has recently been given an attention as the place for dumping the most decisive greenhouse effect gas CO_2. From the basic experiment conducted by a test rig to simulate the discharge of liquid CO_2 into the deep sea, the characteristics and the unsolved subjects of two CO_2 solidification methods, the hydration and the carbonating after dissolution, were discussed.

1. Introduction

There are several gases which have a greenhouse effect due to their absorption characteristics to electromagnetic waves. Among those, carbon dioxide (CO_2) plays the most decisive role in coping with the global warming, since it shares by far the highest concentration. It is estimated that its contribution to global warming reaches 71% of all greenhouse effect gases and it has already brought a warming of 0.55°C[1].
From the analysis of the air confined in the ice bed at Antarctica, it was unveiled that its content had continuously been increasing ever since the Industrial Revolution[2]. It seems thus undoubted that the increase of CO_2 content in the atmosphere was eventually originated from human activities. Its accelerative increasing rate reaches 1.5 ppm/yr at present[2], which creates a great concern about a severe influence on our future. Tremendous amount of CO_2 should be treated for some favorable effects to be anticipated, which is the most different point from other pollutants to have been experienced until now.

These circumstances call our attention to the sea deeper than 500m as the location for dumping of CO_2, where CO_2 is liquidized. And after confirming experimentally that CO_2 and water (sea water) turn into hydrate at higher pressures than about 4 MPa and lower temperatures than about 5°C[3][4], the project of CO_2 solidification through its hydration is going to start[5]. On the other hand, prior to this idea, another way for solidification utilizing the large dissolving ability of the deep sea (more than 5 % weight)[6] has been proposed[7]. Thus the measures for CO_2 solidification in the deep sea can be classified into the following two measures, that is, hydration between CO_2 and sea water and non-hydration where insoluble carbonates are created as a result of neutralizing reaction with ions of alkaline-earth metals such as Ca^{2+} and Mg^{2+} after dissolution. In this study, focussing on these two measures, the characteristics and unsolved problems of each method are arranged from the results of the basic experiment.

2. Method Of Experiment

Figure 1 shows the test rig to simulate the discharge of CO_2 into the deep sea. This test rig consists mainly of a vertical tube of which inner diameter, height and volume are 50mm, 2m and 0.9 liter respectively. Its charac-

teristics are highest permitted pressure of 7 MPa (equivalent to the deep sea of about 700 m below surface), continuous injection of CO_2 by self-pressurization, temperature control by the cooling tube, observation with naked eyes and a video camera through peep windows and so forth. Following the purpose of this study, the figure and stability at the creation of hydrate were examined for the hydration, and the upward velocity of single CO_2 droplet and dissolution rate for non-hydration. Tap water and sea water from the sea surface were used for comparison.

3. Results And Discussions

No clear different influences on the hydration between tap water and sea water were measured in this experiment. The results and remained subjects to be solved for each method are as follows.

3.1 Hydration

Since the authors were not aware at August 1990 that CO_2 may turn into the hydrate under the condition of the deep sea , the experiment was begun bearing in mind the dissolution process of CO_2 droplets into water at high pressures, that is, non-hydration. Photo 1 displays an outlook of CO_2 droplets passing through the interface between water(lower side) and liquid CO_2. Although every droplet should disappear in liquid CO_2, some droplets can be seen. We felt rather difficulties why such phenomenon like this occurs only below about 5 °C. A newspaper reported on September 3 that CO_2 turns into the hydrate at certain condition[8]. This information gave us the interpretation to above mysterious phenomenon that CO_2 droplets in Photo 1 are coated with thin hydrate which enables them to be seen even in liquid CO_2.

Then the condition of hydration was roughly examined and the same

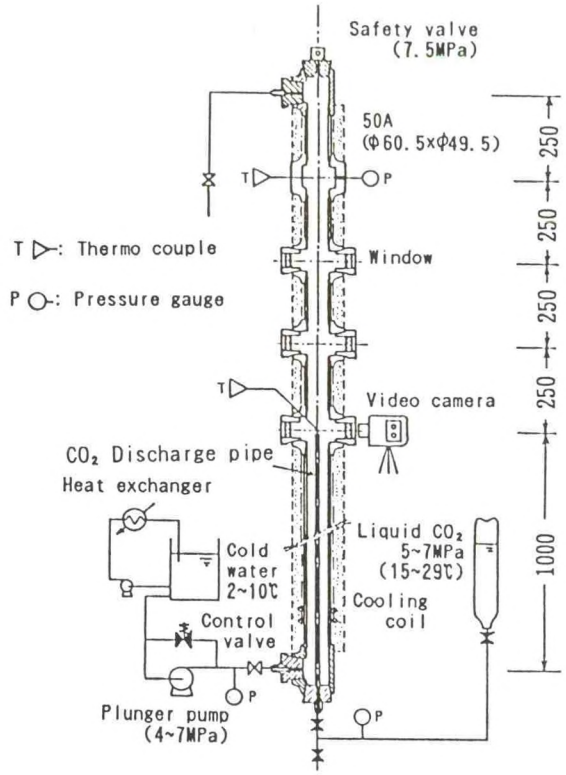


Fig.1 Simulation Test Rig for Discharge of Liquid CO_2 into the Deep Sea.

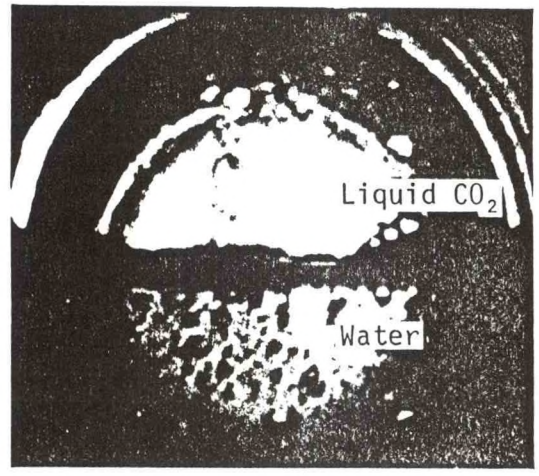


Photo 1.
Passage of CO_2 Droplets Coated with Thin Hydrate through Water-CO_2 Interface.

results as the above report was obtained. Photo 2 displays, however, that the figures of hydrate creation are strongly dependent

on the way of CO_2 insertion into pressurized water. When liquid CO_2 is introduced through sintered porous metal, hydration advances deeply into liquid CO_2 and the hydrate looks like snow (Photo (a)) and sometimes the discharge of CO_2 was prevented by choking of passages. Whereas in case of discharge from a pipe with 10mm of diameter, the hydrate created on the surface of liquid CO_2 is so thin that it appears like a chimney (Picture (b)) or like a bunch of grapes (Picture (c)). It was also cleared that the hydrate does not dissolve within several minutes equivalent to time duration for CO_2 droplet to dissolve into pressurized water. Further hydration into liquid CO_2 was not observed even when the condition for hydration attains, because the hydrate is a kind of chemical compound, which is one of large differences from phase changes. Although the specific gravity of hydrate is said to be 1.1[8], CO_2 droplets covered with hydrate go up in water, since the specific gravity of liquid CO_2 is around 0.9 at 5 MPa. The precise condition of hydrate decomposition has not been cleared yet, but CO_2 droplets covered with hydrate may vaporize when they reach the depth where the liquidizing condition of CO_2 breaks. Figure 2 shows the specific gravities of liquid CO_2 and sea water in the deep sea.

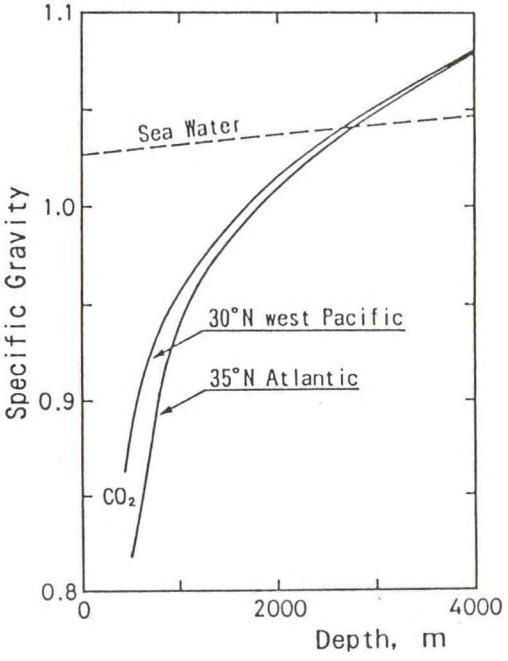
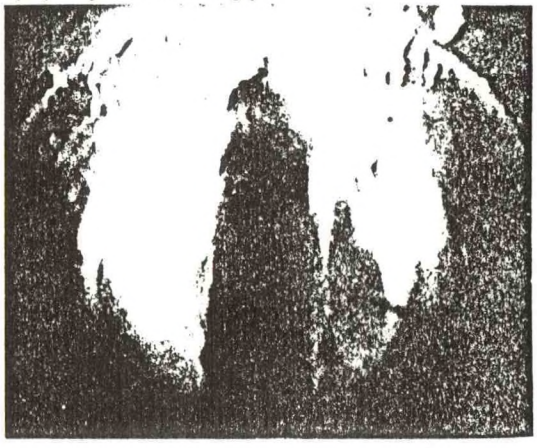


Fig.2 Specific Gravities of Liquid CO_2 and Sea Water.

(a) Snow Type



(b) Cylinder Type



(c) Grape Type

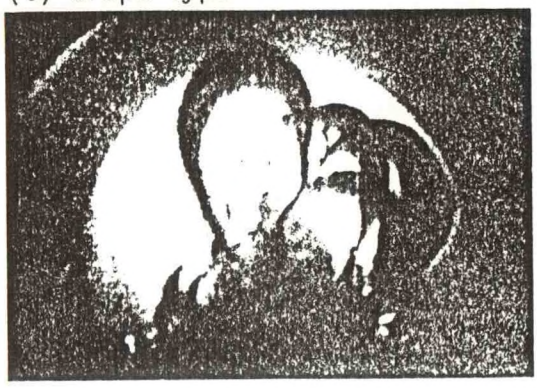


Photo 2. Variety of Hydratation.

The former becomes larger than the latter at the depth over a certain value of about 2,750 m which varies a bit in different regions.

From above discussions, the solidification of CO_2 by hydration is effective when liquid CO_2 is discharged in deeper seas than the above certain depth or when clusters of perfect hydrate are discharged into the deep sea where the condition not to decompose the hydrate satisfies. In this case, the following subjects have to enough be cleared and considered;

(1) reaction heat at hydration,
(2) countermeasures against the choking of passages for CO_2,
(3) apprehension of covering the bottom of the deep sea with unknown substance hydrate [9], and
(4) economic assessment comparing non-hydration discussed later.

3.2 Non-hydration

Figure 3 shows the state diagram of CO_2 and the vertical temperature distribution in the typical locations of two oceans[10]. The sub-deep sea where CO_2 is liquidized spreads out in the depth of 450 to 700 m for west Pacific of 30°N latitude and 550 to 1300 m for Atlantic of 35°N. Straight solid line ① and dotted line ② in Figure 4 are the theoretical terminal velocities for a small solid sphere and a droplet, respectively[11]. The rising velocity of single CO_2 droplet in the sea water at 5 MPa and temperature of 6°C seems to be near ①.

Next, let us examine the dissolving process of a single CO_2 droplet in the sea water. Here we assume that CO_2 concentration in the water is far lower than the saturated condition and the dissolving rate across a unit interface area of droplet is constant. After some algebraic arrangement, we get the simple relation that

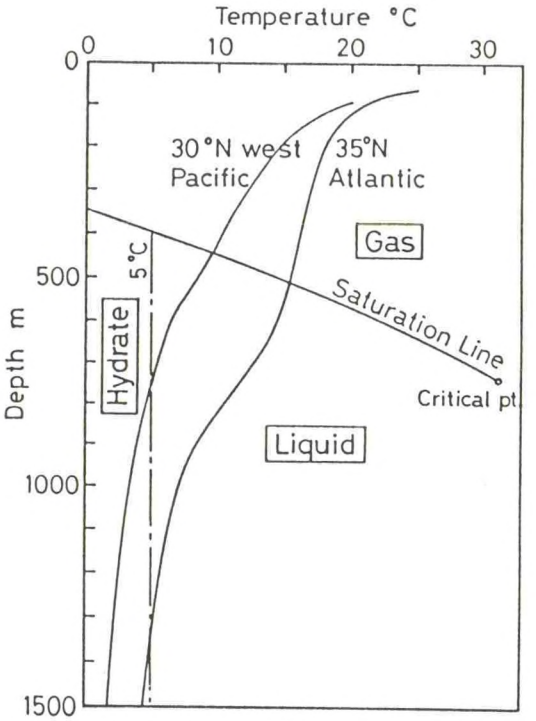


Fig.3 Vertical Temperature Distribution and State Diagram of CO_2.

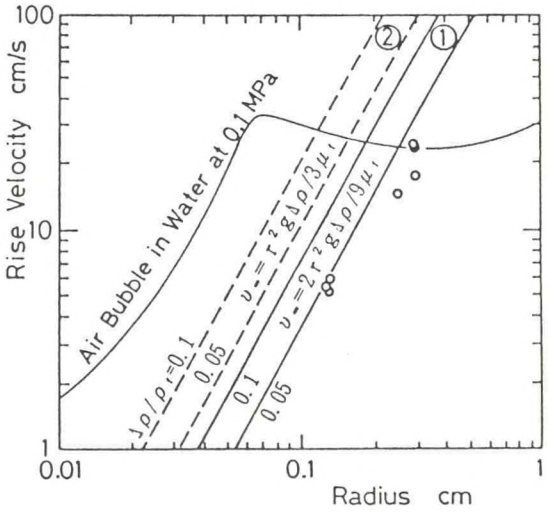


Fig.4 Rising Velocity of a CO_2 Droplet.

the diameter of droplet decreases straight with lapse of time. Photo 3 shows the shrinking process of a CO_2 droplet attached a horizontal pipe. The data shown in Figure 5 proves above assumption and the proportionality constant

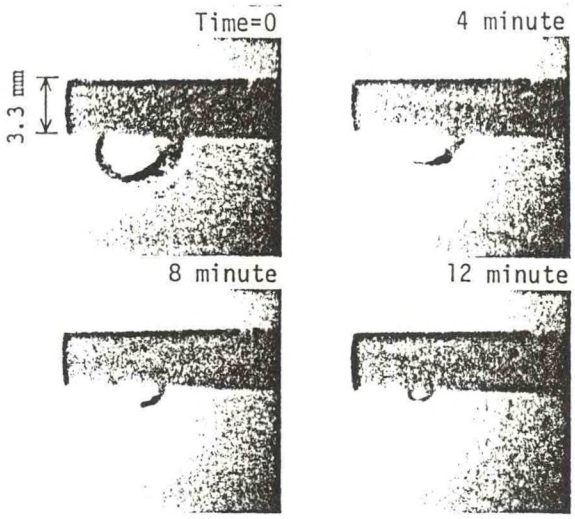


Photo 3. Dissolving Process of a CO_2 Droplet.

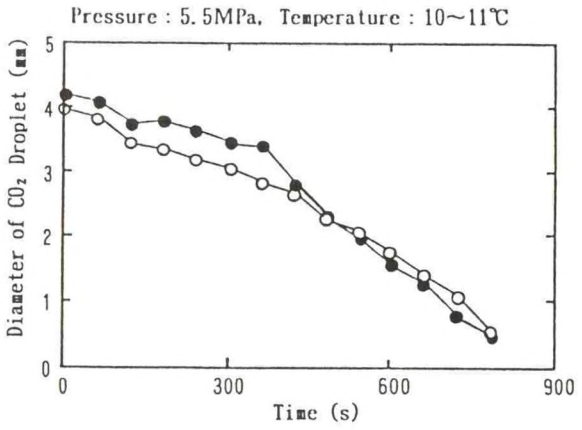


Fig.5 Shrinking Process of a CO_2 Droplet.

is evaluated to be about $5X10^{-6}$ m/s. Using this value, the diameter of droplet which disappears just at 100m ascending is estimated to be 3.7 mm. Since both the rising distance and the mass of a droplet are of proportion to third power of the diameter, the dissolution rate during the time that single droplet rises an unit distance is constant and independent of its diameter. That is, CO_2 droplets rise in the sub-deep sea with dissolving homogeneously.

Figure 6 shows a conceptual example of marine CO_2 discharge base applying the principle of non-hydration in which liquid CO_2 collected from a power station of 1,000 Mw (about 300 kg/s) is discharged into the sea deeper than 600 m. The concentration of CO_2 around dissolving region does not exceed 1/10 of the saturated value if the current is 1 cm/s.

Above discussions show the possibility to realize the application of the non-hydration to CO_2 treatment in the sub-deep sea. There still remain the following subjects not clarified in this experiment, however.

(1) to elucidate the distribution of pH (hydrogen exponent) and the process that dissolved CO_2 turns into the carbonate.

(2) to evaluate how the convection induced by the ascending movement of CO_2 droplets and the small density difference effects to the environment of the sub-deep sea.

(3) to estimate the largest diameter of CO_2 droplet to dissolve before approaching vaporization depth when liquidized CO_2 is

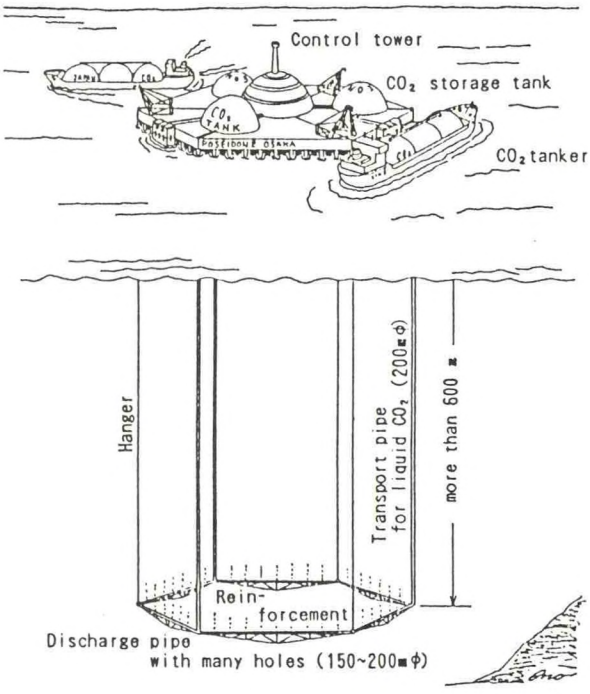


Fig.6 Example of the Marine CO_2 Discharge Base.

discharged at the sub-deep sea where no hydration occurs.

(4) Since CO_2 in the storage tank on a marine base will be a few tens degree below zero to keep liquid state, CO_2 may be discharged at such low temperature, if no heat is transferred from sea water during the time of transport to the sub-deep sea. In this case, it has to be made clear whether only hydrate, only ice or both are created on the surface of CO_2 droplets. And if it becomes experimentally clear that dissolution of CO_2 into sea water is difficult in the discharge at such low temperatures, an appropriate method for heat exchange between CO_2 and the sea water before discharge will have to be devised in order that its surface is not covered with ice. Figure 7 shows above two conditions of CO_2 discharge into 600 m deep sea, combining the diagram of specific gravity of liquid CO_2. A stands for the initial condition of CO_2 before its transport to the sub-deep sea, B_0 is the discharge point for the case of no heat exchange and B_1(or B_2) is that for the case of heat exchange added.

4. Conclusions

Basing on the data obtained in the simulation experiment for the solidification of CO_2 through damping into the deep sea, the characteristics and the unsolved subjects of the hydration given much attention recently and the carbonating seemed to be almost forgotten were arranged.

Since thin and insoluble hydrate is apt to be created on the surface of liquid CO_2, and since the specific gravity of liquid CO_2 does not exceed that of sea water in the region shallower than some 2,750 m, the hydration might be

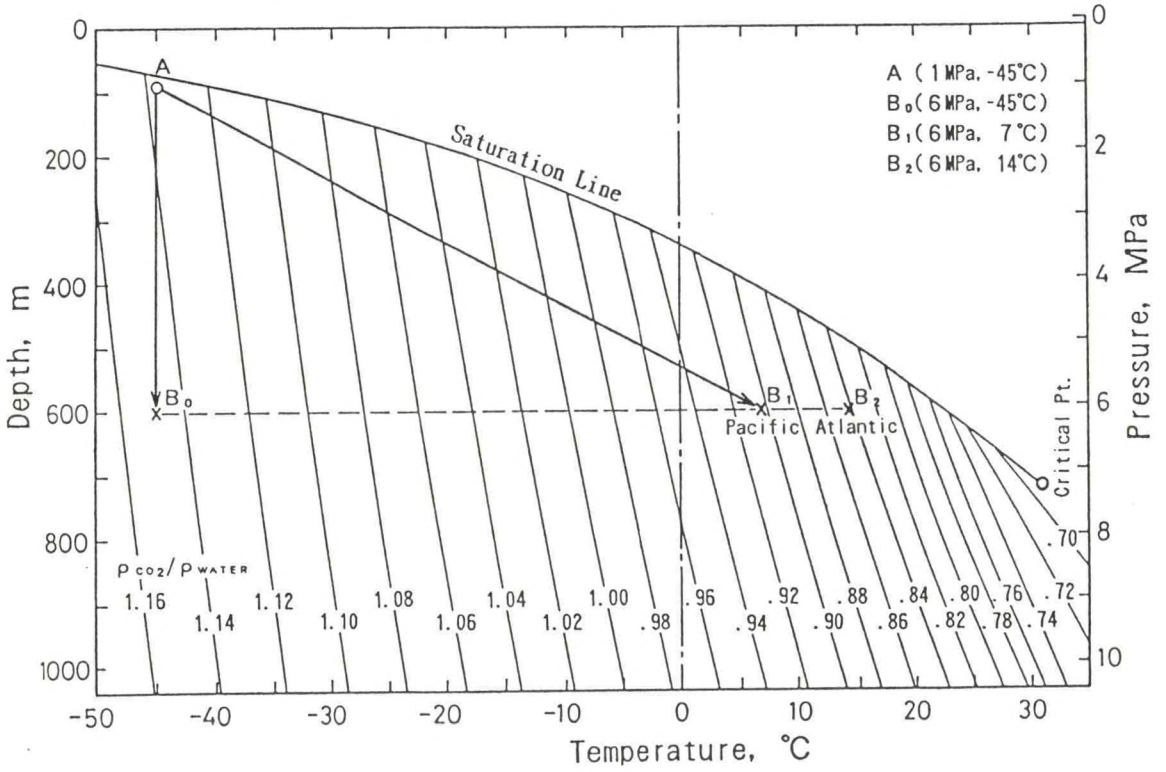


Fig.7 Specific Gravity of CO_2 during Discharge to 600 m Deep Sea.

ineffective to discharge CO_2 into the deep sea shallower than the critical depth. This fact gives a large restriction to seek favorable locations for the hydration. Moreover, it is also needed to evaluate how the hydrate influences the environment of the deep sea after the elucidation of its behavior.

The non-hydration aims to turn the dissolved CO_2 into the insoluble carbonate utilizing the high dissolution ability of the sub-deep sea ranging from 450 to 700m. Since this method,of which possibility was proved in this basic experiment, is to promote merely the natural process occurring in the sub-deep sea, it seems to be superior in the angle of economy and environment. There remain several subjects still unsolved, however; for example, influences of the convection induced by the rising movement of CO_2 droplets and small density differences on the environment, the process for dissolved CO_2 to turn into the insoluble carbonate, discharge of liquid CO_2 colder than the sea water, and so on.

Since the study on the behavior of CO_2 in the circumstances of the deep sea from the engineering viewpoint has just seen its dawn, we have sometimes met unexpected phenomena up to this time. It is crucially important to clarify the unsolved subjects one by one through experiment as much as possible. And any promising method should finally be confirmed by the experiment conducted in the real deep sea.

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CARBON FIBER REINFORCED PLASTIC (CFRP) PRE-STRESSED CONCRETE

Takao Hirota*

I. Introduction

Utilization of fiber reinforced plastic (FRP) rod as a pre-stressed concrete tendon is considered to be effective to eliminate corrosion problem of marine concrete structures. Some of previous studies were made on glass fiber reinforced plastic (GFRP).

In this paper, the author and his group studied various FRP for the tendon materials. And the group selected the CFRP for the most suitable material for further study.

The reason for selecting the CFRP instead of the GFRP or the AFRP is partly because the CFRP has similar tensile strength and has similar modulus of elasticity as steel. The GFRP and the AFRP have smaller modulus of elasticity. The smaller modulus of elasticity has an advantage to maintain tensile stress even after some settlement of concrete or relaxation of the tendon. On the other hand, introduction work of prestressing force requires longer margin of elongation on the cable, which causes difficulty in the field operation particularly for longer span post tension structures. Moreover, if the modulus of elasticity is small, deflection of the actual structure will become large. Excessive deflection is not convenient when it is used for long span beams. The CFRP has more chemical stability and heat resistance compared to the GFRP and the AFRP.

In order to improve bonding strength in the concrete, a strand type CFRP has been developed and is called as CFCC (Carbon Fiber Composite Cable). The new CFCC rod has cleared various tests including physical strength, chemical and thermal resistance, fatigue and bonding characteristics in the concrete. The results of such tests are quite satisfactory. Actual application design for a pier deck structure is now under way.

Application of the CFCC for highway bridges and guide way for the linear motor car is also contemplated. Only snag for application of the CFCC is its relative high cost. As soon as use of the CFCC increases, however, the cost to produce the CFCC will be reduced similar to many other newly developed materials.

II. Characteristics of fibers

In order to utilize the CFRP as the material for prestressed concrete tendon, the nature and the characters of the CFRP have to be fully examined. The CFRP is made of

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Table 1. Characteristics of various fibers.

Name	Carbon			Aramid					Glass
material	coal pitch	PAN	PAN	P.P.T.amid		C.P.P. O.P.T.	n.a	n.a.	E Glass
filament size( )	9~ 14	7	7	13	13	12	n.a	12	13
density (g/cm3)	1.8~ 2.2	1.77	1.77	1.44	1.44	1.39	n.a	1.39	2.54
tensile strength (kg/mm2)	250~ 350	370	350	370	280	>310	164	310	350
elastic modulus (kg/mm2)	18~ 80 x 1000	24 x 1000	24 x 1000	13 x 1000	6 x 1000	7.1 x 1000	7.9x 1000	7.1x 1000	7.4 x 1000
ultimate elon-gation %	0.4 ~ 1.5	1.52	1.3	2.9	4.0	4.4	2.4	4.4	3.4

carbon fibers and the matrix resin which combines fibers into a solid rod.

The characteristics of various fibers used for the FRP are shown in the Table 1. As indicated in the table, the characteristics of a same fiber varies by its material and manufacturers.

The Figure 1 indicates relations between stress and strain for various fibers.

Fibers are difficult materials for handling by themselves. To use as a tendon, proper treatment for these fibers is necessary. When the fibers are consolidated or bound into a rod form, equal distribution of stress for each fiber is essential. If the stress for each fiber is not evenly distributed, the strength of the rod will be reduced. To eliminate this uneven distribution of stress, a special technique to consolidate fibers is necessary. In practice, the fibers are combined with resin while equal tension is given to all the fibers.

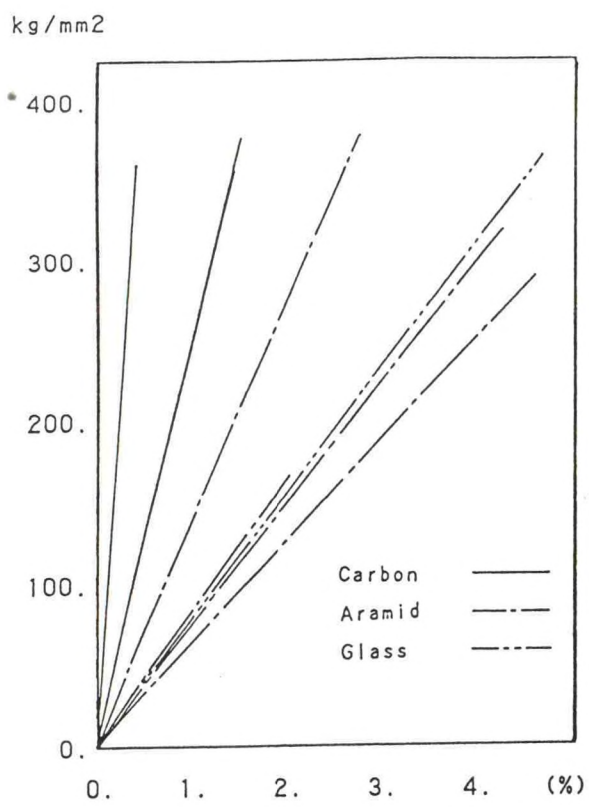

Figure 1, Stress & Strain curve of various fibers.

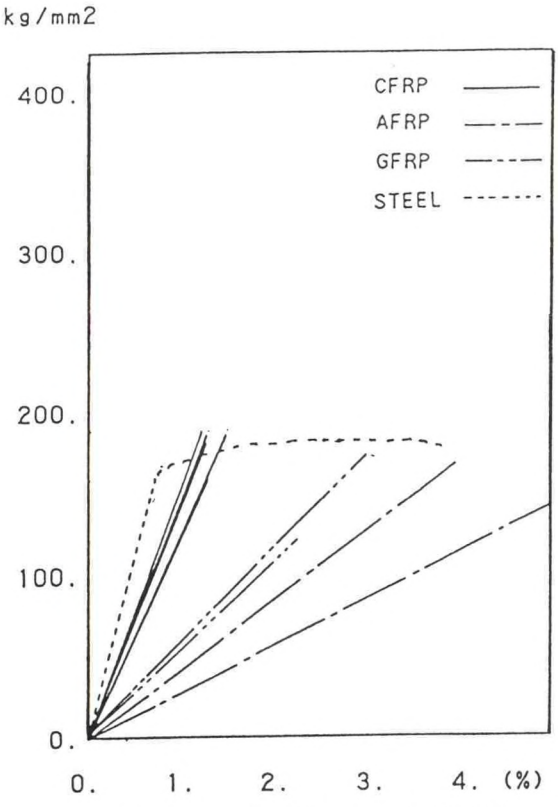

Figure 2, Stress & Strain curve of variou rods.

III. Characteristics of FRP rods

The characteristics of various FRP rods are shown in the Table 2. Similar to the characteristics of fibers, the characteristics of rods vary according to their materials and manufacturers.

Relations between stress and strain for various rods are shown in the Figure 2.

Unlike steel, all the FRP rods have no yielding points and stress and strain curves are straight until they reach to their breaking points.

The FRP rod has usually diameter of no more than 8 mm. Because if the diameter exceeds a certain level, peripheral area become insufficient to deliver sufficient stress of the rod. The strand type, however, has sufficient peripheral area so that the maximum diameter can be increased to at least 40mm which can hold 109,300kg of breaking strength.

Low specific gravity of the FRP is one of the advantages other than corrosion resistance. It reduces not only whole weight of the structure but also facilitate handling of materials during construction.

Table 2. Characteristics of various FRP rods.

	CFRP					AFRP		GFRP		STEEL
Type or form	Rod		Strand (CFCC)	Rod		Rod		Rod		PC Rod
d(mm)	7.9	1.5~ 6.0	5.0~ 40.0	3.0	7.98	6.0	6.03	9.0	7.98	8
A(mm2)	49.0	1.5~ 22.4	10.1~ 85.3	7.1	50.0	28.3	28.6	63.6	50.0	50.3
matrix	Epoxy			Poli-ester	Vinil ester	Vinil ester	Poli-ester	Vinil ester		
Fiber/A (%)	65			63	65	65	68	64	73	
Specific Gravity	1.57	1.5	1.5	1.55	1.57	1.28	1.32	2.05	2.16	7.85
Tensile Strength (kg/mm2)	184	170~ 180	160~ 170	150	180	160	170	115	165	150
Elastic Modulus (kg/mm2)	15000	14000	14000	12000	12500	4100	2750	5300	5600	20400
Ultimate Elon-gation %	1.21	1.5	1.5	1.25	1.2	3.8	2.8	2.2	2.7	>4.5
Manufac-turer	A	B	B	C	D	E	D	C	E	

IV. Chemical stability and relaxation tests

Chemical stability tests were made for those materials and disclosed that the CFRP has almost no change in its strength after exposure in the severe conditions both high temperature as well as low and heigh ph value solution.

Relaxation loss of CFRP is less

than steel rod. And relaxation loss of CFCC is as low as less than one half of steel strand cable.

V. Strand type CFRP rod (CFCC)

The CFRP rod alone is stiff and smooth on the surface. If the diameter of the rod is large, the rod is far from flexible and which causes difficulty in application of curved tendon. Therefore, the solid CFRP rod is only practical with less than 8mm in diameter.

Smooth surface of the rod causes difficulty with bond in concrete and also at terminal grip fixtures. This tendency worsens at the increase of the rod diameter. Therefore, the diameter of a single rod should not be large. To eliminate or at least to reduce above mentioned difficulty, both flexibility and bonding strength, the surface of the rod have to be wrapped with poli-ester thread.

A strand type CFRP cable was developed by a wire rope manufacturer. And is called as CFCC. The CFCC is more flexible than the solid rod for the same diameter, thus making for easy handling. The strand type has wider surface area compared with that of the normal rod. Thus it can carry more bonding stress in the concrete.

The strand type cable has also thread wrapping on the surface of the individual element. The wrapping is done at the time of manufacturing and fixed with the same matrix. The wrapping gives not only more surface friction for better grip but also increases strength against lateral pressure to the rod or the cable.

VI. Bonding Strength

Bonding strength of the CFCC rods in the concrete were tested and were proved that the bonding strength were sufficient. Bonding strength of the CFCC was greater than that of steel strand or rod.

Oveerlap of the CFCC can be treated almost similar to the case of deformed steel bar.

VII. Fatigue test

Fatigue tests were made for the CFCC. The results of the tests are shown in the Figure 3. The fatigue strengths are mainely affected by the maximum stress of the reciprocated load and less affected by the stress amplitude. Within a level of the maximum stress, fatigue resistance is sufficient regardless with their stress amplitude.

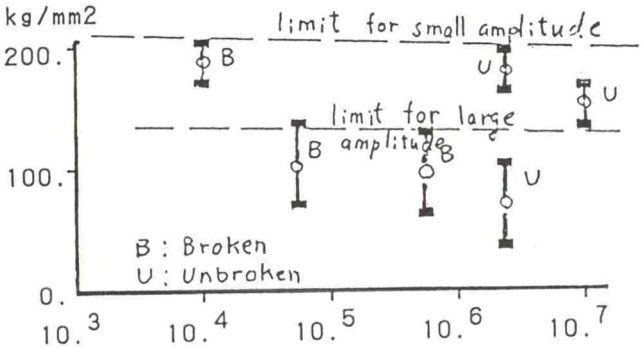

Fig. 3 Fatigue strength of CFCC

VIII. Loading tests for pre-tension beams and unbond post tension beams.

Immediate application of the CFCC to a port structure will be suitable for pre-stressed concrete pier deck. A conventional pre-stressed concrete beam deck is commonly used in many ports in Japan. Such structures are apt to be exposed to salinity which causes corrosion of the steel tendon. The CFRP pre-stressed concrete beam can prevent such corrosion problem and thus expand its life span.

To establish such structure design, both pre-tension and post-tension beam loading test should be made. The pre-tension beam loading test is to examine the normal strength of a deck beam for the deck load. And the post-tension beam test is mainly to check lateral strength of such deck beams combined with the lateral bond cable which forms a sort of a unbond post-tension block beam.

IX. Terminal fixtures

Usually, terminal fixtures are necessary for post tension pre-stressed concrete tendon. In case of non ferrous tendon, steel terminal fixture is not suitable by several reasons. First of all, the steel will tend to be corroded under the circumstances where FRP tendon is required. Moreover, the conventional fixture designed for the steel tendon is not suitable for the FRP because the FRP rod has comparatively less compressive and shearing strength and cause failure at the terminal.

Consequently, several type of terminal fixtures have been developed. For the CFCC post tension cable, grouting in the sheath seems to be sufficient to hold post tension stress in ordinary cases due to its good bonding characteristics in the concrete.

X. Miscellaneous accessories

Even if the main tendon become non corrosive materials, other material and accessories such as stirrups, sheath tubes require protection. Stirrups made of CFRP, GFRP and carbon and glass hybrid FRP have been manufactured by several makers. They have several sizes and types. They are formed into any shape in the factory. Most of them, except for few types, cannot be bend in the site.

XI. Application of FRP to structures

While basic study for the CFRP (including CFCC) has been in progress, several trial structures in the field have already been constructed.

Three small span road bridges using the CFCC have been built in Japan. A new bridge is planned with the CFCC at a private road in Germany.

A pier deck design using the CFCC pre-tension beam and post-

tension lateral reinforcement is under way by the author's group. Upon completion of few more laboratory tests of reduced size element models, actual installation as a part of reconstruction of an old pier will be made.

The pre-stressed concrete guide way for the high speed linear motor car of the JR is also contemplated. The JR group has conducted fatigue tests of the CFCC beams and has proved their durability for over two million cycle of 60% load fatigue test.

XII. Conclusion

The CFRP has almost equal strength as high tension steel with slightly less modulus of elasticity. The CFRP has not only high chemical stability but also has smaller relaxation rate than steel. Its coefficient of thermal expansion is only $0.6 \times 10^{-6}/°C$, only 5% of PC strands.

Its durability for fatigue and weather exposure is, needless to say, already proved by application for airplane parts. Its non magnetic characteristics extend prospect for further use for the linear motor car project.

Therefore, the CFRP is best suited among various FRP rods.

A bare CFRP rod is, however, difficult material for handling because of its smooth surface and its relatively low shearing strength.

Development of the CFCC (carbon fiber composite cable) has solved most of the difficulties accompanied by the CFRP and opened promising future of its application.

Its corrosion resistant nature allows the assemble work or use of such material at the site where is exposed to the sea water or even under the water. Usually building work of floating marine structures requires dry-docks. If the structure is to be a large size, the required dock becomes also large scale. With this CFCC, a floating structure of any type and size can be joined while afloat in the water without using a dry dock. Because the joining cable work requires no water-proof consideration.

The CFCC may also be used for out-cable type pre-stressed concrete structure. Further more, its light weight allows design of longer span beams and other structures including cable supported bridges and suspension bridges.

DEVELOPMENT OF 3-DIMENSIONAL AUTOMATIC POSITION AND ATTITUDE CONTROL SYSTEM FOR ROV

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ABSTRACT

The tethered Remotely Operated Vehicle (ROV) has recently come to have the potential to tolerably perform as an underwater surveyor or a work vessel in the modest current.

It is, however, difficult to accurately control its position and attitude only by the operator's maneuver in the offshore current, because of its various motions caused by current, reaction of the manipurator, drag force of the tether cable, etc.; without any adequate automatic maneuvering control system, ROV cannot be put to practical use at an underwater work site.

Using the dynamic position control technique, KHI developed a precise 3-demensional automatic maneuvering control system which can greatly improve the capability of ROV.

This system was installed on the vehicle and was tested in the Osaka Bay in 1989. The results indicated its excellent performance in the automatic control including hovering and translation of position and attitude.

This paper reports on the system configuration of the maneuvering control system, general arrangement of the vehicle, and some of the test results.

MANEUVERING CONTROL SYSTEM

Fig. 1 shows the system configuration.

Fig. 2 gives a block diagram of the automatic maneuvering control system.

The control system is based on feedback control, as well as feedfoward control applied to attitude adjustment as shown in Fig. 2.

Maneuvering modes are as follows.

(1) Automatic Control Modes
(Closed loop position & attitude control)
(1-1) Automatic hovering mode
(1-2) Automatic translation mode

(2) Manual Override Mode
(Closed loop rate control; Joystick control mode combined with automatic hovering mode.)

(3) Manual Joystick Mode
(Open loop control; Customary mode provided for comparison with automatic control mode)

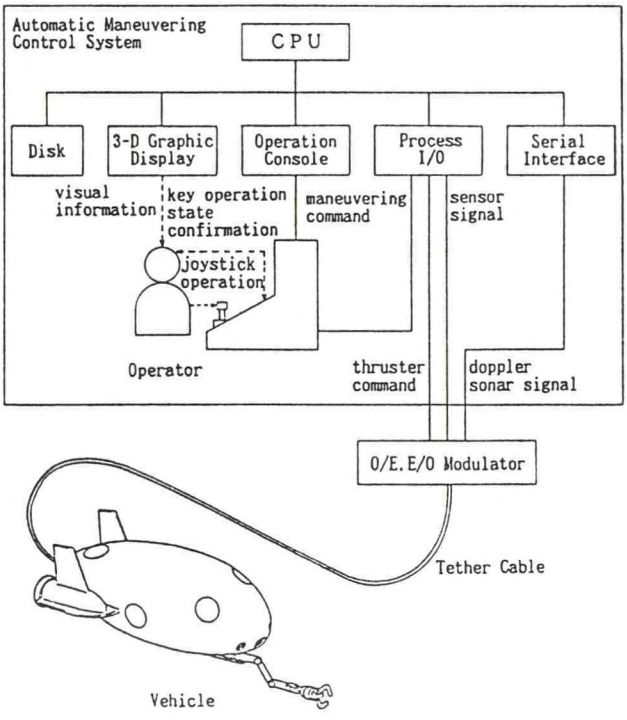


Fig. 1 System Configuration

A 3-dimensional color graphic display to give visual information to ROV's operator is also developed and arranged on the operator's console.

A photograph of the display is given in Fig. 3. It makes the operator imagine like he is just on board the vehicle.

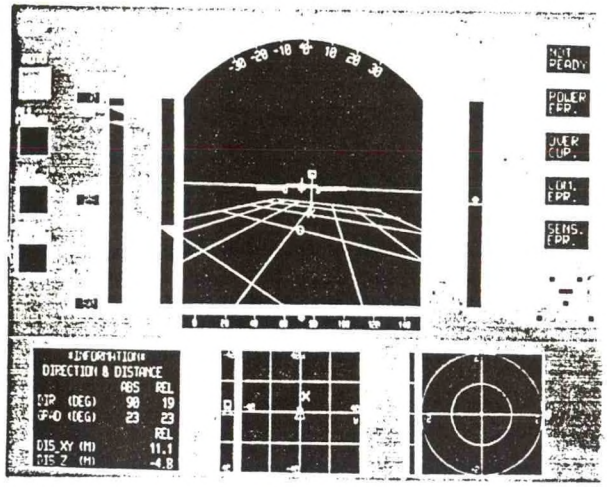


Fig. 3 Example of 3 Dimensional Graphic Display

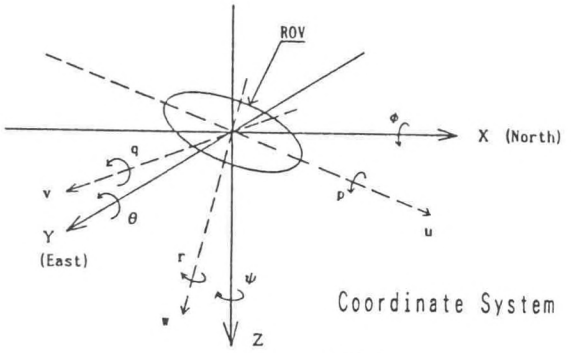
SENSORS AND THRUSTERS

Sensors for feedback control of position and attitude are as follows.

(1) Position (X, Y, Z) & Velocity (u, v, w)
3-axial doppler sonar: Position of vehicle is estimated by integration of velocity.

(2) Attitude (ϕ, θ, ψ) & Angular Velocity (p, q, r)
3-axial rate gyro & gyrocompass

(3) Altitude (A) & Depth (D)
Altitude sonar & pressure sensor:
These are used as auxiliary sensors for doppler sonar Z-signal. Operator can select one of 3 signals (Z, A and D) from console.



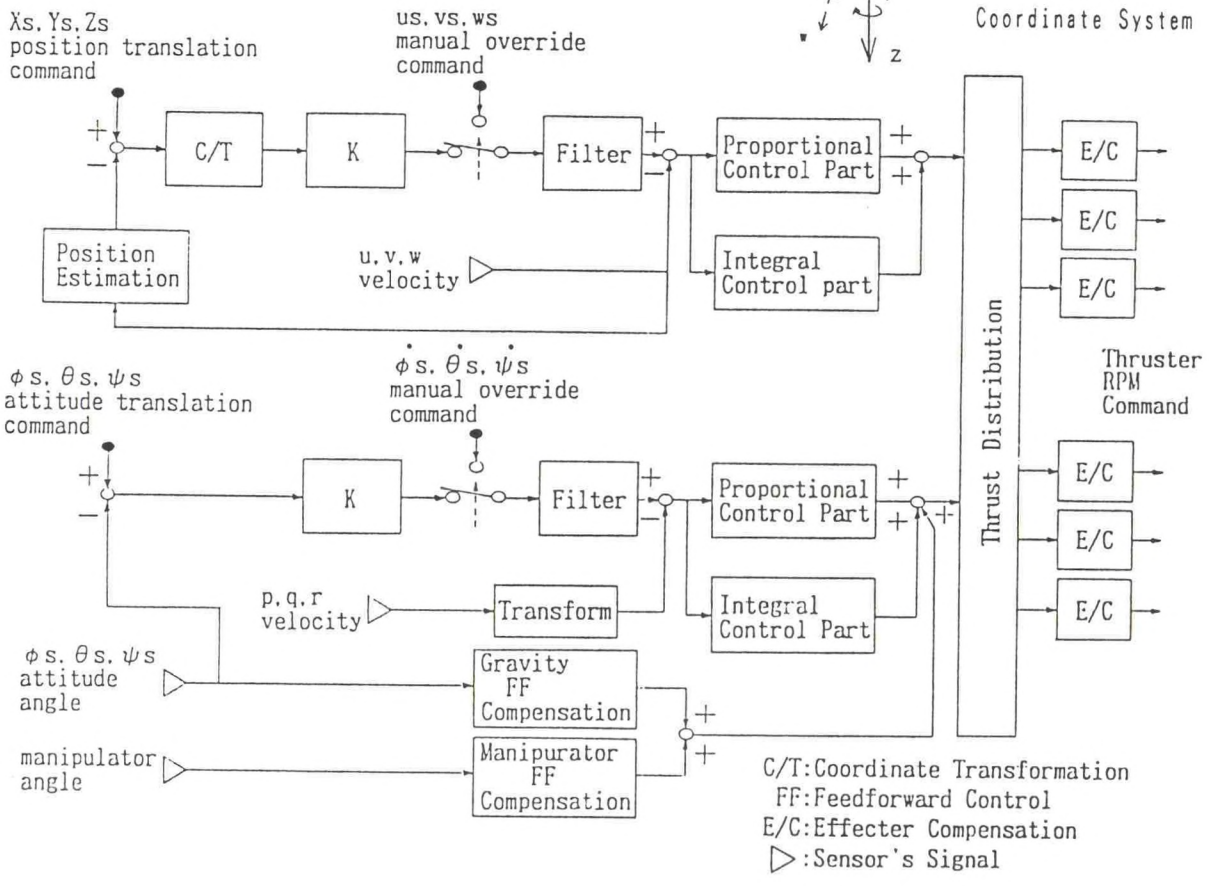


Fig. 2 Block Diagram of Automatic Maneuvering Control System

A small sized, hydraulic servo thruster is newly produced in this development. A hydraulic motor, an axial mechanicai seal, a servo valve and a tachometer are compactly arranged in a pressure -compensated case.

Fig. 4 shows this thruster.

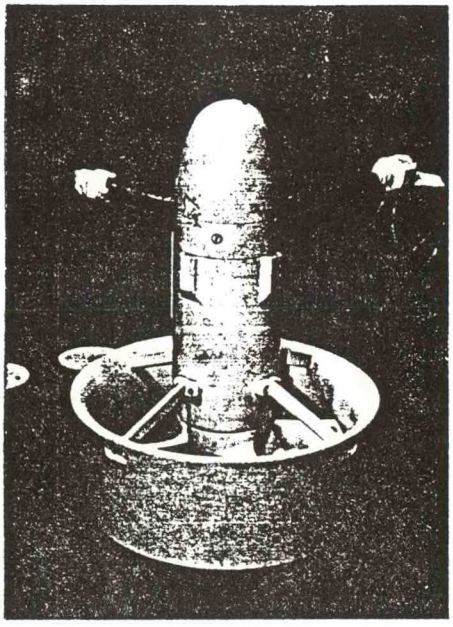


Fig. 4 Hydraulic Servo Thruster

VEHICLE

General specifications and arrangement of the tested vehicle are shown in Table 1, Fig. 5 and Fig. 6.

The body of the vehicle is covered by glass-fiber reinforced plastics board.

Table 1 Specifications of Vehicle

Items	Specification
Exterior Dimensions	Length 2.7m Width 1.6m Height 1.6m
Weight	1.7tons in air -20kg in water
Propulsion	6 Hydraulic Thrusters 2 axial, 3 vertical, 1 lateral
Manipulator	4-motion
Hydraulic Power	18kw, 210kg/cm², 46ℓ/min.
Instrumentation	Doppler Sonar Gyrocompass & Attitude Sensor Altitude Sonar Depth Sensor TV Camera Underwater Lights
Tether Cable	Electro-optic Cable

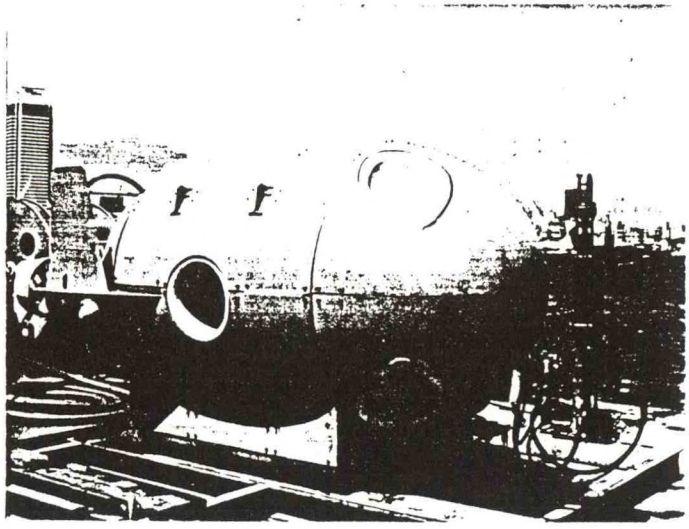


Fig. 5 Vehicle

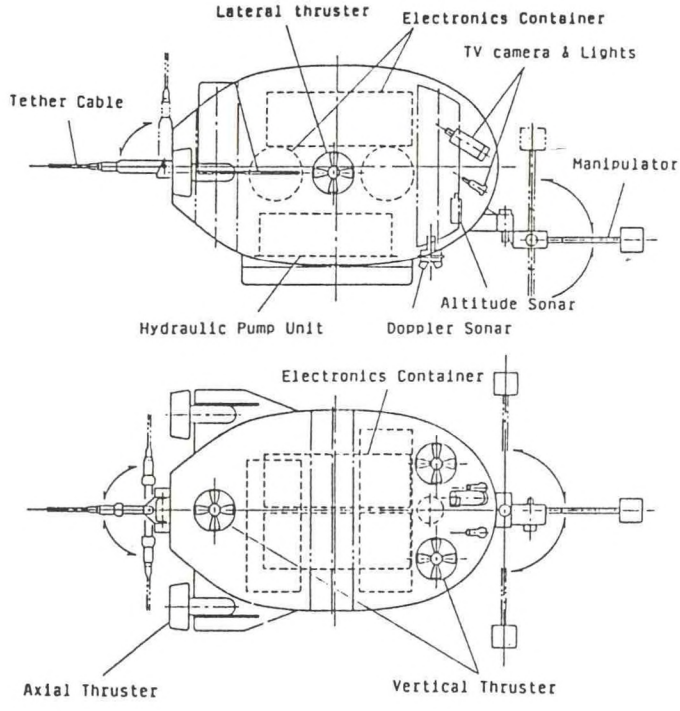


Fig. 6 General Arrangement of Vehicle

TEST RESULTS

A completed vehicle and an automatic maneuvering control system were combined and tested at the Osaka Bay in December 1988 to February 1989 (see Fig. 7).

Some of the test results are shown in Figs. 8, 9 and 10.

(1) Automatic Hovering Mode

Fig. 8 is a time chart of hovering performance in the manipulator operation with 30Kg·m moment of force.

It is seen that the automatic hovering mode can stabilize the vehicle like a subsea platform, while the customany manual joystick mode makes the vehicle unstable.

(2) Automatic Translation Mode

Fig. 9 is a time chart and locus of translation performance.

The motion of the vehicle is very smooth and efficient in the automatic translation mode, but the vehicle moves in an undesirable and unstable direction in the manual joystick mode.

(3) Manual Override Mode

Fig. 10 is a time chart of manual override control, which shows the availability of this mode.

In this case, only Z-axis is in the manual override mode, and the other axes are in the automatic hovering mode.

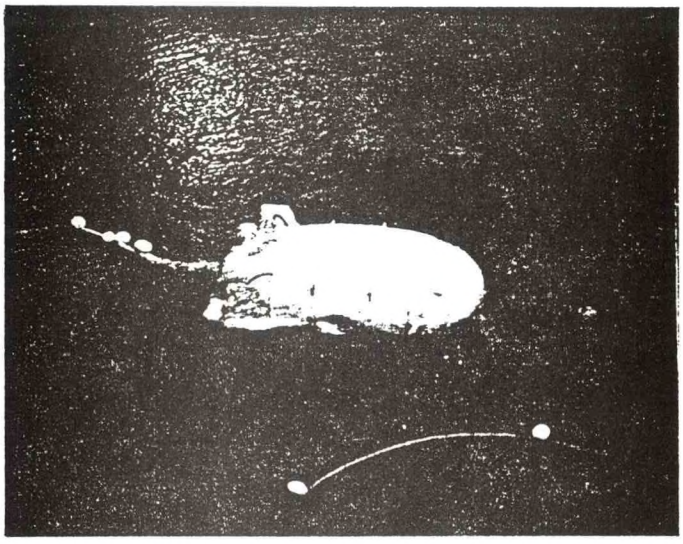


Fig. 7 Sea Trial

The conclusions from the test results are as follows.

(1) The maneuvering of automatic hovering mode and automatic translation mode are very precise and efficient in comparison with the manual joystick mode.
The offset of the automatic hovering control is very small; that is, no more than ±0. 1m in position and 0. 5degree in attitude.

(2) The manual override mode is useful in combination with the automatic hovering mode.

(3) The 3-demensional graphic display is very effective for operator's requirements on monitoring and maneuvering.

We are confident that this system will greatly improve the capability of ROV at an underwater work site.

ACKNOWLEDGEMENT

We wish to express our appreciation to the Ship and Ocean Foundation for their continued support.

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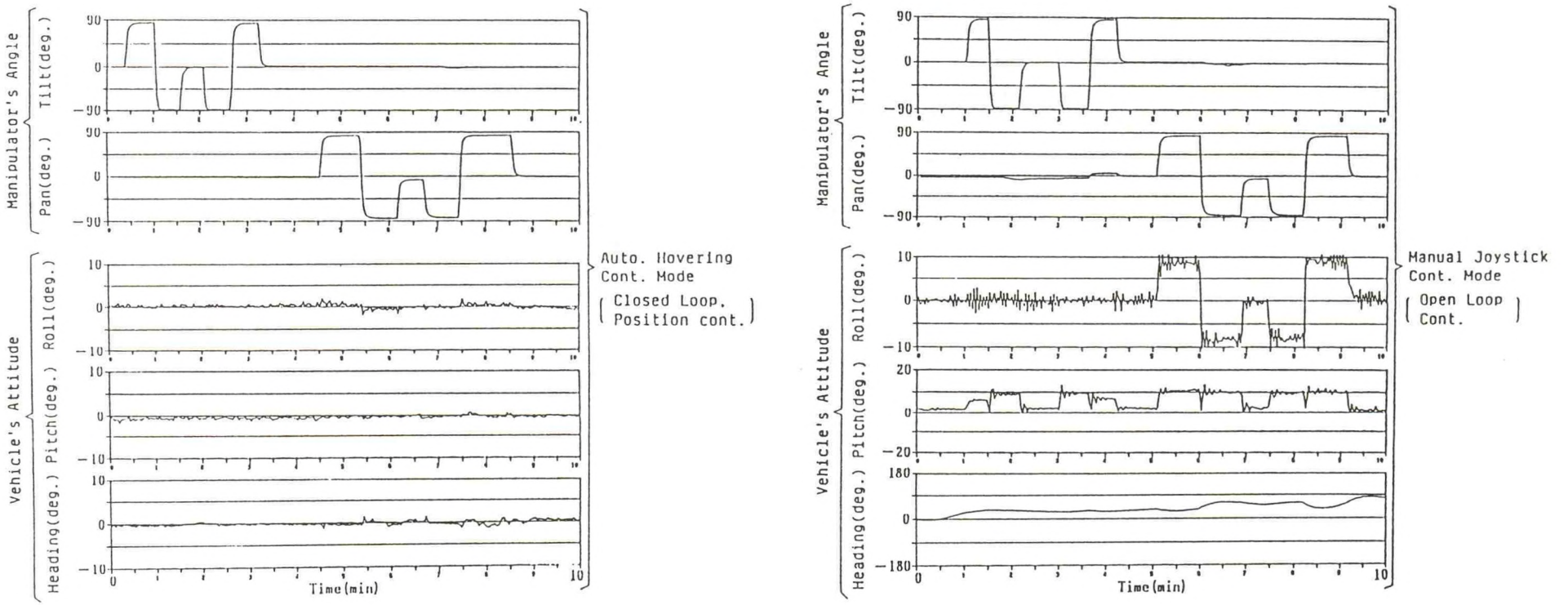
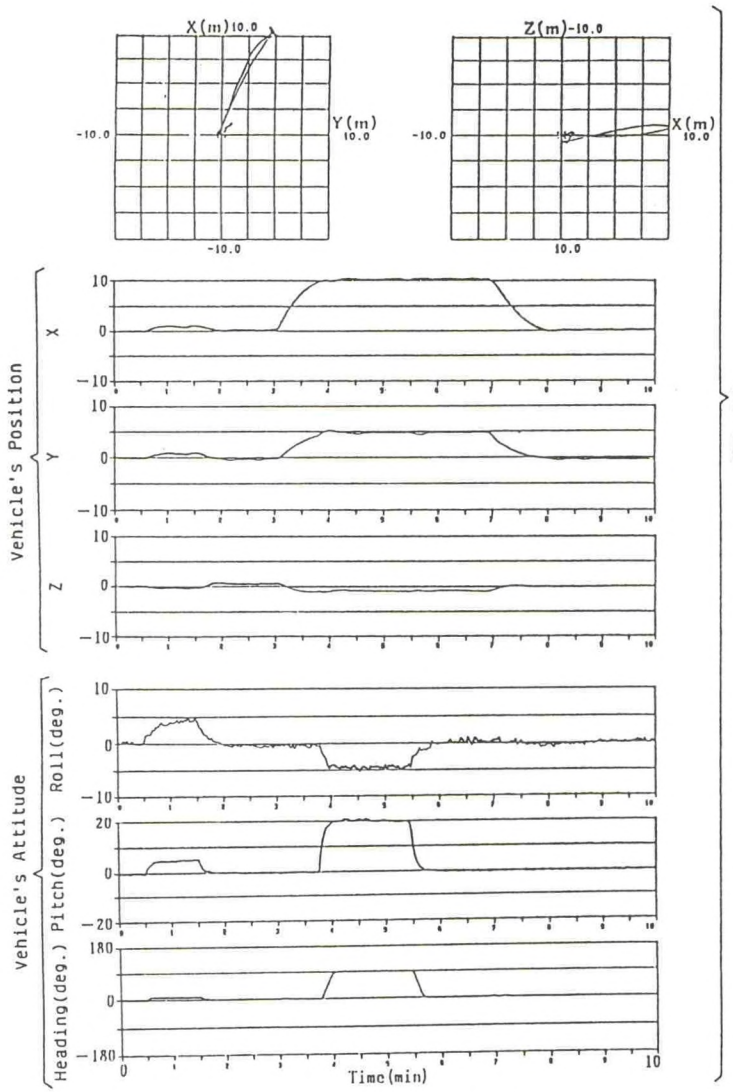
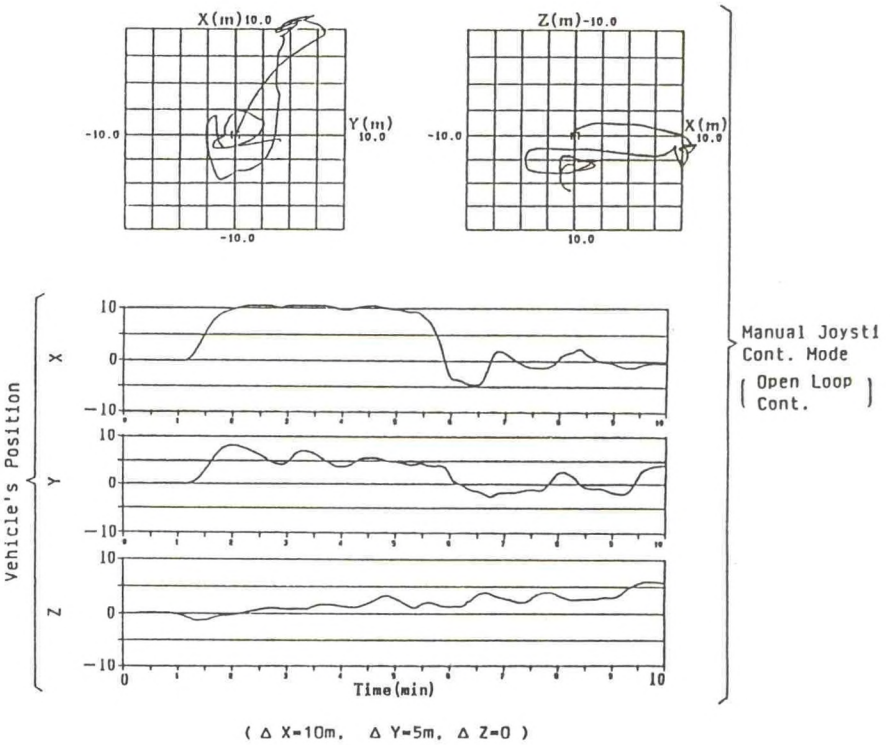


Fig. 8 Example of Test Results:
Performance in Automatic Hovering Mode
in Manipulator Operation



(Δ X=1.10m, Δ Y=1.5m, Δ Z=-0.5,-1m
Δ φ =4,-4deg, Δ θ =5.20deg, Δ ψ =10,90deg)



(Δ X=10m, Δ Y=5m, Δ Z=0)

Fig. 9 Example of Test Results:
Performance in Automatic Translation Mode

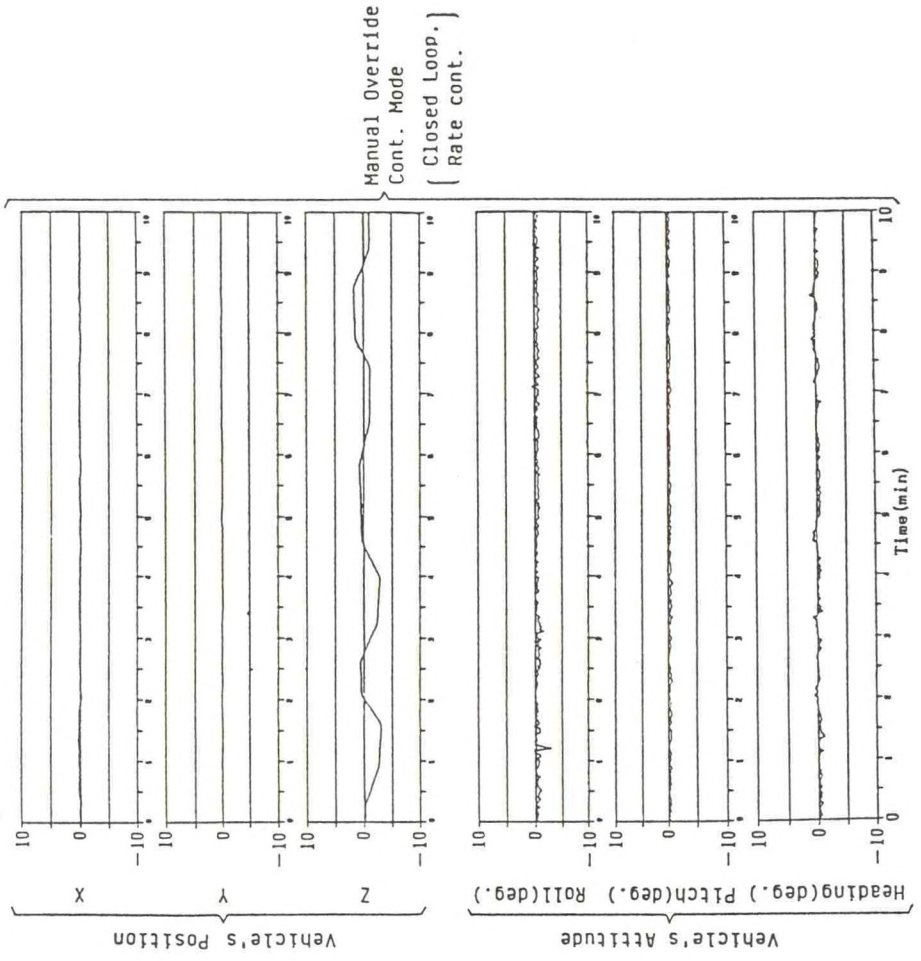


Fig. 10 Example of Test Results:
Performance in Z-Manual Override Mode

DEVELOPMENT OF ADVANCED SUBSEA ROBOT

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1.INTRODUCTION

Since 1984,the research and development of Advanced Robot Technology has been carried out in Japan.This R &D involves the nuclear power robot,subsea robot and disaster prevention robot.

This paper describes the subsea robot and mainly introduces the conceptual design of the total system and briefly describes the plan of the verification experiment.The subsea robot system is to support the offshore oil exploitation.The various elementary technologies have been developed and the conceptual design of a total system for the subsea robot was made taking these results into consideration in FY1987.

The advanced subsea robot which supports the offshore oil exploitation has been researched and developed according to the schedule under mentioned.

Underwater operations for support of offshore oil exploitation requires enormous amounts of time and labor because they are operated under severe environmental conditions unique to the ocean, such as darkness, water pressure,current, low temperature,and absence of oxygen. The production of offshore oil is carried out through a clearly defined process, involving drilling production wells,installing pipelines and platforms,and operating the platforms.At each of these stages,underwater support operations are executed over a broad range of areas.The most important tasks include: observation,inspection,checkup,cleaning of underwater equipment and structures,exchange, repair and recovering of parts and machines, and monitoring and support operations necessary for installing underwater facilities and machines.

Most of the underwater support operations have been conducted by the human diver system, however among these operations, at least, the following items may be replaced by the advanced robot:

1) Visual inspection

2) Cleaning work

3) Non-destructive test work

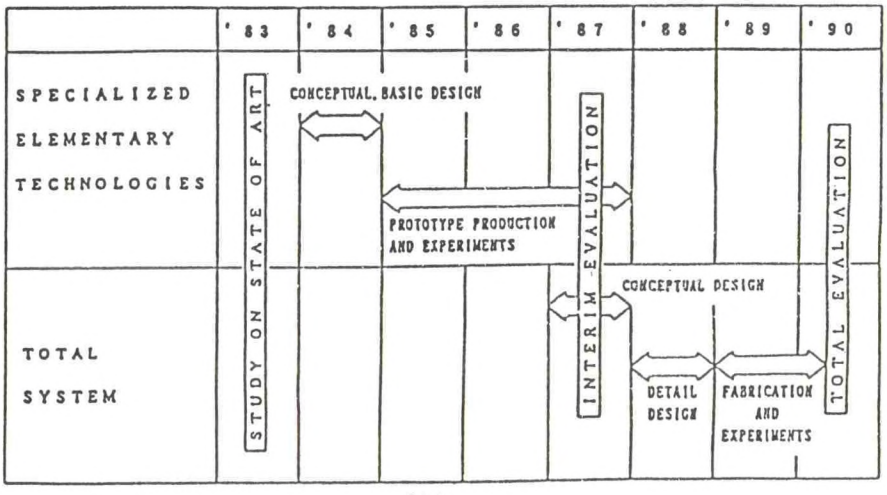

Fig1. R & D SCHEDULE

2. CONCEPTION OF THE SUBSEA ROBOT

Fig.2 Shows conceptual view of the total system of the subsea robot.

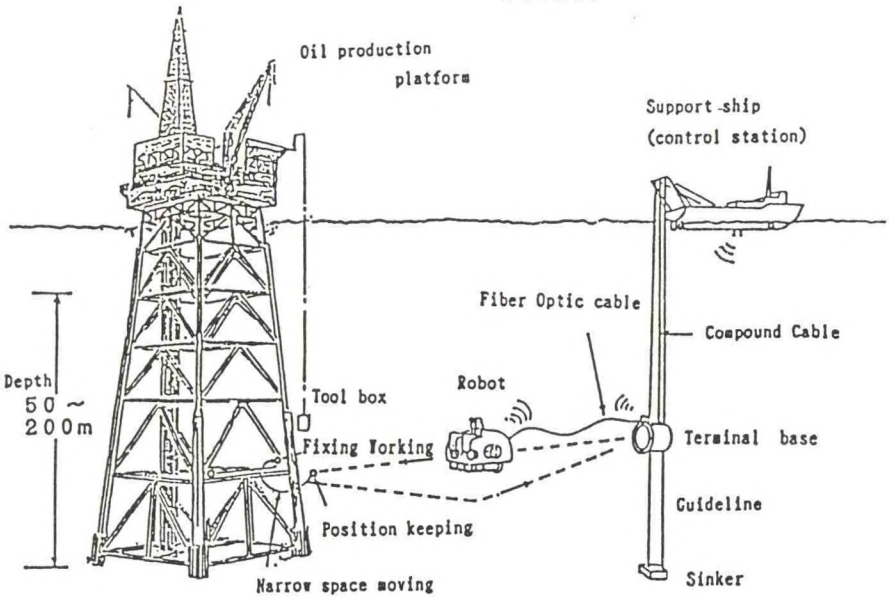

Fig. 2 TOTAL SYSTEM CONCEPTUAL VIEW

As operations of the subsea robot, the followings are expected, with a focus those operations concerned with the maintenance and inspection of nodes of the jacket type platforms, that require highly sophisticated functions. As things stand now, the work depth has been set mainly at 50 - 200 meters, with emphasis on practical application.

1) Visual inspection

Exterior inspection work. Precision inspection of the metal surface by the naked-eye after the marine growths clinging to the surface are removed.

2) Cleaning work

Work to remove clinging organisms with a cleaning tool. Work to clean up (with a tool) the surface of the structure (especially the welds) to facilitate non-destructive inspection.

3) Non-destructive inspection work

Ultrasonic test of damage (operation using ultrasonic prove)
Magnetic particle inspection (operation using MPI equipment work)
Work to measure the thickness of the members (operation using ultrasonic thickness gauge).

4) Simple maintenance work

Opening and closing the valves, replacing the anti-corrosion anodes, and installing and recovering of the beacon and transponder.

As for system design of the subsea robot, the following condition have been set up.

1) Basic conditions of ocean

Sea water depth : 50-200m
Tidal current : max.2Knot
Transparency : min.5m
Wave height : max.5m
Seawater temperature: 2°-30°C

2) Objected platform

Type : Jack type oil production platform
Fouled condition : Attached by barnacles, oysters etc of about 20mm
Working part: mainly cross points of legs and braces.

3.TOTAL SYSTEM OF THE ROBOT

The robot shall have both good remote controllability and autonomy to achive the above mentioned missions,under severe enviromental conditions.The robot shall be provided with batteries for it's power source which can be automatically charged at a launcher in the sea. Communications between the robot and the support ship shall be carried out by the optic data transmission system through optic fiber cable.The total system of the robot basically consists of the sub-systems such as "mobility","manipulation"and "perception",and these sub-systems are controlled by a supervisory computor.

Special features of the robot system are as follows;

1)Hard ware

Man-machine with a tele-existence display.
Variable vector propellers (VVP)
Manipulators with sensitive hand
Sea water hydraulic actuator
Acoustic imaging apparatus
Fiber optic gyroscope

2)Soft ware

Supervisory control including animation displays.
Motion control of the robot using VVPs
Co-operated control between attachment legs and VVPs
Hybrid position/force control with sway compensation for manipulation

Principal particulars of the robot system are as follows;

1)Robot body

Size:3.2m(L),2.7m(W),2.7m(H)
Weight:6.2ton(in air)

2)Mobility

Speed:3knots(in static water)
Plopulsion : 3-VVPs(170kgf each)
Attachment leg : 3-legs(800kgf each) Differential pressure method.

3)Manipulator

Construction: 2-working arms with 1-extension arm
Degree of freedom : 6 deg+grasp
No of finger : 3(muscle type)
Handling weight : 10kgf

4)Perception

Acoustic imaging system : 800KHZ,B mode and C mode. 0.5-50m range,±30° view
TV camera: Stereo type 2sets

5)Others

Power source: Silver oxide zinc batteries
Power unit:Sea water hydraulic pump and actuators

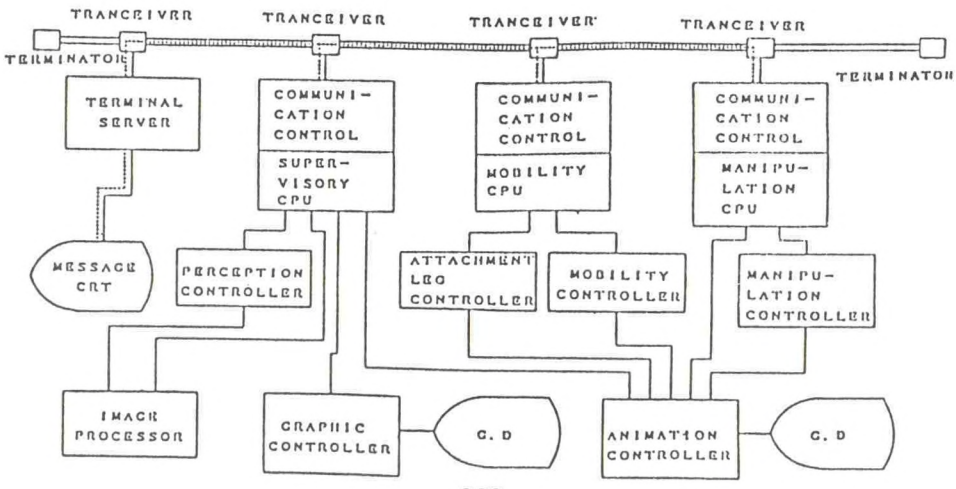

FIG.3 CONTROL NETWORK SYSTEM

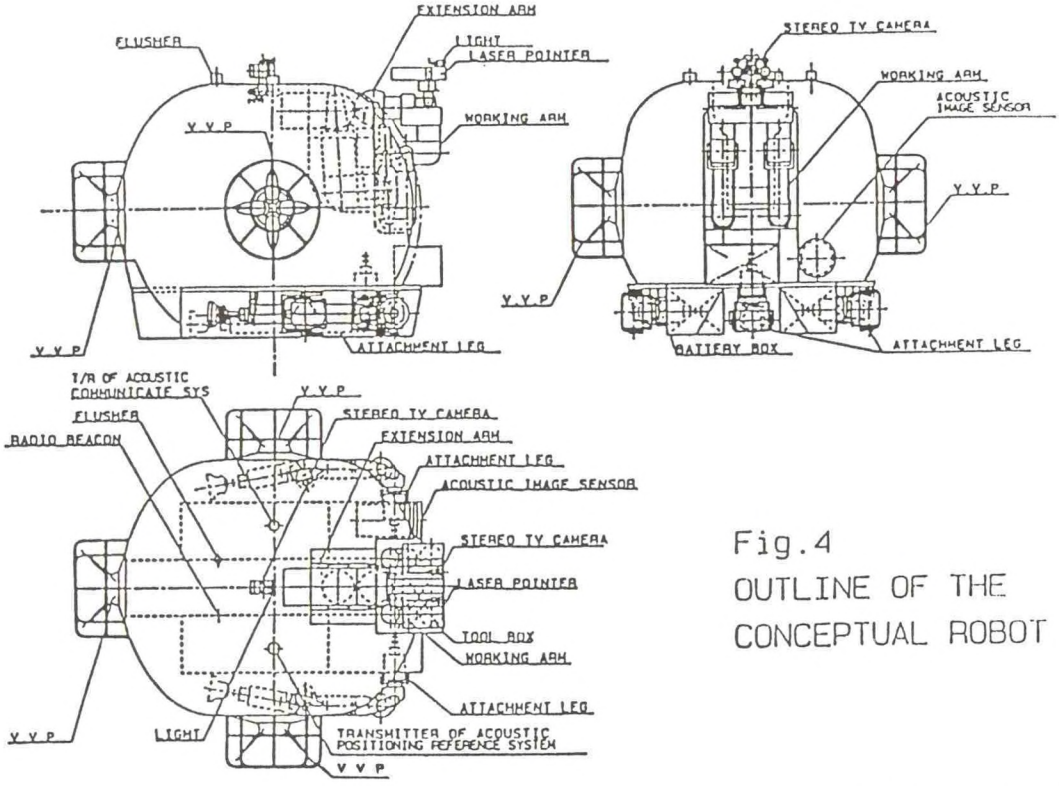

Fig.4
OUTLINE OF THE
CONCEPTUAL ROBOT

4.MOBILITY SUB-SYSTEM

To execute the required tasks,the robot should run to working sites,pass through legs and bracings of the complex structure, engage on subsea work, and return to the terminal base safely.Therefore,sophisticated motion controls are required for the robot.In order to achieve the maneuverability under these circumstances,we have developed the variable vector propeller (VVP) which can continuously generate any degree of thrust in any 3 - dimensional directions and the attachment leg which can extremely rise accuracy and efficiency of work in the sea.

1)Underwater running and position control

The robot automatically controls it's 3-dimentional motions for path following and position keeping in tidal current.These controls have been established by the force pre-compensated optimal control,the thrust distributed control taken with body form and fluid characterristic and verious sensors applied with kalman filter technique.And also the fiber optic qyroscope which can precisely detect robot directons and attitude has been developed.

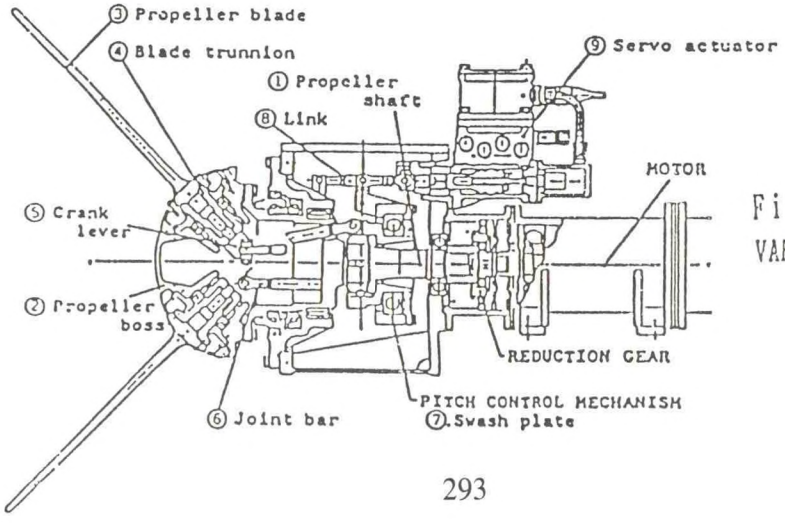

Fig. 5 CONSTRUCTION OF
VARIABLE VECTOR PROPELLER

2)Attachment leg and control

To increase the stability of position and the reliability of work while the robot is working in tidal current,the attachment legs are provided on the subsea robot.Surfaces of the platform structures are not always of the same size and shape,and are usually fouled by barnacles, oysters or mussels.From this point of view,the suction pads which can firmly attach on irregular surface have been developed.Position and attitude of the robot can be adjusted precisely by the co-operated controls between 3-legs and propellers.

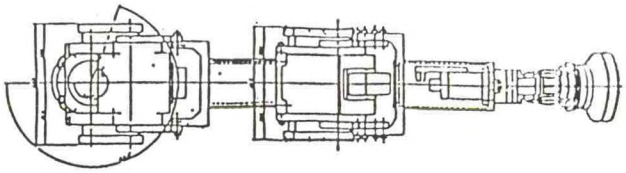

Fig.6
OUTSIDE DRAWING
OF ATTACHMENT LEG

5.MANIPULATION SUB-SYSTEM

Manipulation is one of the essential functions for the robot to carry out the various operations.

The high performance manipulator and the compact hydraulic actuator have been developed.

1)M1anipulator and control

To increase efficiency of manipulation works,the manipulator is required to have a wide area.So this manipulator system has totally 18 degrees of freedom,that consists of two working arms with six degrees of freedom respectively and an extension arm which moves both working arms widely.As for materials,aluminum alloy and CFRP are adopted for light weight and stiffness.
Such various sensors as, pressure,distance,force, visual sensors have been developed also.
To rise manipulation performance,the special control system have been established, that is a hybrid position / force control system with disturbance compensation, in this system,the close visual sensor and the force sensor are used to feedback position and force to the manipulator,and a rolling signal of robot body is feedforwarded also.

2)Sea water hydraulic actuator

More light and compact actuator system to drive propellers,attachment legs,manipulators,etc is essentially required to establish a efficient robot system.From this point of view,the high efficient,small and light sea water pump,the high response servo valve adopted with electric ceramic element and the small and high powered rotary actuator of yawing vane type have been developed.

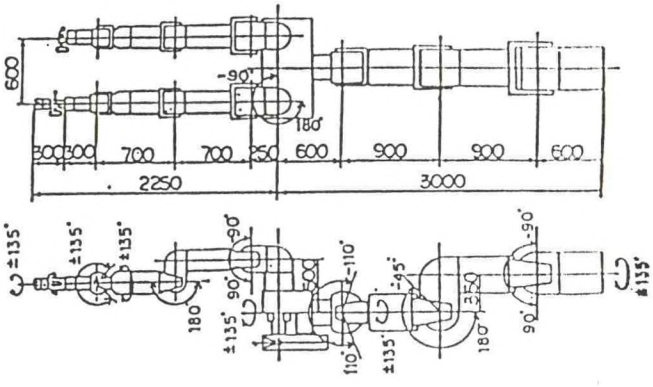

Fig. 7
OUTLINE DRAWING
OF MANIPULATOR

6.PERCEPTION SUB-SYSTEM

As for perceptive function, the TV camera and acoustic imaging systems have been adopted.In thesea water,the use of TV camera system is limited in the field of vision,so the acoustic imaging system has been developed and used to compensate the TV system.

1)Acoustic imaging system

The acoustic imaging system which consists of high resolution tranceiver array and high speed signal processor has been developed.And it was confirmed that this system can detect a wire rope of 25mm dimaeter at 10m front on the route of the robot.

2)TV camera system

The tele-existence display which provides stereo visions and rises operational performance of the robot has been developed.And also the position sensing way by processing TV image has been developed,that is,the detailed robot position shall be detected by matching the TV image data of the object and it's computor models which are made by using construction data of the platform.

7.VERIFICATION EXPERIMENT

The experimemt was carried out to confirm such key points of robot functions as (1) motion control,(2) attachment to the platform,(3) manipulation and (4) one-man operation,in the pool at the shipyard's dock in December 1990.

1)Key functions to be confirmed

- 3-dimensional motion control.
  Path following,position / attitude keeping and narrow path running.
- Fix to and leave from platform.
  Manual/automatic fixing to and leaving from the imitated platform under current disturbance.
- Manipulation
  Visual inspection by TV camera,cleaning work by wire brush and non-destructive inspection.
  One-man operation using telexistence.
  Harmonization of manual and automatic operations.

2)Main particulars of the experimental robot

- Body dimension : 3.2m(L),2.2m(W), 2.0m(H)
- Body weight : 4.0ton(in air), 0kg(in fresh water)
- Speed : 1.0knot
- Thrust of Propulsion unit : 20kgf/set
- Attachment leg sucking force : 200kgf/leg
- Manipulator: 2-working arm (mechanical 3-fingers hand for left arm)
- Power system: Oil hydraulic system
- Power supply: Electric supply through power-optic composite cable

3)Experiment facilities and program

For the experiment,a pool which has the dimension of 35m(L),25(W) and 11m(H) has been constructed in the shipyard's dock.And an imitated platform structure has been installed in the pool.

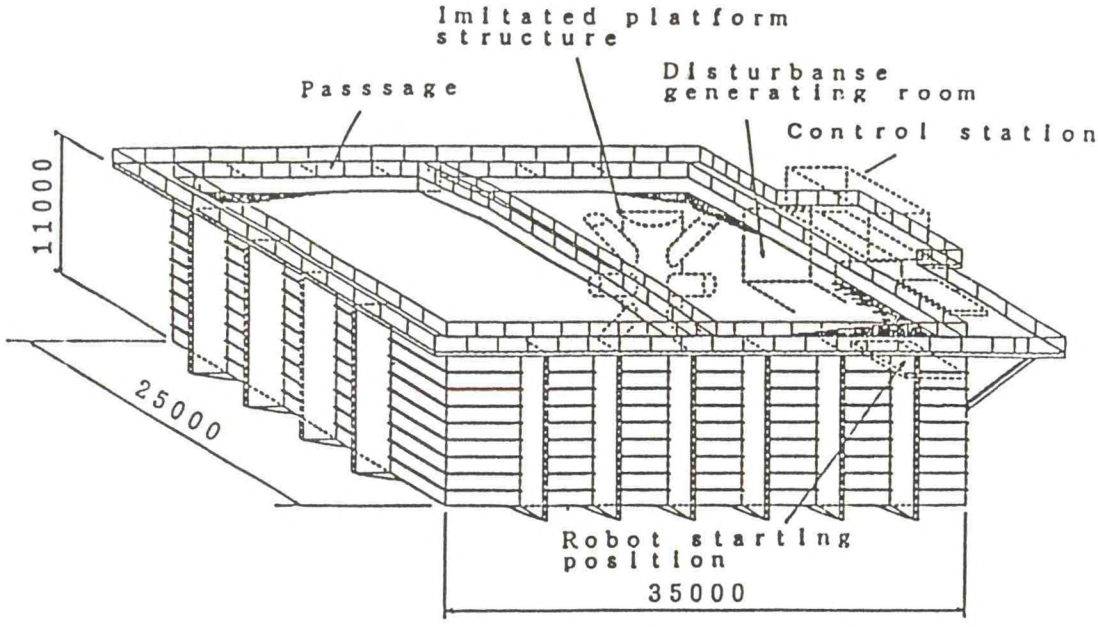

Fig. 8 POOL FOR EXPERIMENT

8. CONCLUSION

The research and development of elementary technologies for the advanced subsea robot have been carried out successfully and the total system of the robot has been designed conceptually. At the next stage, the verification experiment by the experimental robot has been carried out successfully and the key functions above mentioned have been confirmed satisfactorily.

However, this doesn't mean that the design of a robot for practical use has been completed. That is, it takes more emergy and time to develop the practical advanced subsea robot.

The development of a robot of practical use shall be done by private enterprises or other parties on a commercial bases, in this case, the selected elementary technologies will be adopted to manufacture the most suitable robot for the required task.

9. ACKNOWLEDGEMENT

This work was performed under the management of ARTRA (Advanced Robot Technology Research Association) as a part of the R & D of the large-scale project (MITI) sponsored by NEDO (New Energy and Industrial Technology Development Organization).

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Coastal Ocean Space Utilization

Floating Manufacturing Facilities for Economic Coastal Enterprise

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Clifford E. McLain
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Abstract: In many coastal economic areas, particularly where topography limits land based economic development and land transportation access, the location of both port and manufacturing facilities on a floating base may provide the most cost effective basis for economic development. This is especially true where the economic development is based on limited local natural resources. A completely self contained port and manufacturing support facility concept has been developed by Brown & Root and is described in the paper.

The Requirement

In many economic coastal regions, the problem of developing industry and port facilities is limited by several factors associated with the geography of the region. The factor include: terrain, remote location, lack of development, and ecological concerns. The authors have, over the past two years, examined the case of a particular area of interest within the U.S., the region of South East Alaska. All of the limiting factors just mentioned are present in this region, which, at the same time, features excellent ocean access through the coastal "Inland Passage".

A glance at the geography of the long SE extending "pan handle" of Alaska illustrates the problem. A rugged and indented coastline provides excellent ocean going access in deep water, but the coastal mountains, ranging unbroken into the interior eastward prohibit land based roads or railroads. In fact, from Ketchican in the south to Seward, at the beginning of the Aleutian chain, only three towns are connected to the interior by road or rail (Haines, Cordova, and Valdez) and none are interconnected by land along the coast. Also highly characteristic is the strong dependance upon natural resources, principally timber, mining, and fishing (Valdez is, of course, the terminal for Alaskan pipeline oil). There is also a strong concern for the effects of permanent port building and land development on the local ecology, particularly on local coastal fisheries.

Within the Alaskan context, there has developed a strong regional concern that economic growth be maintained, and yet so planned and managed that the environment will not be unduly injured. For this reason, land fill extensions to develop ports and harbors, or to create land for industry, have been severely limited in recent years. An additional consideration is that, for the natural resource industries such as timber and mining, the resource base is limited. Only so much timber can be cut in one area, for example, before moving to another. Yet the cost of transportation dictate that the processing (lumber mills, etc.) should be close to the source. The ideal answer would seem to be to move the industry to the resource on some type of transportable platform.

Although Alaska has been the principal location of study by the authors, there are certainly many areas of the world in which coastal development is rendered particularly costly by these same limiting factors. The ability to install and remove both part facilities and industrial assets associated with local coastwise economic assets would both greatly assist in reducing the costs of development which must be amortized in the utilization of local resources, and the total cost of developing that resource into a marketable product with transportation access.

Interestingly, a very similar set of requirements to these economically derived needs arise for the U.S. in the context of its potential international activities, in future military and economic assistance activities. In these instances, the need to rapidly put in place significant port and material handling facilities, as well as support functions (power, fresh water, sanitation services,

etc.) in remote and undeveloped areas may also be best met,wherever there is sea access, by transportable, floating facilities which can be moved from place to place, without significant site preparation, as needed to meet changing transportation and support needs.

A Floating Port Industry Concept

Brown & Root, U.S. A. Inc. has developed a unique concept termed the Landing Ship Quay/Causeway (LSQC), initially to meet perceived U.S. military requirements for a quickly implacable port facility which could be moved quickly to any location having sea access and, within a few hours (not days), establish a highly capable facility for what is termed by the U.S. military as a Logistics-Over-The-Shore (LOTS) operation. In this configuration, an ocean going vessel (a converted tanker) is equipped with a unique self-extending causeway which is extended from ship to shore - to a maximum extend of over 3000 feet in the current design. The causeway can accept two way truck traffic and also carries piping and power connections for support of bulk fluids and slurries from ship to shore, or from shore to ship. The ship itself is ballasted to sink to the sea floor offshore, serving as the dock facility. A levelling mechanism is contained in the ship hull. The causeway is then extended to the shore, supported by self contained adjustable piles which seat themselves on support pads on the sea floor. A variety of offshore slopes and sea floor types can be accommodated, but of course there are upper limits on the degree of slope that can be used. The ship is equipped with overhead cranes for handling cargo and is broad enough to permit easy turn around by normal truck traffic. A significant capability for supporting power generation and for personnel quarters and support can also be provided. This concept is illustrated in Figure 1.

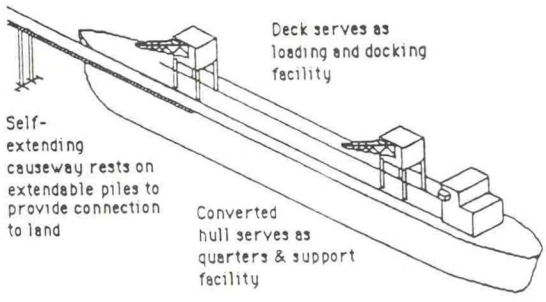

Figure 1. The LSQC Concept Design

The LSQC concept, originally conceived as an economic answer to potential U.S. military deployment requirements, and still valid in that particular application, served as the basis for the development of a movable floating industrial port complex which could be quickly installed in support of coastal natural resource development. A particular example, applied to coastal timber resource development, is illustrated in Figure 2.

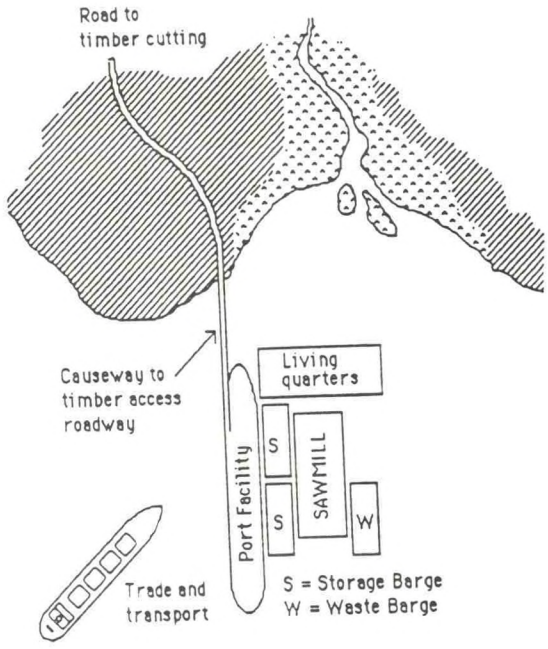

Figure 2. Floating Sawmill Facility

In this instance, a number of coastal areas, widely dispersed along a coastline inaccessible by road, contain harvestable timber. However, no single area contains enough timber to amortize a typical land based lumber mill and associated port facility within competitive world market prices for lumber or other wood products. Transportation costs for carrying logs to a remote permanent traditionally designed wood products industry are high, and there

are environmental concerns about rafting floating logs in the ocean over these distances. Finally, the disturbance to coastal fisheries of installing new port facilities, considering the limited use of such facilities, is coming under much more severe environmental scrutiny. Such problems typify the concerns of the Alaskan timber industry today, but in a larger sense represent the concerns of many coastal development projects where resources and the environment pose limitations which are difficult to reconcile by traditional methods.

The LSQC concept offers a new way to solve these problems. The self extending causeway does not require any site preparation other than a road head to meet its land terminus. No harbor dredging is needed. The ship itself (the ship can be of a variety of types, including towed barges) serves as the dock, and its hull depth, when ballasted to rest on the bottom at high tide, serves to establish the hell depth for shipping. Note than the normal large tanker based LSQC hull depth would, for most coastal areas around the world, support a maximum keel depth of 35 to 40 feet at dockside. The self extending causeway is supported by self contained adjustable piles which do not require any specific preparation of the sea floor and do not impede local coastal flow patterns or disturb the local waters. In the Alaskan case, this is a property which is particularly important, since there has been concern about the potential for land filled causeways to disrupt the local coastal fisheries environment.

Finally, the causeway and ship based terminus forms a base for the attachment or collocation of floating industrial facilities for processing the natural resource (in figure 2, timber). A complete floating facility with mills, living and support accommodations, and all sanitary facilities can be provided. Moreover, since all of these facilities can be carefully controlled and constructed, the overall impact of the associated industrial activities can be significantly reduced over fixed land based facilities which must necessarily watch costs in order to be within the amortization limits imposed by the estimated lifetime of the local natural resource base.

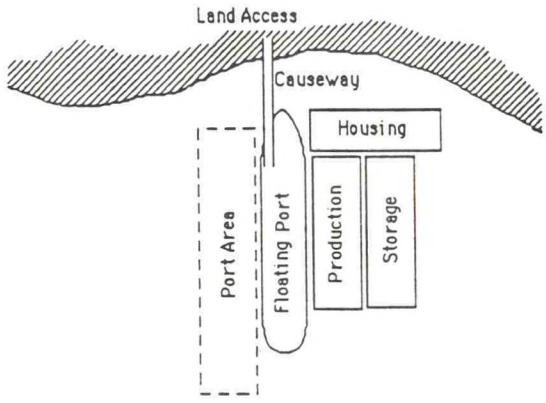

Figure 3. Generalized Floating Facility

The overall concept for the floating economic enterprise development is illustrated in Figure 3. In this figure, all of the essential elements of the concept are combined to form a floating self contained economic enterprise entity which includes:

1. Access to a coastal based asset
2. A fully operational port facility
3. A fully supported processing facility to convert the natural resource into a value added produce which can be shipped to world markets
4. Complete facilities for housing and supporting the personnel needed to operate the facility.

Conclusions

The test of the concept is whether it meets the requirements for industrial investment in the local context of labor, resources, controls, and investment environment and in the worldwide marketplace. In small scale, the floating facility concept is already in operation in Alaska in support of small scale timber cutting operations. For many remote sites, the combination of a self installing mobile port and causeway system and floating self contained industrial real estate offer the only economically reasonable road for development. Dual purpose facilities for support of both government and private enterprise are also a significant possibility.

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Tokyo, Japan, May 13-15, 1991

Considerations for the Design of Floating Airports

by
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ABSTRACT

An analysis of the motions of a very large floating mat-like structure for use as a floating airport is presented. This situation is different from the usual treatment of ship motions principally because the wave lengths are small compared to either horizontal dimension of the platform. The linearized analysis is based on the assumption that the waves and resulting motions are two-dimensional and that the wave amplitudes are small. A panel method based on an extension of Frank's method is used to analyze the hydrodynamic aspects and Bernouilli-Euler beam theory is used to analyze the strucutral aspects. The consequences of the platform motions for aircraft landing and takeoff is then discussed and an analysis of these motions is made. The results of ample calculations for platforms of various rigidities are presented and discussed.

INTRODUCTION

There has been considerable interest in the last few years in the possible use of very large floating structures (VLFSs) for a variety of purposes including: airports, manufacturing facilities and for habitation. A variety of different studies of VLFSs has been made by several researchers. These studies will not be cited here, but the reader is referred to Riggs, Che & Ertekin (1991) for a bibliography and discussion of some of the most recent of these. The particular focus of this paper is specifically on the potential use of these platforms for airports, particularly because there are a great many social and environmental advantages for such a use and there are a number of unresolved technical problems.

If a floating airport it is to be used for standard commercial aircraft (an assumption we shall make) then it will have to have a number of different characteristics. It must be much larger than any floating structure which now exists. An airport requires at least one runway and one taxiway, structures for administration, maintenance and fuel storage, and several electronic and physical aids to navigation, etc. For a floating airport to be used by a Boeing 747, say, a minimum platform will have to be approximately 2500m long and 300m wide. Such a floating structure could not be built in one piece, since there are no facilities or locations which would permit such construction. As a result, the platform will necessarily be constructed in modules and assembled at sea. Although the problem of assembly is a critical and very demanding one, we shall not address this problem here. Because such a platform will have a limited draft, the length of such a platform compared to its draft will be much larger than any ship in existence. Thus, the platform will be relatively more flexible than a ship and elastic deformations may be more important than rigid-body motions.

There are a number of different geometries proposed for a VLFS for use as an airport. The two principal ones are an assembly of modules with substantial vertical columns (similar to semisubmersible or column-stabilized oil platforms), and a mat-like structure (a very large barge). Each has it own advantages and disadvantages. For example, the column-stabilized approach offers the possibility of smaller motions because the waterplane area can be made quite small. However, the wetted surface area of the typically proposed column-stabilized platform is much higher than for a mat-like structure and the design of a strong shear connection between the modules is difficult. Further, the good motions performance is achieved by de-

creasing the waterplane area of the columns. This leads to substantial static deformations of the platform under large loads (a 747 weighs about 4,000 kN fully loaded). Mat-like structures have very simple geometry and can be constructed in unsophisticated facilities. However, the assembly of mat-like structures at sea may be more difficult and the motions are likely to be more severe than an equivalent column-stabilized structure.

It is the purpose of this study to concentrate on mat-like structures and, in particular, to investigate its motions characteristics so that these potential disadvantages can be better understood.

THE MODEL

We consider here the possibility of a mat-like floating airport moored in deep water relative to the waves under consideration. Estimation of the survival of a VLFS is a particularly difficult undertaking since it would require both nonlinear hydrodynamic and structural treatments such as steep and breaking waves, large amplitude structural responses and the like. For our purposes here we restrict our consideration to situations where the platform is used for flight operations, i.e., landing and takeoff of airplanes. It is assumed that flight operations will be feasible in a variety of different weather systems from calm weather up to moderate weather systems, where the motions of the platform will preclude further operations. We shall therefore assume that the linearized hydrodynamics can be used to describe these waves the flow they create about the moving platform, and that ordinary, linearized Bernouilli-Euler beam theory be used to describe the platform motions.

We anticipate that the platform is moored in one of three ways: with a fixed mooring such that the main runway is aligned with the predominant wind and wave direction, with a single-point mooring, or with dynamic positioning so that the platform streams in the direction of the wind and waves. Aligning the runway with the wind is preferred for both landing and takeoff; the alignment with the waves is assumed but is not unreasonable. As a result of this orientation, the typical wave length will be much smaller than the length of the platform, a situation which makes the hydrodynamic problem difficult.

Ordinary slender body theory typically used in ship motions incorporates an implicit assumption the wave length is large compared to the characteristic ship dimension. When the wave length becomes small (as is the case here) other theories are more appropriate. In particular, Newman's unified slender body theory (see Nihous & Webster, 1984) has been used before for similar problems involving wave energy extraction. We shall, however, not use this theory for the current study, but rather report the results of calculations made with the assumption that the flow is approximately two-dimensional and that the wind and waves are aligned exactly with the runway direction. This assumption implies that the platform is also wide with respect to the wave length. This is approximately true for the anticipated waves of interest for flight operations. However this assumption would probably be poor for survival conditions, where much longer waves would be encountered.

The problem is shown schematically in Figure 1. The platform assumed to have a length L, a uniform draft T and a depth d. The platform is assumed to be horizontal in the free surface when no waves are present. The incident waves are proceeding in the positive x direction and the mat-like platform is moored so that it does not have a horizontal velocity. As a

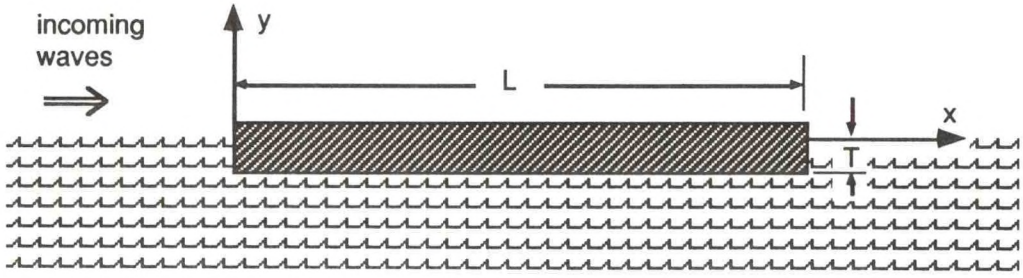

Figure 1. Coordinate System

result of the action of the waves, the platform will move and deform, and it is this motion which we wish to determine.

The Hydrodynamic Model

Although a discussion of the foundations of the theory are presented below, details of the development will not be presented here. They can be found in ben Hamida & Webster (1991). The steps required to perform a full three-dimensional computation are not much different from those presented in this paper and the final equations are functionally the same. The two dimensional analysis was undertaken to gain some insight into the problem without the large penalty in cost and time represented by the computational effort involved in a full three-dimensional analysis.

The fluid is assumed to be incompressible and inviscid, and the flow irrotational. The flow can therefore be represented by a velocity potential, $\phi(x,y;t)$, which satisfies Laplace's equation, $\Delta\phi = 0$. As previously stated, the waves and the platform motions will be assumed small enough to permit linearization of the free surface conditions and the kinematic boundary conditions on the platform. The resulting problem is thus linear and we can superpose solutions. We decompose the velocity potential into three parts: an incoming wave train ϕ_I, a diffraction potential, ϕ_D, and a radiation potential, ϕ_R. That is,

$$\phi = \phi_I + \phi_D + \phi_R \qquad (1)$$

All three potentials individually must satisfy the linearized free surface boundary condition and all three are harmonic in time and in space as well. It is convenient to express this and other functions in complex notation. We will distinguish all complex variables which refer to temporal variations from their real counterparts by using a tilde over the variable. Thus, the free surface elevation, η, and ϕ are given by

$$\begin{aligned} \eta(x,t) &= \mathrm{Re}_j\{\tilde{\eta}(x)\, e^{-j w t}\}, \\ \phi(x,y,t) &= \mathrm{Re}_j\{\tilde{\phi}_I(x,y)\, e^{-j w t}\}, \end{aligned} \qquad (2)$$

The incident wave potential is specified. The radiation and diffraction potentials satisfy a radiation boundary condition, that specifies that the waves are outgoing, and the following kinematic boundary conditions on the body:

$$\frac{\partial\phi_R}{\partial n} = V_n \text{ and } \frac{\partial\phi_D}{\partial n} = -\frac{\partial\phi_I}{\partial n}, \qquad (3)$$

The problem is a linear problem and, without loss of generality, it is convenient to consider the motions produced by a regular incoming wave train with an amplitude a, a frequency ω and a wave number, $\nu = \omega^2/g = 2\pi/\lambda$, where λ is the wave length. For instance, the incident wave and the corresponding potential are

$$\begin{aligned} \eta(x,t) &= -a\sin(\nu x - \omega t), \\ \phi_I(x,y,t) &= \frac{a g}{\omega} e^{\nu y}\cos(\nu x - \omega t). \end{aligned} \qquad (4)$$

The Structural Model

As a result of hydrostatics and of the waves and motions of the platform, pressures will be exerted on the sides and bottom of the floating platform. The platform will deflect in response. Because the platform is necessarily a very shallow beam, we shall ignore the horizontal deformations resulting from forces on the ends of the platform and concentrate on the vertical deformations of the beam resulting from the vertical forces acting on the bottom of the platform. Let $y = \tau(x,t)$ be the vertical deformation of the platform from its static equilibrium position at time t. The pressure on the bottom of the platform can be computed by Euler's integral, evaluated at y = -T (consistent with the linearization).

If the beam in is held undeformed, the net vertical force per unit length acting on the beam is the hydrostatic pressure plus the hydrodynamic pressure (due to the waves) minus the weight loading. It is assumed that the platform is constructed so that the force due to the hydrostatic pressure will exactly cancel the weight distribution. Thus, the platform will be unstressed, undeformed and perfectly horizontal when there are no waves. The deformations of the platform therefore result only from the action of the external dynamic pressures on the bottom and external hydrostatic pressures due to deformation. The motions are assumed to be governed by Bernouilli-Euler beam theory, which when combined with the loading yields

$$D(x)\frac{\partial^4\tau}{\partial x^4} + \rho T\frac{\partial^2\tau}{\partial t^2} - J(x)\frac{\partial^4\tau}{\partial x^2\partial t^2} = \qquad (5)$$

$$= p(x,t)\, n_y = \left\{ -\rho \frac{\partial \phi}{\partial t} - \rho\, g\, t \right\} n_y,$$

where:

$D(x) = \dfrac{E\, I(x)}{1 - \nu_s^2}$ is the flexural rigidity,

E, ν_s are the modulus of elasticity and Poisson's ratio,

I(x) is the structural moment of inertia in bending per unit width, and

J(x) is the mass moment of inertia of the section per unit width.

The first term in (5) represents the local internal loading due to the bending of the beam, the second term that due to the local vertical acceleration of the mass of the beam, and the third term due to the rotation of a section of the beam. For the long, slender beams under consideration here, the rotational inertia term is very small. We shall retain it, however, since it does not complicate the problem to do so.

Let the complex vertical deformation be given by $\tau(x,t) = \mathrm{Re}_j \{\tilde{\tau}(x)\, e^{-j\omega t}\}$. Equation (8) can then be rewritten in complex notation as

$$D(x) \frac{\partial^4 \tilde{\tau}}{\partial x^4} + J(x)\, \omega^2 \frac{\partial^2 \tilde{\tau}}{\partial x^2} + \rho\, (g\, n_y - T\, \omega^2)\, \tilde{\tau} = j\, \rho\, \omega\, \tilde{\phi}\, n_y. \qquad (6)$$

The platform is freely floating and, as a result, the shear force and bending moment on both ends of the platform is zero. Thus,

$$\left. \frac{\partial^3 \tilde{\tau}}{\partial x^3} \right|_{x = 0,\, L} = \left. \frac{\partial^2 \tilde{\tau}}{\partial x^2} \right|_{x = 0,\, L} = 0 \qquad (7)$$

Equation (6) and boundary conditions (7) couple the platform structural response and the hydrodynamic loads and provide closure for the problem.

SOLUTION SCHEME

We shall use the general method for the computation of the two-dimensional vibration of a body presented by Webster (1979) as the foundation for the solution to this problem. This method is an extension of Frank's method for the computation of the flow about two-dimensional bodies in a free surface. In this approach the kinematic boundary condition on the boundary is satisfied only at discrete points (called collation points). The reader is referred to the original paper for the details. The treatment here of the diffraction problem is, however, new and the reader is referred to ben Hamida & Webster (1991) for these details.

The solution proceeds in three steps, performed sequentially. The first involves solution of the radiation problem for arbitrary, but yet unknown, vibration of the platform. The solution of the diffraction problem can then be written down directly from intermediate results of the radiation problem. Finally, the radiation and diffraction results are combined with the incident wave potential. The dynamic boundary condition on the interface between the water and the platform (9) is then used to determine the unknown vibration pattern of the platform in response to the incoming waves.

The Radiation Problem

We consider an arbitrary vibration of the platform and, for the time being, we place no particular restriction of the underwater geometry. For the studies here, we will assume that the bottom is flat, although the method does not need to be so restricted. The arc length measured along the underwater part of the platform is decomposed into panels. An unsteady sources are distributed uniformly over each panel (with constant strength along the panel and varying sinusoidally over time). The source strength on the ith panel is different from that on the kth panel; the strength on the ith pane is given by $\sigma_i(t) = \mathrm{Re}_j \{\tilde{\sigma}(x)\, e^{-j\omega t}\}$.

With some manipulation, one can express

$$\tilde{\phi}_{R_m}(z) = -j\, \omega\, H_{mk}(\omega)\, \tilde{c}_k, \qquad (8)$$

where repeated indices indicate summation. The matrix $H_{mk}(\omega)$ encapsulates all of the hydrodynamics of the problem and, as shown, is a function of ω. Further, $\tilde{p}_{Rk}$, the complex pressure on the kth panel due to a motion, $\tilde{c}_m$, of the mth panel can be determined from Euler's integral, yielding

$$\tilde{p}_{R_m} = j\, \rho\, \omega\, \tilde{\phi}_{R_m}(z) = \rho\, \omega^2\, H_{mk}(w)\, \tilde{c}_k \qquad (9)$$

Thus, (8) and (9) state that if we know the com-

plex amplitude, $\tilde{c}_k$, of the normal deformation pattern on all N panels, then we can compute the complex radiation velocity potential, $\tilde{\phi}_{R_m}$ and $\tilde{p}_{R_m}$, the pressure resulting therefrom.

This form of the solution is not unique to two-dimensional problems. If we had analyzed the three-dimensional problem, then the solution could have been expressed similarly, this time with the indices k and m ranging over all of the panels.

Frank's method is well known for having computational difficulties. Some of the difficulties, such as properly accounting for the branch cut in the complex square root are well known and are solved by careful programming. Others include the so-called irregular frequency problem. There are frequencies at which no solution exists and these frequencies become more closely spaced as the ratio of body length to wave length increases. Steps were taken to assure that hese difficulties did not occur in the computations.

This computation is, in addition, more difficult than the similar application of Frank's method for rigid cross sections typical in slender body ship motion studies. First, the situation where the platform length is much greater than the wave length requires that a very large number of panels be used in the computation. The number of panels used in the current study is 310. The size of the matrix also means that double precision calculations are necessary to achieve consistently accurate results and this further strains the memory capacity of the computer.

The Diffraction Problem

With the solution of the radiation problem in hand, it is straight forward to compute the solution of the diffraction problem. We note, in passing, that it is not possible to use the Haskind-Hanaoka relations used in ordinary ship motions computations here since the body is not rigid and we do need the pressure distribution on the platform. The kinematic boundary condition for the diffraction potential given in (3) is of similar form to that for the radiation problem and thus

$$\tilde{\phi}_{D_m} = H_{mk}\left\{-a\,\omega\, e^{n(\bar{y}_k + j\,\bar{x}_k)}\,(j\,n_{1_k} + n_{2_k})\right\}. \tag{10}$$

where $(\bar{x}_m, \bar{y}_m)$ are the coordinates of the mth collocation point and H_{mk} is the same hydrodynamic matrix as in (8) and (9).

The Combined (Hydroelastic) Problem

To solve the hydroelastic problem we will make explicit some assumptions which were referred to earlier. These are:

- The bow and stern of the undeformed platform are vertical and the bottom is flat and horizontal.
- Deformation of the bow and stern panels does not occur.
- The only hydrodynamic loadings of interest are those on the bottom of the platform.

The underwater periphery of the platform is discretized such that i = 1,np corresponds to panels on the bow, i = np+1,np+nb corresponds to panels on the bottom. Then $\tilde{c}_m \equiv 0$ for i = 1,np. On the bottom y = -T and the normal is (0,1). Thus for i = np+1, np+nb, $\tilde{c}_m = \tilde{\tau}$ evaluated at the corresponding collocation point. It is convenient to introduce new indices (denoted by a') which range from 1 to nb and correspond to only the bottom panels (i.e., i = i' + np).

The dynamic pressure, $\tilde{p}$, due to the combined incident wave, radiation and diffraction potentials can be assembled from (4), (8) and (10), yielding the following hydroelastic equation in terms of nondimensional parameters (we keep $\tilde{t}_{k'}$ and $\tilde{h}_{k'}$ in dimensional form since there is no advantage not to)

$$\left\{\hat{D}_{m'}\hat{T}^4\frac{\partial^4\tilde{\tau}_{m'}}{\partial\hat{x}^4} + \hat{J}_{m'}\,\hat{T}^2\,\sigma\frac{\partial^2\tilde{\tau}_{m'}}{\partial\hat{x}^2} + (1-\sigma)\,\tilde{\tau}_{m'}\right\}$$

$$-\sigma\hat{H}_{m'k'}\,\tilde{\tau}_{k'} = \tag{11}$$

$$\left\{\tilde{\eta}_{m'} - s\,\hat{H}_{m'k'}\,\tilde{\eta}_{k'}\right\}e^{-\sigma}$$

$$-j\sigma H_{m'k'}\left\{\tilde{\eta}_{k'}\,e^{\sigma\bar{y}_k}\,\Big|\,\begin{matrix}\text{bow}\\ \\ \text{stern}\end{matrix}\right\},$$

where $\hat{D}_{m'}(x) = \dfrac{D_{m'}(x)}{\rho g T^4}$, $\hat{T} = \dfrac{T}{L}$, $\hat{x} = \dfrac{x}{L}$,

$$\hat{J} = \frac{J}{\rho T^3}, \quad \sigma = \frac{T\omega^2}{g} = \nu T, \quad \hat{H}_{m'k'} = \frac{H_{m'k'}}{T},$$

and where $-1 < \hat{\bar{y}}_k = \frac{\bar{y}_k}{T} < 0.$

There are several features of equation (11) which should be noted. First, the bending and rotational inertia effects become small rapidly as $\hat{T}$ (the draft-to-length ratio) becomes small. $\hat{T}$ for typical floating runways is of the order of 0.01 or less and thus one can expect such a runway to be rather flexible. Second, the contribution from the bow and stern is also small when $\hat{T}$ is small (this is not obvious, but it can be shown by direct computation). Third, whereas each component of $f_{m'}(\omega)$, the excitation terms, involves the wave amplitude, the sum is not wavy in x at all. Figure 2 shows the real and imaginary parts of a typical excitation.

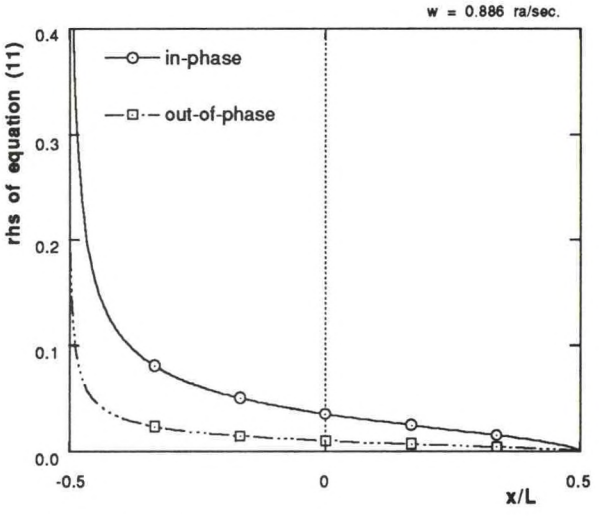

Figure 2. Typical hydrodynamic loading.

Finally, suppose that the draft is small and terms of the order of $\hat{T}^2$ and the contribution from the bow and stern are neglected. Then for waves which are long compared to the draft (σ small), a solution to (24) is $\tilde{\tau} = \tilde{\eta}$ (to order σ^2). This case corresponds to a very flexible mat floating on the surface and the wave train passing through undisturbed.

The derivatives of $\tilde{\tau}_{k'}$ in (11) can be approximated by centered finite differences yielding a discrete version of the coupled problem,

$$\{\hat{S}_{m'k'} - s\hat{H}_{m'k'}\}\,\tilde{t}_{k'}(\omega) = \{I_{m'k'} - s\hat{H}_{m'k'}\}\,\tilde{h}_{k'}\,e^{-\nu T} - j\sigma H_{m'k'}\left\{\tilde{h}_{k'}\,e^{s\bar{y}_k}\,\middle|\,\begin{matrix}\text{bow}\\ \\ \text{stern}\end{matrix}\right\},$$

or

$$\hat{C}_{m'k'}(\omega)\,\tilde{t}_{k'}(\omega) = \hat{F}_{m'k'}(\omega)\,\tilde{h}_{k'} + \hat{F}_{\text{bow/stern}} = a\,f_{m'}(\omega), \tag{12}$$

where $\hat{S}_{m'k'}$ is the discrete form of the bracketed part of the lhs of (12), $C_{m'k'}$ is the combined hydroelastic matrix, $I_{m'k'}$ is the identity matrix, $F_{m'k'}(\omega)$ is the hydrodynamic forcing matrix and $a\,f_{m'}(\omega)$ is the forcing vector. The complex deformation transfer function, $\tilde{\mu}_{j'}(\omega)$, is defined by

$$\tilde{\mu}_{j'}(\omega) = \frac{\tilde{\tau}_{j'}}{a} = \hat{C}^{-1}{}_{j'm'}(\omega)\,f_{m'}(\omega) \tag{13}$$

The boundary conditions also have to be applied at the ends of the platform.

ALLOWABLE MOTIONS

Before we estimate the motions of example mat-like structure, it is important to ask what motions is it possible tolerate. At any instant in time, a floating airport runway will have static deformations as the result of temporary load distributions on the mat and dynamic deformations as a result of the actions of waves. The profile of the runway will affect both landing and takeoff, but the question here is how large can these deformations be before the safety of the operation is impacted. The Federal Aviation Administration (FAA) issues a number of circulars which govern airports and airport design. Unfortunately, although there are specifications for flatness ("... the runway is to be flat within 3/8" (1cm) within a distance of 16' (5m)."), these specifications are primarily local and are aimed at guiding the construction rather than the design of the runway. In order to get a definitive insight into the need for flatness in a context of the whole runway, it would be necessary to consider the airplane and its interaction with the runway.

Most modern airplanes use a tricycle landing gear with a single nose wheel assembly and a pair of sophisticated main wheel assemblies aft of the center of gravity of the plane. The airplane then is not unlike an automobile with a wheeled spring-damper suspension holding it off the road. Loads to the airplane are transmit-

ted through this assembly in response to the relative motions of the airplane and the runway. These loads for a given airplane will depend chiefly on the displacements and velocities of the landing gear, as seen in a coordinate system fixed in the airplane.

A runway-associated failure can occur in two principal ways. First, if runway irregularities cause a wheel assembly to move a distance upwards relative to the aircraft larger than the landing gear was designed for, the gear will "bottom out". The impact loads from such an occurrence will almost certainly lead to failure of the gear and perhaps even failure of the primary aircraft structure. On the other hand, if runway irregularities cause a wheel assembly to move a distance downwards relative to the aircraft larger than the landing gear was designed for, the aircraft will become airborne unexpectedly and may "bounce". Although this is not necessarily a catastrophic failure, it can lead to problems especially during takeoff when the airplane is loaded to its maximum weight. The typical designed total stroke (maximum excursion - minimum excursion) of a commercial aircraft landing gear is of the order of 1m.

The dynamic characteristics of the landing gear on commercial aircraft are chosen to optimize the performance of the craft during landing and takeoff from typical land-based runways. These runways are usually smooth and the principal loads occur during the impact of landing. For runways which are undulant rather than smooth (such as runways on a floating structure in waves) it is likely that the landing gear will be stiffer and have more damping than is optimal. For typical commercial aircraft the speeds at takeoff can be 80 - 100 m/sec and landing speeds of 60 - 70 m/sec.

The motions of a floating runway can have many different characteristics, depending on the waves and the configuration of the platform. If the runway is very flexible and the waves are long with respect to the draft, the deflection pattern will match the incoming waves. This pattern is of the form of progressive waves. For stiffer platforms, other motions are possible, including standing waves and progressive waves with phase speeds different from the celerity of the waves which caused them, or combinations of both. As a result, interpretation of the motions of a runway on the feasibility of landing requires further analysis.

Consider the floating runway shown in Figure 1 with the runway aligned with a seaway composed of small (linear) regular waves of frequency ω. The vertical deformation at any point x on the runway will be sinusoidal in time and given, as before, by $\tau = \tau(x,t)$ and $\tilde{\tau}(x)$ is the complex deformation. The vertical deformations, $\tilde{\tau}_0(x)$, seen by an observer travelling at a speed u_0 have the same amplitude, $|\tau(x)| = \sqrt{\tau_1^2 + \tau_2^2}$ as that seen by a fixed observer and are time harmonic. However, the time dependence will be different. If the x coordinate of the moving observer is given by $x = x_0 + u_0 t$, then (27) becomes

$$\tau_0(x,t) = \mathrm{Re}_j \{ \tilde{\tau}(x_0 + u_0 t)\, e^{-j\omega t} \}. \qquad (14)$$

If we denote the derivative of $\tilde{\tau}$ with respect to x as $\tilde{\tau}'$, then the vertical velocity and vertical acceleration experienced by a moving observer at a point x are given by

$$\dot{\tau}_0(x,t) = \mathrm{Re}_j \{ [u_0 \tilde{\tau}'(x) - j\,\omega\, \tilde{\tau}(x)]\, e^{-j\omega t} \}, \text{ and} \qquad (15)$$

$$\ddot{\tau}_0(x,t) =$$

$$\mathrm{Re}_j \{ [u_0^2 \tilde{\tau}''(x) - 2\, u_0\, j\, \omega\, \tilde{\tau}'(x) - \omega^2\, \tilde{\tau}(x)]\, e^{-j\omega t} \}.$$

The observed velocity and acceleration at any point x on the runway will depend not only on the speed of the aircraft but also upon the original location x_0 of the aircraft at time t = 0. Since it would be very difficult to coordinate the landing or takeoff of an aircraft with the wave-induced motions of the floating airport, the worst velocities or accelerations which can be experienced at any point have a magnitude equal to the magnitudes of the functions on the right-hand side of (28), or

$$|\dot{t}_0(x)| = \sqrt{(u_0 t_1' + \omega t_2)^2 + (u_0 t_2' - \omega t_1)^2}\,, \qquad (16)$$

and

$$|\ddot{t}_0(x)| = \sqrt{\begin{matrix}(u_0^2 t_1'' + 2\, u_0\, \omega\, t_2' - t_1\, \omega^2)^2 \\ + (u_0^2 t_2'' - 2\, u_0\, \omega\, t_1' - t_2\, \omega^2)^2\end{matrix}}\,.$$

The formulas in (16) will be used below to evaluate the deformations of the floating runway.

For comparison, it is interesting to compute the motions caused by a runway with the limit of FAA construction requirement for unsmoothness of fixed runways. If the runway is not moving and has a sinusiodally varying amplitude of 0.5 cm with a wave length of 5m, then the values of maximum velocity and acceleration for an aircraft taking off at 100 m/sec are

$$|\dot{\tilde{t}}_{o_{max}}(x)|_{FAA} \approx 0.6 \text{ m/sec, and}$$

$$|\ddot{\tilde{t}}_{o_{max}}(x)|_{FAA} \approx 75 \text{ m/sec}^2$$

EXAMPLE COMPUTATIONS

With the theory presented above, it is possible to investigate a great variety of different platform configurations. There are different choices of materials; concrete and steel are the most often mentioned. Many of the new composite materials may also be very attractive alternatives. For each material there are questions with regard to the bending rigidity required. An increase in rigidity increases the natural frequency of the platform and this, in turn, increases the frequency of the natural modes. Whether or not this reduces the amplitude of deformation or the critical motions in (30) remains an open question.

Although the upper surface of the runway must be flat, there is no need for the bending rigidity, D, to be constant along the platform. The theory presented above allows D to vary in the x direction from a uniform platform ($D(x) \equiv$ const.) to a hinged one ($D(x) \equiv 0$ at the hinges). The following example studies are are directed at the simplest case of a uniform platform, although clearly more complicated ones can be easily treated by this theory.

There are essentially three nondimensional variables which describe the platform: the draft to length ratio, $\hat{T}$, the nondimensional rotational inertia, $\hat{J}$, and the nondimensional rigidity, $\hat{D}$. The platform response, τ/a, involves an additional nondimensional variable: the wave number, $\sigma = 2\pi(T/\lambda)$. Because the problem treated here is linearized, the incoming wave amplitude can be considered as unity and the results are response amplitude operators (RAOs). In the computations below, the rotational inertia, J, will be assumed to be zero and $\hat{T} = 0.005$ (corresponding to a runway of length 2000m and a draft of 10m). The rigidity, $\hat{D}$, will be allowed to vary.

If the platform were constructed of steel and the internal structure were to remain empty, then the draft would be about 15% of the platform depth (like an empty tanker) and most of the platform would be above water. This configuration is probably unacceptable and that ballast would be required to achieve a reasonable draft. Platforms constructed from concrete are heavier and would need less ballast. In any case, a wide variety of bending rigidities is possible for platforms with the same draft and depth. A range of nondimensional bending rigidities was selected, given by $\hat{D} = h^2 \hat{D}_0$, where the parameter h which varies from 0.3 to 1.0 and where $\hat{D}_0 = 0.134 \times 10^{-2}$ corresponds to a steel structure without ballast which has a gyradius equal to the draft. The smallest choice of h yields a rigidity $^1/_{11}$ of this value. This range should cover most platform structures.

Figure 3 shows the computed RAOs at two resonant conditions. As seen in this figure, the worst motions are at the bow and the stern. Each set of curves in this figure shows the magnitude of the amplitude of the motions (25) and the perceived velocity and acceleration by a plane taking off at 80m/sec (29) as a function of longitudinal position. The scalloped appearance of the amplitude results from a standing wave pattern on the platform. It is seen that the perceived velocity and amplitudes are not so scalloped. This is so because the the wave pattern of the platform appears to be a progressive pattern in the moving coordinate system of the airplane. In any case, even at the resonances, the RAOs of the mat's amplitude distribution are always less than unity for the bending rigidities shown. For smaller rigidities, however, resonances with larger amplitudes are possible.

Figure 4 shows the variations of the amplitude of motion at the bow and stern for 8 different platform rigidities. Resonances occur when rigidity of the platform is such that the platform's natural mode corresponds to the wave exciting frequency. It is seen from these curves that the principal contribution to the motions in a seaway will be from these very sharply-tuned resonances.

DISCUSSION & CONCLUSIONS

In all cases, an increase in the bending rigidity (increases in h) causes a systematic variation of deformation pattern from deforma-

tion wave lengths equal to the water wave length (for very small rigidities) to deformation wave lengths comparable to the platform length. These computations show that, at resonances, the RAOs remain of order of unity or less for all bending rigidities and decrease in size very slowly with increasing bending rigidity. Away from resonances, the motions are small. The highest deformations occur at the bow and at the stern (the stern motions are almost always worse). At resonance the magnitude of the deformation pattern is symmetrical. The magnitudes of the velocities and accelerations seen by the aircraft are similar in nature to the deformations, although these motions do not vary as much longitudinally. Even for relatively large waves, the velocities and accelerations arising from the deformation of the platform are still less than FAA criteria.

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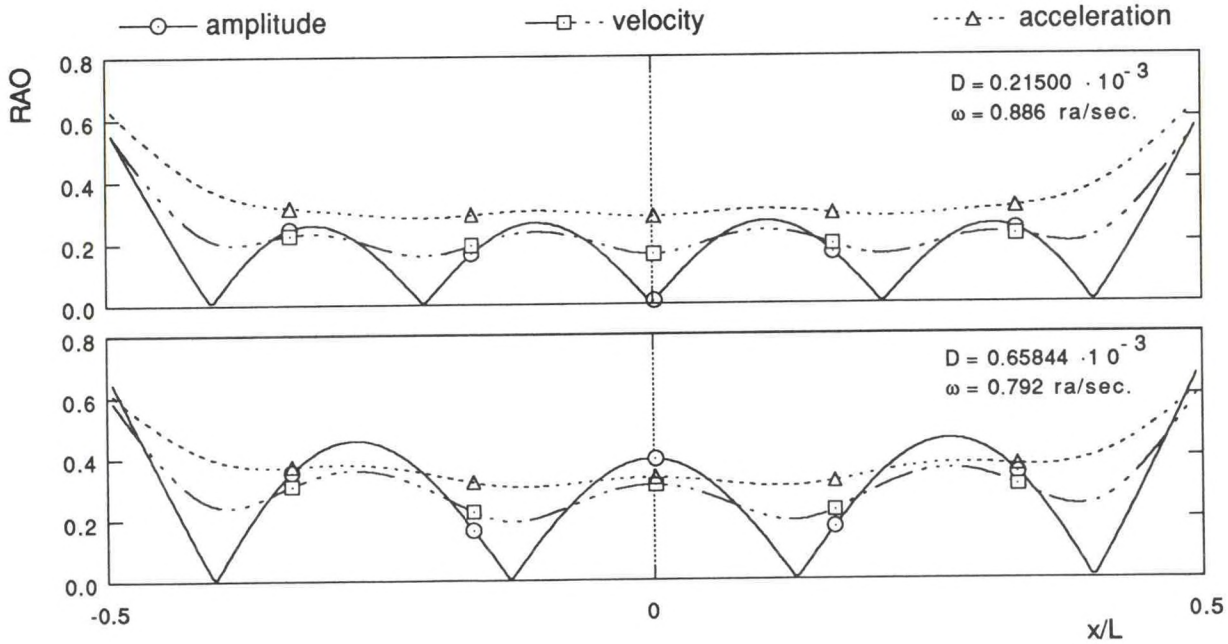

Figure 3. Deformation patterns for two mat-like platforms at a resonance.

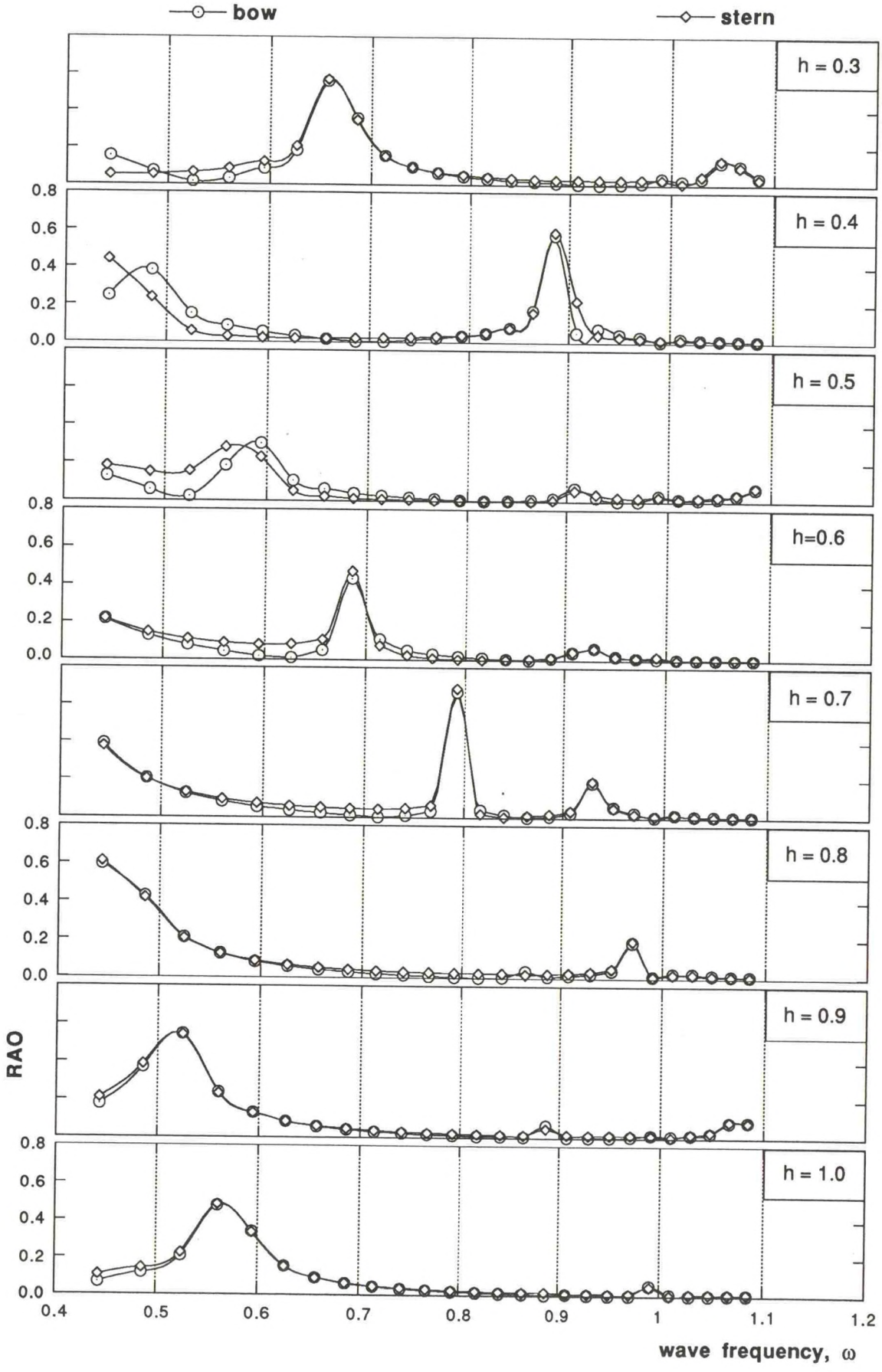

Figure 4. Response of platforms of various stiffnesses to waves of various frequencies

OCEAN SPACE UTILIZATION: TECHNOLOGY TRENDS AND FUTURE CONCEPTS

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ABSTRACT

Coastal ocean space development has long been the focus of attention for seafaring nations and is growing in importance and interests to a coastal-minded society. The emphasis is on ocean space development for economic gain and societal benefit in harmony with the environment. To assess trends in planning and developing offshore facilities, over 400 projects were reviewed for the 30-year period between 1961 and 1990. Of these, 50 projects were further divided into facilities for production and urban residential/amenity assistance. Future emphasis will be towards integrated multiple-user/multiple-function offshore complexes focusing on an information-oriented, high-tech global marketplace.

1. INTRODUCTION

The wise use of coastal ocean space in harmony with the environment to meet the burgeoning needs of a coastal-minded society is a major goal as we enter the 21st Century. The coastal regions of ocean-bounded nations are developing rapidly, and some are doing so in an unplanned manner and without serious concern for the environment or quality of living. Since the industrial revolution, industrialized nations focused mainly on economic wealth, allowing the vastness of the land, ocean, and air environment to accept and defuse many insults to the environment. Now the people of industrialized nations are placing great value on the quality of the environment and living a better life.

Some environmental damage has already been done to coastal regions in the form of marine pollution, coastal erosion, and coastal smog; and to the global environment in the form of global warming and ozone depletion. Environmental programs have begun measuring, monitoring, and assessing environmental health; steps are being taken to stop further pollution and reverse the impacts; and new developments are expected to carefully consider potential impacts to the environment. Besides the present state of the environment, the population has also been growing exponentially over the last 40 years and is expected to almost double over the next 40 years from over 5 billion to about 9 billion. This steady increase equates to less land per person, doubling the need for food, potable water, energy, and material resources and a potential increase in environmental impact. The population growth continues to increase more rapidly in the coastal region where 50 percent of the population and industry lives within 50 miles of the coast and is expected to increase to

75 percent by the year 2000. In Japan, the figure is closer to 70 percent because of their relatively uninhabitable mountainous terrain. Even though inland space may be available in the U.S. and in some prefectures in Japan, the need to provide more coastal space for the coastal-oriented public seeking spatial openness, the coastal view, fresher air, marine recreation, and other social amenities of well integrated coastal communities is steadily increasing.

In Japan, the need for additional coastal real estate has resulted in developing artificial islands in estuaries and coastal areas for a variety of dedicated uses such as power stations; a new municipal airport; and integrated, high-quality living, working, educational, and recreational facilities. In Japan, major coastal development projects have been completed and others are under way and planned in major coastal areas including Tokyo, Yokohama, and Kobe-Osaka regions. In the U.S., several major port and harbor communities such as Los Angeles, Long Beach, Baltimore, and New York have begun or are planning large-scale coastal ocean space revitalization projects.

In order to assess trends in planning and development of offshore facilities, over 400 projects were identified in the literature for the 30-year period between 1961 and 1990. Of these, 50 projects were further divided into facilities for production, urban residential, and urban amenity assistance.

Future trends in coastal development include: port and harbor modernization and waterfront development; integrated living, working, and recreational facilities; a seaward extension of land-based facilities, artificial islands, and floating facilities and cities; and hybrid combinations of fixed and floating structures or partially buoyant structures.

2. ENVIRONMENTAL CONSIDERATIONS

The coastal environment is being impacted by slow natural processes punctuated by occasional natural disasters and human-induced impacts that appear to cause faster change. The slow geophysical natural processes have a profound impact usually dealing with time scales of centuries; however, occasional natural disasters such as earthquakes, tornadoes, and hurricanes are major forces that greatly impact coastal living and have significant implications in urban planning and structural design. Besides natural disasters, man-induced disasters exist such as global warming, ozone depletion, acid rain, and marine pollution. The significance of these on coastal ocean space utilization (COSU) is briefly described below.

2.1 Natural Disasters

Earthquakes have had a major impact all around the world. The Pacific rim countries and especially major coastal cities are located on the rift zones of the "ring of fire." Earthquake engineering has advanced structural designs to provide a high degree of shock mitigation for buildings on land. Construction of artificial islands on rift zones would be obviously avoided; the effect of tremors would depend on the degree of direct coupling and how much would be isolated by layers of sediment and the magnitude of the shearing lateral forces.

Floating facilities would have the added advantages of using the water as a buffer; however, an artificial island or floating facility near shore would require a design consideration for a tsunami which could be the result of an earthquake or coastal avalanche. Historic environmental data on earthquakes and tsunamis would normally be consulted in making a site selection and estimating the environmental forces involved. Similarly, historic data on typhoons and hurricane tracks and tornado paths are needed in the site selection process to consider those forces in structural design and protection of property. In regard to tornadoes, Doppler radar can provide as much as 30 minutes warning to permit people to seek appropriate shelter. Regarding the protection of human life against hurricane disaster, hurricane tracking radar and observation techniques provide early warning. In the U.S., all of the coastal basins of the East Coast and Gulf of Mexico have been modeled using computer techniques to predict hurricane landfall and the level and extent of storm surge. This provides a more localized warning to enable residents to evacuate and move in the right direction.

Many coastal cities in the U.S. and Japan are vulnerable to high magnitude typhoons and hurricanes. For example, in the U.S. over 20 years ago, Hurricane CAMILLE was the first category five hurricane in 40 years to hit a coastal city, resulting in very severe losses (256 lives and $1.5 billion) in 1969. Since then, many new coastal communities are located near shore at sea level and some on reclaimed land. Most of these low-lying communities are vulnerable to the devastating effects of powerful winds and storm surges. A storm surge from a category five hurricane striking the coast would be truly devastating for these coastal communities.

2.2 Global Warming

The phenomenon of global warming over the past century has been attributed to atmospheric accumulation of greenhouse gases such as carbon dioxide and methane, which act like a blanket to trap the sun's radiant heat. Greenhouse gases are produced by all forms of combustion, especially by automobiles, power generation, and the burning of wood in clearing forested land such as the Amazon Rain Forest. The environment's ability to assimilate carbon dioxide is being reduced because expanding urban development, deforestation, and destruction of rain forests increase the losses of trees and vegetation—the natural assimilators of carbon dioxide. The processes and capacity of our oceans to assimilate or release carbon dioxide is not well known at this time. Though exact figures cannot be predicted, the general consensus is that global warming will increase and produce deleterious effects impacting agriculture, causing sea-level rise, and affecting quality of life while society adjusts to its effects.

A consensus of researchers agrees that the Earth, on average, has warmed about $1^{o}F$ over the past century. If CO_2 levels double by the middle of the next century, global average temperatures may increase several more degrees. The resultant warming will not be uniform over the Earth—least in the tropics and greatest at the poles where it would melt some of the polar ice caps. The melted ice, most of which is now on land, and the thermal

expansion of the oceans would cause global sea levels to rise 30 to 60 centimeters (cm). Scientists continue to debate the exact magnitude and timing of worldwide warming.

The 1980s were the warmest decade in the last century and 1990 is one of the warmest years on record. Warming of the seas has already caused environmental degradation of coral reefs around the world. As the sea warms up, the coral polyps that build the reefs with their skeletal remains stop feeding on micro-algae and become weak and die; then the reefs lose their red, yellow, and golden hues, leaving the coral with a bleached look. These reefs can serve as early warning indicators of global warming of the seas.

Over the past 50 years, global sea levels have been rising at about 3.0 millimeters a year (three times the rate of the previous 50 years). If this trend continues or possibly escalates, sea levels could rise as much as 30 to 60 cm by the middle of the 21st Century, flooding some coastal cities and villages. This will create a concern in designing and constructing homes, buildings, ports, and harbors for future coastal communities.

Technology plays a vital role in providing: a wide variety of atmospheric and ocean measurement systems and large-scale networks to monitor the effects of global warming; conservation measures to reduce consumption of fossil fuels; a means to reduce CO_2 emissions; alternate fuels for transportation; alternate energy sources to supply electrical power; a means to redeem CO_2; and new water supplies to offset scarcity due to warming.

Sea-level rise is a major concern for coastal urban planning and structural design. A global sea-level measurement network is in place and can be referenced to a Very Long Base Interferometer (VLBI) System for obtaining absolute water-level measurements on the order of 1 cm. There are 16 VLBI stations worldwide that establish accurate geodetic references which are coupled to the Global Positioning System (GPS) satellite network for absolute water-level accuracy worldwide. Such absolute accuracy will enable determining whether the sea level is rising, or the land is subsiding or eroding. This is important information for coastal planners.

2.3 Marine Pollution

Regarding marine pollution, finite limits are being reached in many coastal areas, as highlighted by beach closings, prohibitions on shellfishing, habitat losses, and health warnings to seafood consumers. Many coastal regions around the world, especially near major population centers, have reached critical stages of marine pollution due to sewer outfalls, ocean dumping, land runoff, shipping discharges, and plastic debris from marine recreational activities and marine vessels. In addition, industrial waste and effluents are being discharged in coastal waters, and in rivers and streams that terminate in coastal estuaries. Hazardous material spills, especially those that occur in coastal waters and within the Exclusive Economic Zone (EEZ), are a major polluting concern. Major oil spills such as the EXXON VALDEZ (spilling 11 million gallons) and the AMOCO CADIZ (spilling 60 million gallons) provide documented results of the dam-

aging effects on marine life, marine habitat, beaches, wetlands, and on the economy and quality of life in coastal communities.

Many marine instrumentation systems are used to sample, measure, and analyze: water-quality, marine sediments, and marine life for pollutants. A major program under way at NOAA over the past 6 years is the National Status and Trends Program. This program involves sampling bottom fish, shellfish, and sediments at about 300 sites in coastal waters around the United States; making laboratory measurements of over 70 chemical contaminants in sediments, fish livers, and bivalves; and analyzing annual measurements for year-to-year comparisons to determine the status and trends in pollutant levels. Based on 6 years of measurements, the highest concentrations of both trace elements and organic contaminants were found near major coastal cities of Boston, New York, San Diego, Los Angeles, and Seattle.

2.4 Coastal Data and Information

Most of the developed nations have various data collection, processing, assessment, dissemination systems, and archival centers holding the kinds of environmental information identified in the previous sections. The scope, extent, quality, and accessibility of this data differ in each nation. In the U.S., major efforts have been undertaken to access all available sources of data and information taken in the past and present, especially in the coastal ocean and EEZ. This information is electronically stored, processed, and analyzed using desk-top computer systems. More of the data is being entered and accessed, using the Geographic Information System (GIS). Also, the data is compiled in atlases, covering all of the U.S. coastal regions out to the limits of the EEZ. Using this type of data and information is essential to decision-makers involved in all aspects of coastal ocean space development and utilization.

2.5 Environmental Impact of Structures

Marine structures can be largely divided into several types (i.e., floating, fixed, gravity, and reclaimed land types). The degree of their impact on the ocean environment (ecology, climate, and physical characteristics) varies from major in the case of reclaimed land structures to light in the case of a semisubmersible platform. The impact of a structure on the ocean environment is largely determined by: the degree of free flow of seawater (including content of dissolved oxygen, nutrients, and any imparted temperature change); the degree of sunlight penetrability to stimulate photosynthesis and carbon dioxide assimilation; and the rate of evaporation (affected by atmospheric and water temperatures). In general, the impact is likely to increase with a larger ocean space coverage area of a structure.

Regardless of its type and size, a structure's use objectives and assigned functions can have a severe impact on the ocean environment. If a structure is intended solely as living space, the impact is relatively small. In comparison, the potential impact is very large in the case of a desalination plant, an OTEC, or a nuclear/coal/oil thermal power generation plant which directly uses very large volumes of seawater as a heat exchange

medium. Furthermore, a petrochemical plant, chemical plant, or a heavy machinery manufacturing plant which produces contaminant industrial waste may cause as much damage as the above.

In considering technical issues relating to ocean control, calm and safe ocean space must be secured to protect and also promote the effective use of the ocean space. Technologies to control high tides, tsunami, and swell are very much localized at present and require urgent development of technologies to safely stabilize and control extensive ocean space.

2.6 Ocean Space Development in Harmony with the Environment

Based on these environmental considerations, guidelines for future coastal ocean space development include:

- Site selection and development for economic gain in balance with the ecological needs of society.
- Avoidance of sites prone to damage by natural hazards, and design considerations which protect against serious damage due to hurricanes, typhoons, and storm surges.
- Minimize alteration of the natural environment. Preference for structures which reduce alteration to natural circulation, temperature, and chemical constituents of the body of water intruded.
- Avoidance of hydrocarbon fuel combustion by using alternate fuels relatively free of pollutants for electric power plants and transportation systems.
- Energy alternatives including solar and solar-derived ocean energy systems; advanced safe nuclear power systems including future development of nuclear fusion; and conversion to hydrogen for a clean-fuel economy.
- Municipal waste management systems based on recycling waste materials and clean incineration of toxic wastes within acceptable standards.
- Special handling and storage of toxic materials and treatment facilities to neutralize wastes.
- Incineration at sea within acceptable standards and possible use of fly ash for manufacturing environmentally safe building materials.
- Ocean energy conversion for electrical energy and other cost-effective products such as freshwater and nutrients for aquaculture.
- Artificial upwelling systems that stimulate photosynthesis for open-ocean ranching and controlled absorption of atmospheric CO_2.
- Environmental monitoring systems that periodically monitor environmental parameters that are indicators of environmental health.

3. EVOLUTION OF OCEAN SPACE DEVELOPMENT PROJECTS

A total of 402 ocean space development projects were identified in the literature for the period between 1961 and 1990. These included completed development projects, those previously planned and proposed, and those currently under way or planned. In the case of planned projects, only those which have been determined to be technically feasible through engineering analysis (excluding financial factors) were selected. These projects are classified in Table 1 in terms of their functional characteristics (production, recreation, urban and residential space, transportation/communication, safety/disaster prevention/national land conservation, and others) and resource characteristics (biological, mineral, seawater, and ocean energy and space such as coastal or offshore development). The classification results show that production facilities are the top category in terms of function, followed by transportation-related facilities. In terms of resource development, mineral and seawater resources are first, followed by offshore space development projects. Fifty projects were selected based on the criteria that they are ocean space utilization projects for the benefit of society and not just coastal land reclamation projects. These 50 projects were further divided into production facilities (industrial production base, oil and gas storage, and production base), urban amenity assistance facilities (power generation plant, airport, recreation facility), and urban residential facilities (marine city). Their structural types (reclaimed land type, gravity type, fixed type and floating type) and physical characteristics (in terms of distance from the nearest coast, sea depth, location and space coverage area), graphically illustrated in Figures 1 through 4, were compared and the following observations can be made.

3.1 Structural Type

The reclaimed land type is the most common of both current and planned projects because of technical feasibility and relative economy. The floating-type structure is usually associated with deep sea, single-function small projects.

3.2 Relationship Between Sea Depth and Distance from Coast

There is an obvious growing trend for production facilities to be located in deeper waters because of diminishing coastal resources and access to more resources. In comparison, urban amenity assistance facilities are mainly located in shallow seas near large cities for such obvious reasons as access cost (which depends on distance and available modes of transportation). Urban residential facilities are either located in shallow, near-coastal areas (less than 20 m deep and 1 km distance from the coast) or in deeper offshore areas (20-100m deep and about 5 km distance from the coast). The former is associated with reclaimed land-type structures while the latter is associated with either reclaimed land-type structures or floating-type structures.

3.3 Relationship Between Area Size and Distance from Coast

The size of production facilities tends to diminish with increased distance from the coast and these are mainly associated with single-function facilities. Conversely, the size increases with multi-functional features when the distance from the coast is less. Urban amenity assistance facilities tend to be very extensive, covering 100 to 10,000 hectares (ha) and are located near large cities. A tendency exists for these facilities to be associated with coastal, shallow sea, and large size development. Urban residential facilities increase in size with provisions for urban amenity assistance facilities, but their locations have become bipolarized to shallow sea, coastal development, and deep off-shore development.

3.4 Environmental Considerations

In the case of both urban amenity assistance facilities and urban residential facilities, public parks and gardens are planned as part of the utilization of artificially created land in order to harmonize between comfortable living conditions and to protect the natural environment and wildlife. Regarding ocean environment conservation, there is a trend to create artificial beaches instead of the conventional means of erecting barriers or groins to provide for beach conservation and protection.

3.5 Development Concept

Changes in the types of development projects reflect the requirements of the time period. Before the 1973 oil crisis, many ocean development projects were aimed at national visibility and growth with companies competing with each other for the development of oil and gas resources. Since the oil crisis, however, projects associated with alternative energies such as solar and solar-derived energy became noticeable; the OTEC and wave energy conversion projects are examples. From the functional point of view, a single function plant construction has shifted to a multi-purpose use of reclaimed land. With regard to urban amenity assistance facilities, international airport projects on reclaimed land serving large nearby cities with close cooperation with international ports have become popular, due in part to the globalization of the economy. In the case of urban residential facilities, the conventional new-town-type projects have been increasingly replaced by multi-purpose projects, providing commercial functions with a large service industry sector creating and dealing with intellectual property rights, as well as conference functions for information exchange in addition to the residential function and its cultural and recreational amenities.

4. TRENDS AND FUTURE REQUIREMENTS

4.1 Trends

The changes in ocean space utilization reflect the changing economic and social needs. If the period from the mid-60s to mid-70s (to the mid-East oil crisis) is considered to be the first ocean development period, it was a period of resource exploration and development in both territorial waters and high seas. In this period, secondary marine

industries emerged from the exploitation of oil, minerals, and fish resources. Most projects using ocean space were associated with heavy industries or the concept of coastal industrial cities which would process and exploit marine resources.

In contrast, the second ocean development period lasting from the mid-70s to the mid-80s can be regarded as an age of alternative energy development to respond to the oil crisis. This included an emphasis on nuclear power, and solar and solar-derived energy. An offshore nuclear power plant was designed for a site off the east coast of Florida. Examples of solar-derived energy include ocean thermal energy conversion (OTEC) and wave energy conversion projects. It was a period dominated by the problem-solving type ocean development concept which addressed not only the development of alternative energies, but also the creation of alternative space to deal with the overcrowding of cities and the preference for the amenities of coastal living. An ocean city project and a maritime airport project are the best examples of such projects. Efforts were made to solve problems on land using ocean space.

The third ocean development period commenced in the mid-80s and continues today. It can be described as a period of integrated multiple-use of coastal ocean space influenced by the globalization of ocean development and the tendency towards tripolarizing the international economy. The dominant status of tertiary industries which account for more than 70 percent of the GNP have been pressing the secondary industry-based ocean development to transform to service-type industries and high value-added industries.

The vast consumption of fossil fuels since the industrial revolution, increasing urban development, and the gradual disappearance of the tropical rain forests may cause the global environment to become increasingly warmer. The conventional symptomatic treatment or problem-solving type ocean development approach is only partially capable of handling this new situation, requiring the urgent adoption of a preventive and target-setting type ocean development approach. At the same time, the infrastructures of such large cities as New York, London, and Paris (built at the beginning of the 20th Century) are showing signs of urban deterioration, and the construction of a new infrastructure suited to the new information-oriented society and global marketplace of the 21st Century is needed. The components of such a new infrastructure include international transportation complexes integrating sea, land, and air transportation and performing media functions; international exchange facilities such as convention centers for the exchange of people, goods, money, and information; and intelligent business centers. In addition, the research and development of large-scale environmental control technologies will contribute to the conservation of the global environment. Such an approach can be described as social capital enhancement-type ocean development.

4.2 Future Requirements

As described earlier, we are now in a period of integrated multiple-use of coastal ocean space as we approach the 21st Century. The outlook differs from the conventional singular approach of ocean

development, with opportunities for bold new concepts.

The first ocean development period showed a distinct tendency towards offshore, deep-sea projects, mainly in search of seabed resources. The corresponding structures tended to be floating, single-function types in view of economy and mobility. The second ocean development period focused on alternative energies including extraction of ocean energy, and also as a period for construction of urban amenity assistance facilities to solve the various problems encountered by major port cities trying to combine production/ distribution functions with basic urban functions. The third ocean development period focuses on the information-oriented global marketplace and integrated multiple use of ocean space by such megapolis blocks as the European Economic Community (EEC), North American Economic Community (NAEC), and the Asian Economic Community (AEC), leading to the consolidation of the international infrastructure for the 21st Century.

Construction of a new maritime infrastructure for transportation, information/ communications centers, urban utilities, and amenities is needed to revitalize international cities along the world's coasts. The expected population increase and the migration of the population to megapolis blocks will contribute to the greater consumption of resources, thus accelerating programs to probe and develop new marine resources of the EEZ and the deep ocean.

The next generation requirements for ocean development will first include the development of global environment (oceanic and atmospheric) control technologies using the various inherent capabilities of the ocean. One underlying concept put forth is "The Ocean will save the Earth." Secondly, clean energies and food resources will be developed. One leading candidate for this is a multipurpose OTEC using the ocean's thermal energy for direct use and secondary conversion for hydrogen fuel production. A large-scale seafood production system using cold water nutrients derived from OTEC operation will have considerable potential. Also, artificial upwelling systems can be deployed in a large network to enhance fishery stocks. The development concept for such systems can be termed "Environment Friendly Ocean Development." Thirdly, the creation of a coastal city network for mutual benefit and interaction on a global scale will become an important theme, facilitating the introduction of a safe, rapid mass transportation system; and the construction of an integrated infrastructure. This is in accordance with the basic concept for a "Prosperous Symbiotic System for Ocean Space Utilization."

5. CONCLUSIONS

Coastal ocean space and associated development projects have evolved to a level in which technology is capable and available to address many of the present and future requirements to satisfy multiple-user needs in harmony with the environment. Environmental assets must be considered in our accounting system and perhaps economic forces could be used to preserve the environment. A healthy economy can only survive with a healthy

ecology. Seaward extension of many major coastal cities or regions can be used to develop a new more integrated social, economic, and environmental infrastructure. This could include provisions for a centralized, more rapid multi-made transportation system integrating air, sea, and land transport of people and goods. It could also provide an integrated complex for comfortable living, recreation, and cultural activities, along with a co-located working environment mainly concerned with information-oriented and high-technology products.

Seaward extension could be a direct extension of the shoreline; an artificial island linked by bridges or tunnels; or an offshore floating facility or city which can be linked in the same way; and/or by a high-speed surface craft. As a floating city is located further offshore, other supportive and complimentary ocean facilities can be incorporated in future designs. These include: ocean energy with by-products for freshwater, aquaculture, calm seas, and air cooling; artificial upwelling to enhance photosynthesis and fisheries production via open-ocean ranching and artificial habitats; production of hydrogen from electrolysis of seawater to provide clean fuel for power plants and transportation; environmentally compatible mineral extraction from seawater and the seabed; and a base for environmentally compatible ocean industry.

Coastal ocean space can be developed in an integrated multi-user/multi-function to satisfy social, economic, and environmental needs.

6. DISCLAIMER

The concepts and ideas presented in this paper are the views offered by the authors and do not necessarily represent the views of any organizations with which they are affiliated.

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Table 1. Ocean Space Development Projects

Project Name	Country	Plan (P) Constr (C)	Area (ha)	Dist (km)	Depth (m)	Structure Type
Industrial Use						
Nagova-Port No. 9	Japan	1961-C	218	2	3	Reclam
Yokohama Honmoku Port	Japan	1963-C	594	2.5	12	Reclam
Yokkaichi Kasumigaura	Japan	1967-C	387	0.1	12	Reclam
Oogishima Artificial Is.	Japan	1971-C	515	0.4	15	Reclam
Osaka North Port	Japan	1972-C	615	0.5	10	Reclam
Industrial Is. in the North Sea	NLD	1973-P	50	50	25	Reclam
Multipurpose Offshore Industrial-Port Is.	USA	1975-P	728	13	18	Reclam
Akita-Wan Artificial Is.	Japan	1982-P	780	7	35	Reclam/ Pile/Jacket
Shimonoseki Kitaura	Japan	1984-P	750	1.0	30	Reclam
Oil-Gas Development						
Thums Island	USA	1965-C	16	2	12	Reclam
Ubarana Concrete Platform	Brazil	1967-C	0.2	12	15	Gravity
Roberts Bank Development	Canada	1968-P	90	4.8	21	Reclam
Porto de Areia Blanca	Brazil	1973-C	1.8	1.4	7	Reclam
Namorado Platform	Brazil	1973-C	0.3	90	146	Pile/Jacket
Fisherman Island	Australia	1977-C	600	0.7	0	Reclam
Statford Platform	Norway	1980-C	1.3	150	145	Gravity
Tarsiut Island	Canada	1981-C	1	40	22	Reclam
Shirashima Floating Oil Storage	Japan	1986-C	60	8	4	Float
Power Plants						
Bolsa Island Project	USA	1970-P	15	1	20	Reclam
Atlantic Generating Sta	USA	1970-P	75	4.8	17	Float
Offshore Coal Pwr Plant	Japan	1980-P	120	7	25	Reclam
Floating Is. - Coal Power Plant	Japan	1980-P	2.25	30	100	Float
Nuclear Power Plant	Japan	1980-P	2.96	5	100	Float
Gobou Power Plant	Japan	1980-C	35	0.2	18	Reclam

Project Name	Country	Plan (P) Constr (C)	Area (ha)	Dist (km)	Depth (m)	Structure Type
Airports						
Oita Airport	Japan	1970-C	103	0.1	4	Reclam
Nagasaki Airport	Japan	1971-C	163	1.5	18	Reclam
Boston New Airport	USA	1971-P	735	16	15	Reclam
Honolulu Airport	USA	1973-C	400	0.4	9	Reclam
Lake Erie Int'l Airport	USA	1973-P	0734	13	14	Reclam
Chicago Lake Airport	USA	1975-P	4450	9	17	Reclam
L.A. Offshore Airport	USA	1975-P	4047	8	23	Reclam
Takamatsu Airport	Japan	1978-P	141	1	20	Float
Kansai Int'l Airport	Japan	1988-C	1159	5	20	Reclam
San Diego Airport	USA	1989-P	800	6	600	Float
Recreation Use						
Nagoya Port Kinjyuou Futou	Japan	1963-C	141	1.4	5	Reclam
Tampa Harbor Project	USA	1967-C	240	3.5	5	Reclam
Yokohama Daikoku Futou	Japan	1971-C	321	0.5	12	Reclam
Hart Miller Island	USA	1976-C	40	1.2	5	Reclam
Karita Artificial Island	Japan	1981-C	153	3.5	8	Reclam
City & Residential Use						
Port Island - Kobe	Japan	1966-C	436	0.4	13	Reclam
Monaco Offshore Is.	France	1968-P	6	4.8	300	Float
Hawaii Floating City	USA	1970-P	45.4	5	1000	Float
Rokko Is. - Kobe	Japan	1971-C	583	0.2	14	Reclam
Kawasaki Higashi Oogishima	Japan	1972-C	434	0.7	10	Reclam
Okinawa Aqua-Polis	Japan	1974-C	1	0.3	50	Float
Man-made Is Complex	Japan	1985-P	3000	2	25	Reclam
Offshore Is Project	Japan	1985-P	3400	5	30	Reclam
City Complex Is	Japan	1985-P	5000	5	30	Reclam
Shimizu Artificial Is.	Japan	1986-P	230	0.5	10	Reclam
Oomura-Wan Manmade Is.	Japan	1988-P	1000	2.4	22	Reclam

Abbreviations: Island - Is.; Power - Pwr; and Station - Sta; Netherlands - NLD.

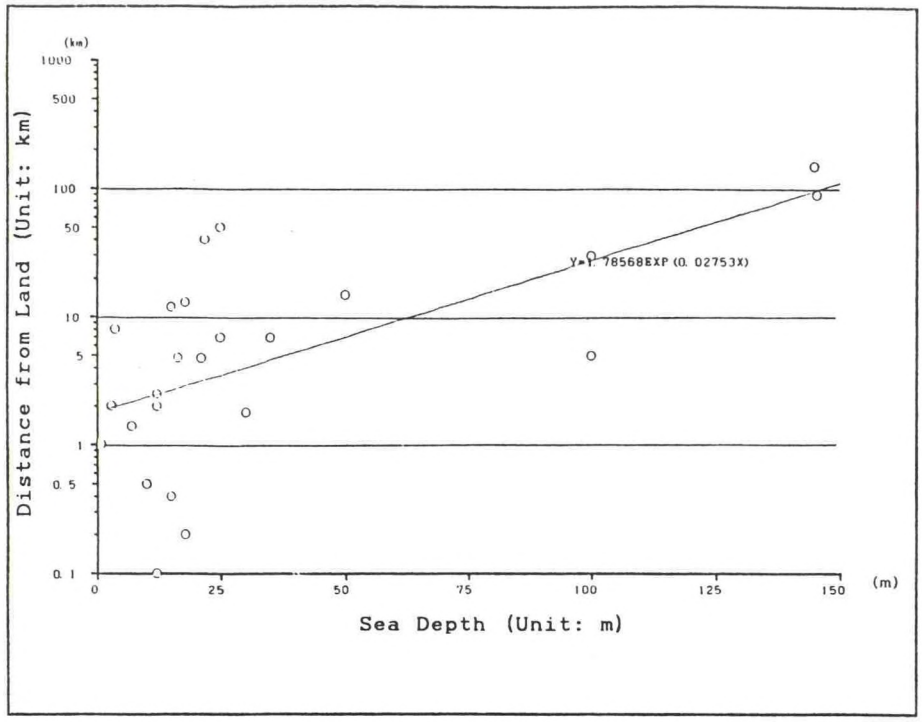

Fig. 1. Production Project: The Relation Between Distance and Sea Depth

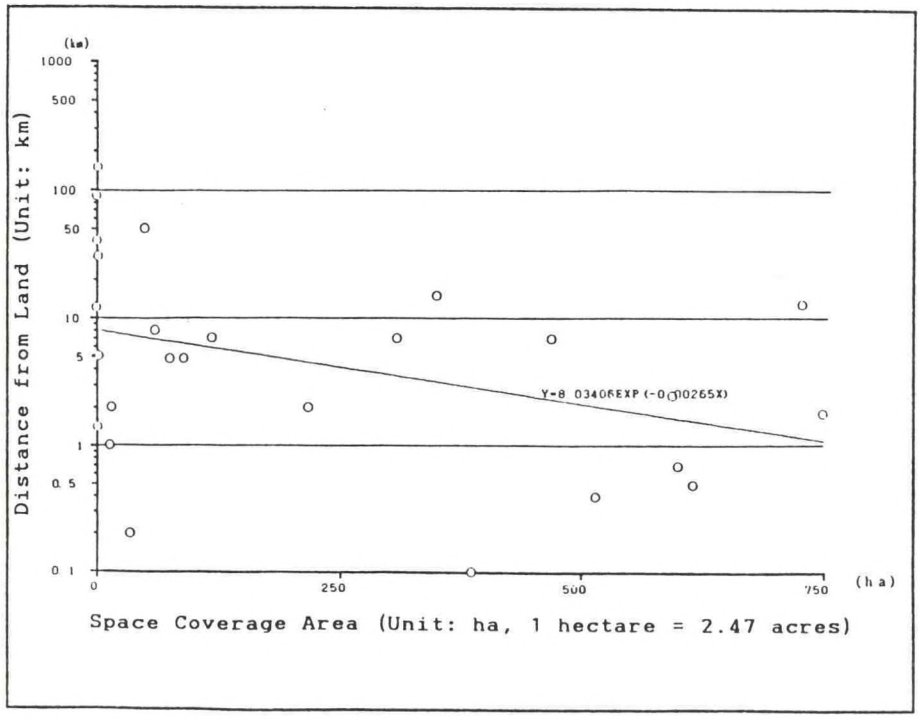

Fig. 2. Production Project: The Relation Between Distance and Area

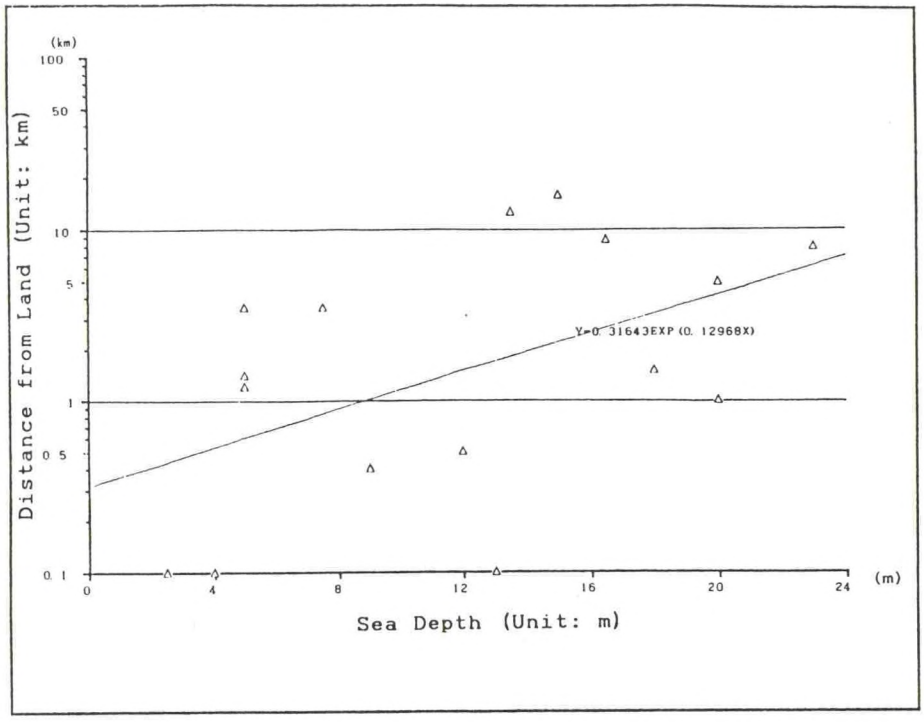

Fig. 3. Urban Assistance Project: The Relation Between Distance and Sea Depth

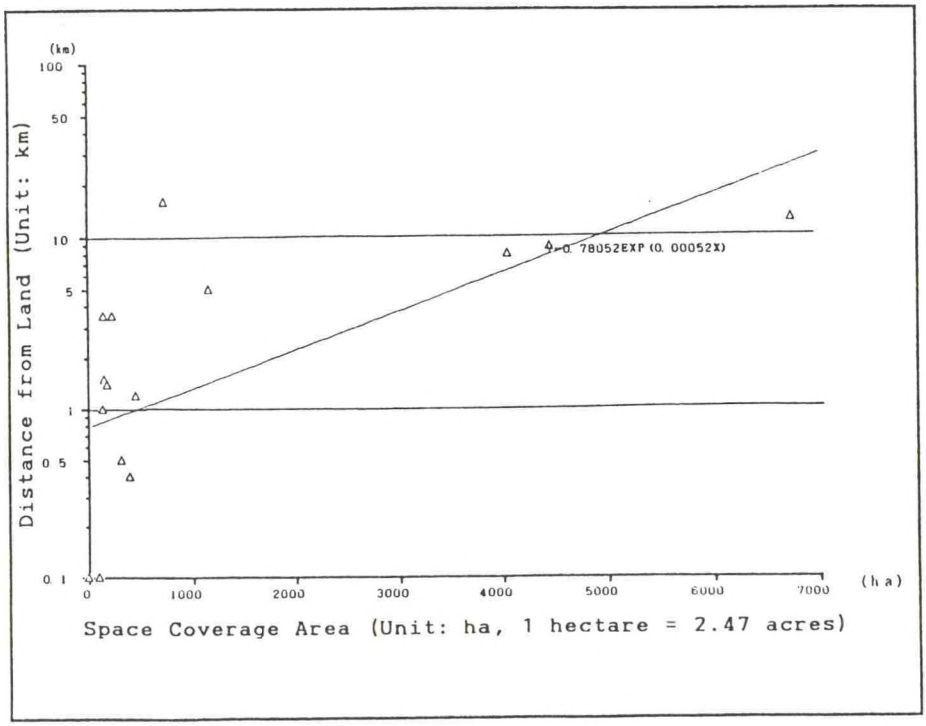

Fig. 4. Urban Assistance Project: The Relation Between Distance and Area

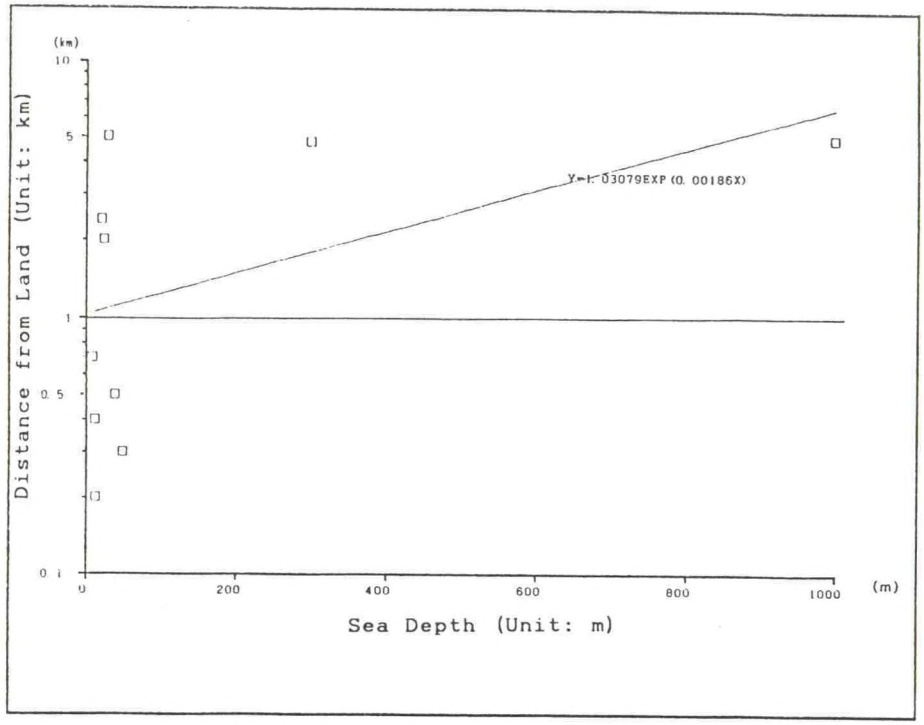

Fig. 5. Marine City Project: The Relation Between Distance and Sea Depth

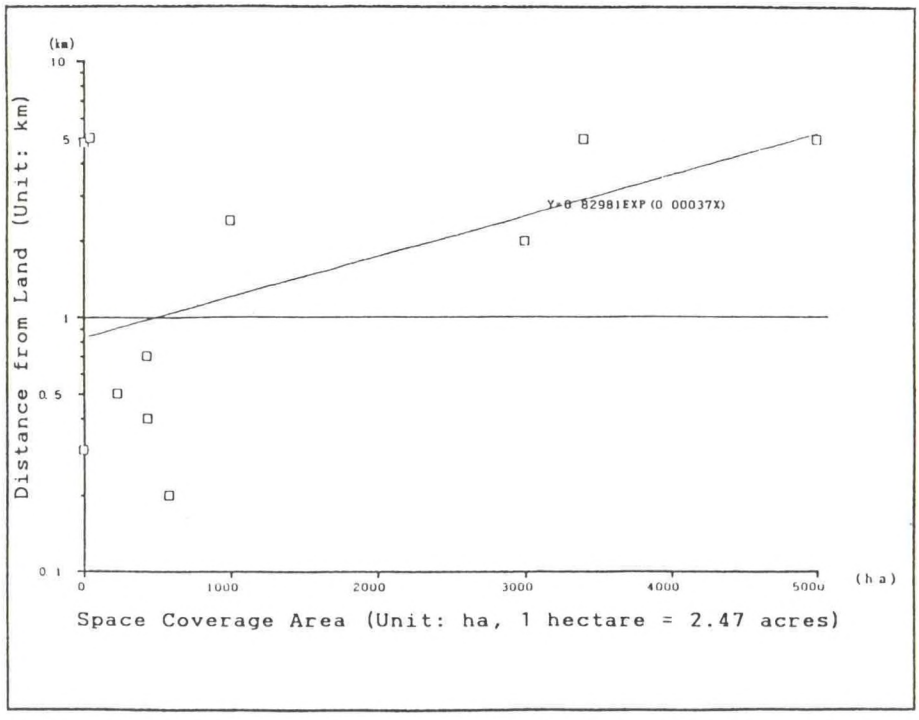

Fig. 6. Marine City Project: The Relation Between Distance and Area

VERY LARGE FLOATING PLATFORMS: AN OPTION FOR MIDDLE EAST PEACE KEEPING

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INTRODUCTION

Now that the Gulf War has come to a close, peace keeping in the Middle East surfaces as a critical objective for this region. Very Large Floating Platforms (VLFPs) offer a viable solution to maintaining forces in this area.

An option for addressing peace keeping military needs is an offshore floating mobile forward tactical base. Aircraft participating in tactical missions and surface craft engaged in patrol activities could be launched and docked from such a floating base. It would also serve as a support and deployment point for personnel involved in tactical missions. Logistic support requirements for the base, as well as for the missions originating from it, call for runways long enough for large transport aircraft as well as docking facilities for large ships. A large stable floating platform of modular construction easily meets all of these military requirements.[1]

Earlier papers (see references 1,2,3,4) and recent workshops (5) have summarized the background, technology and engineering status required for the development of VLFPs. The imperatives to move ahead rapidly in developing VLFPs continue to grow as demands on shrinking resources become more urgent due to continued population growth and turbulent world events. Applications that could effectively utilize VLFP resources include:

- Military Ocean Basing Systems
- Offshore Airports
- Ocean Thermal Energy Conversion Plants / Mariculture
- Waste Incineration / Disposal Plants
- Large Theme Park / Commercial Recreation Facilities

The technology and engineering base is currently in place to support the development of any of these applications.

VLFP development will require relatively large up-front capital investment; therefore, considerable financial advantages must be recognized over the life of the system. In their paper[1], Hightower, Rona and Talkington noted that multiple use of a VLFP would be necessary to provide clear financial advantage required to justify development of the VLFP and its infrastructure. They also noted that while national security was an important issue, declining military budgets would probably make significant United States Department of Defense expenditures

unlikely. However, the recent crisis in the Persian Gulf, combined with increasingly difficult negotiations for continued use of U.S. bases overseas, provides a new perspective in examining the benefits of VLFPs. Large modular floating structures could (1) replace the past reliance on foreign sites for forward area logistic and tactical support missions; and (2) provide immediate fully-operational capability versus repetitive, expensive, long term construction and/or redeployment of assets.

Although the initial costs of VLFP development seem high they are, in fact, very reasonable when viewed in the context of possible follow-on commercial applications. Fortunately, top level requirements for military applications are consistent with many attractive commercial and industrial applications for large floating platforms. This mutually beneficial trend has been demonstrated recently in the space exploration arena, where commercial involvement in initially government-sponsored programs has created economically attractive industries.

It is likely that the commercial payoff in the ocean related industries, noted earlier in this paper, would be realized more quickly than those that occurred with our space programs. This paper briefly summarizes critical factors concerning Middle East stability. In turn, it strongly suggests that the nature of these factors provides sufficient rationale to develop a VLFP peace keeping Persian Gulf base for use by United Nations Security Forces. In addition to addressing peace keeping needs, such an investment will undoubtedly lead to future important non-military uses, as noted above. Finally, the physical ocean conditions of the Persian Gulf are ideal for the initial development of a VLFP.

RECENT DEVELOPMENTS

The Gulf War is over. The objective now is to avoid further hostilities to ensure future stability in the region. The U.N. Coalition must select the next course of action carefully to address these critical sensitivities.

Present plans for peace keeping measures in the area call for a continuous strong U.N. Coalition military presence. This presence is needed primarily because of the continued stress between Arab countries due in part to the following factors:

- Fundamental Arab / Palestinian / Israeli incongruities;
- Kurdish turmoil and the apparent unwillingness of the countries in the region to allow a Kurdish state to exist;
- Irreconcilable religious differences;
- Unwillingness of the Israelis to accept or believe in a promise of peace in the region;
- Uneven distribution of wealth;
- Ready abundance and availability of modern armaments;
- Availability of terrorism as a tool for achieving dislocation and turmoil.

The totality of these factors indicates continued instability in the region requiring the presence, or at the very least the assistance, of a peace keeping, neutral entity such as the U.N. Security Forces. This seems likely to continue for a considerable period of time extending into the next century.

To be most effective, the peace keeping contingent must be as unobtrusive and inoffensive as possible. Staging foreign security forces (with no interference from local forces) for several months while preparing to launch another blitzkrieg war against any offender is certainly not guaranteed. The extent of the destruction of Kuwait will become a barrier to such actions. The loss or

serious curtailment of significantly more of the region's oil production, whether by denial by a new government or from destruction by sabotage or war, would result in a disruption that the industrial countries, and indeed the world economy, can not tolerate.

The peace keeping force, in order to be omnipresent, a deterrence to adventurers, and inoffensive to the population, cannot be lodged where its presence, actions, and non-Islamic character are constant, unacceptable irritants. One solution worth analysis is the installation of such a force offshore on a VLFP, thus avoiding and minimizing the above political realities.

The apparent high cost of developing such a floating base pales when its benefits are considered. Calculation of the cost of Desert Storm and rebuilding Kuwaiti and Iraqi infrastructures make the cost of a VLFP in the Persian Gulf, supporting an adequate United Nations peace keeping force to police the region, appear very reasonable. The inherent stabilizing effect of such a projection of power and the guarantee of borders would allow significant reductions in the required armed forces now maintained by neighboring nations. Coupled with the establishment and maintenance of a competent intelligence service, such a peace keeping VLFP would allow actions to be taken in a timely manner avoiding full blown disasters.

A recent Forum held in Paris (April 10-11) focused on the security of Europe in the 21st century. Removing the threat and cost of potential Middle East wars from their concerns would simplify Europe's political priorities and future planning. The assurance of peace and stability in the Middle East is a critical global issue involving not only Europe but also Asia and the Americas.

RECOMMENDATION

Given the crisis situation that still exists in the Middle East and its economic impact on worldwide stability and peace, it is urged that the use of detached VLFP peace keeping bases be fully explored as soon as possible. Initially, functional requirements from U.N. Security Council representatives can provide baseline inputs for a conceptual design using methodologies developed in recent international workshops.[5] This concept design would form the basis for a critical analysis which would include:

- Determining a realistic schedule for development and deployment;
- Identifying any insurmountable physical obstacles to installing such a floating city in the Persian Gulf or its environs (not likely);
- Calculating costs of a floating base and its peace keeping force;
- Listing the realistic geo-politic, psychological and physical obstacles to VLFP success;
- Matching this sum and effort against the costs, including the economic and industrial dislocation, of another Desert Storm.

The path forward to achieving this objective includes assembling the existing technical experts and information base available on the subject (e.g. the University of Hawaii, the U.S. Navy Laboratories including NOSC, the Japanese, the French and other European technical expertise); preparing a preliminary proposal integrating all of these elements into a cohesive program; providing discussion copies to appropriate U.S., Japanese, and European interests; and organizing and preparing a sound financial backing for the implementation of the program which will include as many interested parties as feasible.

The answer to the question of how to fund VLFP development is crucial to its success. This approach needs to address reasonable cost sharing and benefits derived among the principals. The total cost for a VLFP peace keeping base includes the prior investments in development of the existing technology base. This fact coupled with the pressing needs of the region and the enormous financial burden already borne by the U.N. Coalition nations are reasonable considerations to include in determining the distribution of the cost of construction and operation of such a base.

Successful development means a gain for the Arab nations' stability without the need to maintain a large standing army. Stability is based on the concept that foreign armies are not likely to represent a threat to existing Arab governments if they are not stationed on Arab soil. The U.N. Coalition gains by the ability to establish a presence in the Gulf, without the turmoil and political stresses associated with maintenance of in-country forces. For these reasons, the Arab leaders of oil-producing countries would be wise to cover costs of the development and operation of this first demonstration. This kind of cost sharing arrangement would benefit all parties and would be an important inducement to U.N. Coalition nations to bear some of the costs associated with maintaining troops and heavy equipment in the Persian Gulf area on a semi-permanent basis.

BENEFITS

The Arab nations also gain because much of their investment will be domestic. This factor, coupled with a reduction in their military investment requirements, represents a net savings to the Arab economy.

A major benefit to the West is the realization that — even though construction might take place in the Gulf — the associated technology will be provided by the American, Japanese, and European Coalition nations. That is, Arab nations might pay for this specific application of the technology but, in other worldwide applications, the building of modules would undoubtedly take place in other construction sites adjacent to other oceans under appropriate financial sponsorship.

American, Japanese, and European knowledge and design expertise must initially be used to provide the shipyards needed to build modular platforms: to build the modules, to assemble, and finally, to operate them. Much of this existing information can be learned and absorbed by scientists and engineers from the Arab countries. This kind of technical infusion in their culture is one of the goals of the Arab leaders and is important to their future. With this technical infusion, they will also have a momentary lead in the associated science and technology. This would put the participating Arab countries in a strong competitive position to realize the advantages of industrial expansion onto the oceans of the world.

The successful demonstration in the Persian Gulf will provide the impetus to foster a VLFP marketplace in other parts of the world. If this concept can be rapidly implemented, everyone can benefit and we will all have contributed to a meaningful step forward in peaceful world development.

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RESEARCH REQUIREMENTS FOR OFFSHORE LARGE STABLE PLATFORMS

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Introduction

The concept of floating cities, airports, naval bases and similar structures has been an area of fanciful speculation for several decades. And although attractive and stimulating designs have been prepared, except for a very few "exhibition" or limited special-service applications, no truly large all-weather offshore facility has been designed and priced. The principle reason is a profound lack of technical data, a shortcoming that this paper addresses in some depth. The determination of economic opportunity is possible only when realistic costs can be estimated which, in turn, requires a data bank based on sound engineering confirmed by both mathematical and physical modeling.

The location of major cities throughout the world reflects the historic importance of maritime or waterborne transportation. Once established, cities with their labor force, infrastructure, governmental and cultural establishments and facilities are extremely hard to relocate. Although railroads and highways have impacted this verity to some extent, most of the world's population is still located in the coastal area. With the threat of sea-level rise and the extremely high cost of land in heavily populated areas, the large floating facility deserves in- depth consideration to facilitate reasonably accurate estimates to determine the economic feasibility of the concept.

The Challenge

This paper gratefully recognizes the many excellent techniques and algorithms existent for the analysis of offshore (and onshore) structural components and structures. The research agenda developed herein focuses on their use in this design application and the definition of problems and approaches unique to large floating facilities. The problems have been divided into groups to permit their logical consideration. First, those that are basic in that they are driven by the structure's extreme size of, say, 5 miles long x 2 miles wide x 500 feet deep. Second, those that are operational, again driven by size factors but also the extreme variability of open ocean weather. And, last, those technical problems that are driven by the configuration and structural details of the facility.

Basic Problems

Extensive trade-off studies will be required to determine the final configuration of any large floating facility. The concept of a single rigid structure of the dimensions mentioned above is extremely attractive from the point of view of structural simplification through elimination of connectors between modules. On the other hand, the use of modules, say 1000 ft. long x 500 ft. wide x 200-300 ft. deep dominates our current planning as many sites exist for the construction of such modules in several parts of the world. A

popular concept involves the excavation of a large graving dock, the building of several modules, the subsequent flooding of the area and towing the modules to a protected deepwater area for assembly into major sectors of the facility. The required water depth, say 100 to 150 ft., close to shore in a protected area reduces such construction sites appreciably. When the costs attendant to final assembly and moving of a major facility are included, possible sites in the world are reduced to perhaps ten. Realistic estimates are required to determine the power and time needed to move both modules and sub-assemblies of modules through heavy sea states against high winds and currents to further define the optimum construction sites.

The design and construction of modules will be strongly influenced by several factors: local deckloads, the materials of construction, the loads between modules and the techniques employed for connecting modules to each other. The use of lightweight reinforced concrete is an obvious choice for the construction material if suitable pre- and post-tensioning cabling can be provided and the foundation structure for hinges or other types of connectors can be incorporated in the basic design of the modules. Few questions remain as to the durability and maintainability of such reinforced concrete structures, but conventional welded steel remains an obvious alternate material. The ability to manufacture, subassemble, build into modules and connect modules is well within the scope of modern steel construction. On the other hand, the maintenance of a steel structure in terms of biofouling, corrosion, and wastage are major factors if the long expected life of these structures is to be realized. The use of inorganic zinc coatings and cathodic protection are obvious approaches to the problem, but trade-offs must be conducted to evaluate the relative costs of a modern steel structure and a reinforced concrete structure.

The use of fiber reinforced polymer composites has been suggested for offshore platforms although the quantities required for a single major structure far exceed the world's current manufacturing capacity. It is certainly doubtful, at this time, that our understanding of the strength, effects of water absorption and the longevity of this material is adequate to forecast costs accurately for the early application of these materials to large floating offshore facilities.

As alluded to above, the construction, assembly and subsequent relocation of such an offshore structure must be a major consideration. Obviously, the facility would be moved at slow speeds taking full advantage of wind and current patterns. Normal short duration storms could be the source of local damage and short delays, but clearly such minor extraneous happenings would not be significant factors in terms of the mobility and the power required to relocate such a structure from one area of the world to another. Again, the need for deepwater protected areas for the assembly of the structures is obvious. The need for an extensive industrial infrastructure is equally obvious thereby significantly limiting construction and assembly sites unless the modules were extremely small.

Operational Problems

Early informal calculations have suggested that hundreds of thousands of horsepower would be required to move these types of structures from one location to another. And, in spite of frequent negative legalistic references to the U.N. Law of the Sea Treaty, mooring such a facility with the ability to "weather vane" has tremendous appeal. The problems of disassembly and assembly suggest that the structures will be separable into smaller units consisting of some dozen modules necessitating the disassembly and reassembly at each new site. Hence, great attention must be paid to the facility configuration, the sea state limits and currents at the mooring site.

It is entirely practical in these structures to provide a buoyancy allowance permitting the unrestricted growth of barnacles and seaweed on the underwater structure without loss of freeboard. On the other hand, there is little opportunity, if any, to dry dock such a structure for the removal of marine growth or the maintenance of coatings. On site removal of several decades of macrofouling is

practical and would probably be required if relocation involved great distances. Hence the normal maintenance of such a structure could be addressed to the waterline area and the super-structure, where weathering may be a problem, while the sub-structure would be treated only in conjunction with the relocation of the facility.

As referred to previously, our legal colleagues have raised the issue of mooring such a structure in international waters. Evidence at hand supports the argument that the structure can be moored legally but the maintenance of a mooring system and the ability to handle "hundred year storm" loads has yet to be fully investigated. It is believed that the mooring devices required will be existent systems with "smart work systems" available to make necessary repairs. The maintenance of the structure as a result of sabotage or battle damage, although providing an immediate severe problem in a local area, should be rather routine because of the extensive structure with numerous bouyancy elements.

An additional consideration is the disposition of a facility at the end of its useful life. If the cost of disposition is included in the evaluation of the return on investment of the facility, it is clear that only one approach is viable. Upon removal of items of value and possible contaminants of the marine environment such as fuel oil, the structure would have to be flooded and sunk in a deep ocean area. The cost of breaking up and disposing of such an immense structure on land would be prohibitive. Again, this factor requires additional study if an accurate economic evaluation of the concept is to be performed.

Technical Problems

The concept of a huge offshore floating facility is an exciting prospect for those of us involved in the analytical problems associated with the offshore. Our classic approach of constructing computer models based upon carefully formulated equations will serve us well as a point of departure in the technical problems associated with these structures. Certainly the field of fluid structure interaction with its nonlinear hydrodynamic effects, the effects of breaking waves and combined wind, wave and current loads will provide endless work for the next several generations of graduate students. Unique factors such as the run-up of large seas and the differentiation of the loads to be experienced by the "legs" on the perimeter of the structure with subsequent progressive attentuation are problems unique to this structure. Similarly, integrating the loads from the wind, waves, and currents on the modules and then on the structure as well as the secondary effects of the wind on the waves or the currents on the waves presents a large matrix of complex relationships. Adding to this complexity is the problem of simultaneously accommodating the Reynolds and Froude effects while model testing. It is also clear that refined measuring techniques will be required in even the largest of the testing facilities if significant components of the ultimate loads are not to be overlooked.

The investigation of mooring concepts is also an extensive area of interest and challenge. The behavior of anchors, piles, mooring lines with or without buoyance or riding weights, explosive moorings, and chains and cables provides additional opportunities. The conditions of the seabed and the characteristics of the seabed materials must be investigated on a site specific basis. Slope instabilities, presence of gas hydrates in sediments, the presence of escaping methane or "free gas," and the myriad of local situations all provide variables which must be investigated and included in the final design. Although much work is being done in the area to accommodate the needs of those placing offshore oil structures in deep waters, the program is considerably broadened when the objective of the work is the installation of a huge floating facilities.

Another area of major concern is the development and handling of loads between modules of a multi-segmented structure. In certain applications the joints between several modules must have sufficient rigidity to withstand sudden loads such as a heavily loaded aircraft landing between two modules. On the other hand, designing flexible joints

which would be connectable even in moderate sea states is beyond current practice. The determination of directional loading effects on the entire structure and their influence on the connections between modules must also be carefully investigated.

The design techniques to be employed must be based upon sound theory with adequate codification of the basic knowledge developed. Techniques to define and assure the repeatability of three-dimensional seas of different amplitudes and frequencies are required to permit the expansion of design concepts from mathematical models to physical models and thence to the prototype structure. Extensive design algorithms are clearly required and accurate instruments and techniques must be developed to measure and verify subsequent loads, member deflections and assembly structural deformations.

Closure

This paper is presented to the UJNR in the hope that interested academic, industrial and government organizations will recognize the world. Such recognition should provide the funding necessary to permit the basic studies to be conducted and published thereby importance of large floating offshore structures to the future of our profession and providing the data base for payout analysis and serious consideration by those whose vision include the use of such facilities.

Those among us who were more than casually involved in the United Nations Law of the Sea Treaty preparatory sessions and subsequent negotiations recognize that great and costly accomplishments at sea require continuing cooperation between nations and their professionals if technical and economic success is to be achieved. We realize that the world's oceans are not an infinite source of easy wealth, but that they do provide a huge challenge and extensive opportunities to mankind. In large offshore floating facilities, there are enough problems for everyone! It is incumbent on the international ocean community to undertake the timely research, design, and feasibility analysis needed for the orderly development of these promising facilities.

SEABED FRONTIERS: Challenges for Future Utilization

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ABSTRACT

Expanded utilization of the Exclusive Economic Zone presents a variety of technological challenges. Much of the future development will depend on having the necessary tools to survey, map, probe, sample, and monitor the seabed. Improved technology will also be needed for most of the actual uses--whether to mine and process minerals, bury cables and pipelines, or dispose of waste. A carefully conceived and coordinated plan for EEZ development can ensure that the United States will retain leadership in offshore technology for scientific research, resource recovery, and other long-term activities, while minimizing degradation of the environment. A study by the National Research Council/Marine Board resulted in ten recommendations on general and specific issues related to future uses of the seabed; research, information and technology needs; environmental concerns; and coordination and planning. Included is a recommendation for new legislation to create a formal joint planning and coordination process for EEZ development. The results of this study are summarized and discussions are focussed on marine surveying, mapping, and positioning needs related to seabed utilization.

1. INTRODUCTION AND BACKGROUND

The United States and essentially all other coastal countries are looking to the ocean regimes for a wider variety of uses and for critical resources. Some sixty nations have now proclaimed jurisdiction over the natural resources within the Exclusive Economic Zone (EEZ), i.e. out to a distance of 200 nm seaward of the coastal baseline. The United States EEZ, established in 1983 by Presidential proclamation, is the largest in the world, covering 3.9 billion acres of submarine land--approximately 1.7 times the onshore U.S. territory (Figure 1).

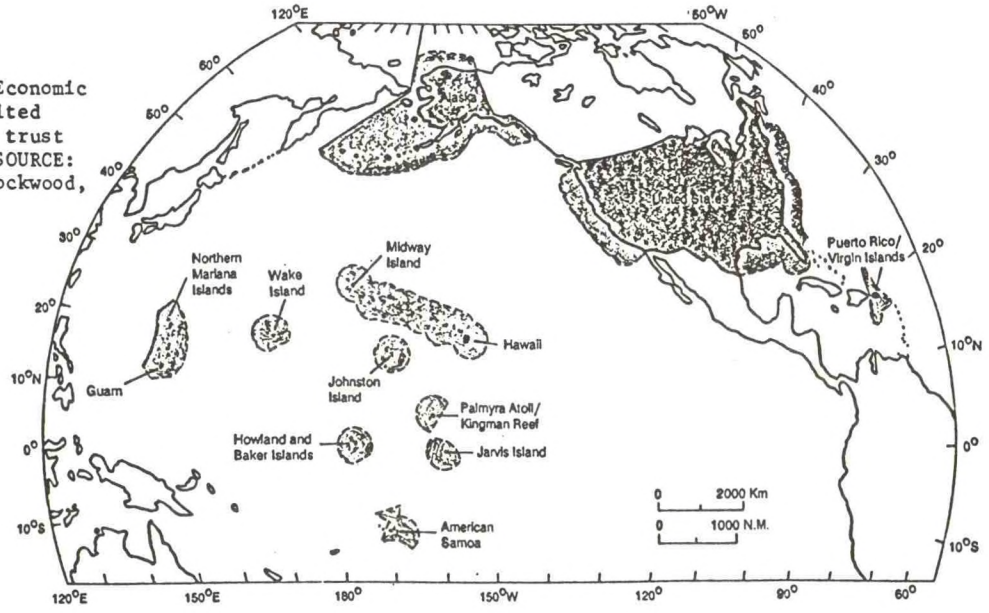

Figure 1. The Exclusive Economic Zone of the United States and its trust territories. SOURCE: McGregor and Lockwood, 1985, p. 2.

The seabed regimes within the U.S. EEZ represent virtually all types of ocean seabed features and processes. The varied characteristics, and inherent remoteness of the seabed with attendent difficulties in making direct observations, present interesting challenges to scientists and engineers. It is only within the last 20 to 30

years that an appreciation of the complexities of the seabed in these frontier areas has begun to emerge. Most of what is known about the shape of the seabed, including the configuration of the deeper strata, comes from remotely acquired acoustic data whereas detailed information about the properties of the sediments comes from widely spaced sampling sites. Given the problems of observing and sampling the seabed, it is also extremely difficult to monitor the behavior of the sediments over a long period of time.

Present and possible future uses of the seabed are almost as varied as the terrain itself. In addition to recovery of hydrocarbon and hard mineral resources, the seabed is used for waste disposal, commercial fishing, military needs and communication cables. But there are other less obvious uses related to the seabed, such as ocean energy resources, pharmaceutical research, archaeology, transport and recreation. Most of these uses, as well as the basic research studies on seabed processes, require seabed surveying and mapping information.

Much of this report is derived from a study by the National Research Council/Marine Board special Committee on Seabed Utilization in the Exclusive Economic Zone, which I chaired from 1987-89. Copies of the Committee report "Our Seabed Frontier: Challenges and Choices" are available from the National Academy Press, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

2. FUTURE USES OF THE SEABED

The contribution of commercial (non-government) ocean business to the U.S. economy has been estimated at 1.7 percent ($76 billion) of the total U.S. gross national product of $4.53 trillion in 1987. This is the same order of magnitude as other well-recognized segments of the U.S. economy, such as all farms ($76 billion), all mining excluding offshore oil and gas ($74 billion), transportation other than water ($131 billion), and communications ($121 billion) (Pontecorvo, 1989). The seabed represents an area of national opportunity and long term economic growth. Uses of the seabed fall into three broad categories (Table 1): *extractive uses* involving activities that remove resources from the environment, *intrusive uses* that disrupt the seabed or degrade the environment, and *benign uses* that take up space but do not significantly impact the environment. Future uses include: expanded oil and gas development, increased mineral exploration and

TABLE 1. Summary of Seabed Uses in the EEZ

Extractive uses	Intrusive uses	Benign uses
Oil and gas	Pipelines	Instruments, (research,
Living resources	Waste disposal (dredged mat.,	monitoring, security)
Minerals	sewage, indust. waste)	Sanctuaries,
Energy systems	Dumping (munitions, scuttling, etc.)	Recreation

production, innovative waste disposal solutions, corridors for cables and pipelines, harnessing ocean energy, conserving and developing biological resources, and the discovery and development of cultural and recreational activities.

a. Oil and Gas Resources: In terms of strategic importance and economic value, the exploration for and production of offshore oil and gas resources will remain the most important economic activity in the U.S. EEZ into the next century. Currently, about 12 percent of total crude oil production and 25 percent of total gas production is produced offshore and it is estimated that U.S. dependence on these resources will continue to increase each year as land reserves decline (Bettenberg, 1987). While current technology is adequate to develop nearshore oil and gas resources, many technical constraints face the offshore oil and gas industry as it moves farther onto the continental slope/rise and into unexplored arctic regions. The environmental hazards of operating in deep and ice-infested waters are considerably greater, and overcoming them will be far more costly than previous offshore oil and gas development operations.

Development of these areas will be affected not only by technical progress but also by nontechnical factors, such as fluctuating world oil prices, the impact of unstable political regimes in oil-producing countries, and a domestic regulatory climate subject to public pressure to protect offshore lease areas. Equally significant will be the extent to which government and industry cooperate to achieve a proper balance between meeting the nation's energy needs, environmental concerns and maintaining a competitive and technically innovative domestic oil and gas industry. The need for surveying and mapping information, including detailed data on subbottom conditions and accurate positioning of installations, is well known. There is certainly room for technological improvements to enhance efficient operation in the frontier areas.

b. Mineral Resources: Except for construction materials, such as sand and gravel, and some placers, it is unlikely that substantial amounts of hard mineral resources will be commercially recovered from U.S. EEZ deposits within the next decade (OTA, 1987; Broadus, 1987). Depressed market prices, together with high costs of mining in marine environments, have created an unfavorable economic environment for development of most seabed mineral resources.

Future national needs could spur development of offshore mining industries for selected critical materials that are now imported by the U.S., such as cobalt, chromium, manganese, and the platinum group metals (OTA, 1987). Because lead times of up to 15 years are required for developing seabed mining systems, it seems prudent to establish the scientific and technical base necessary to assess and recover strategic materials. An integrated program of technology development is needed for comprehensive assessment of hard mineral resources in the EEZ seabed. In addition to the general need for bathymetric and subbottom information, there is a need to develop better tools to remotely identify and assess seabed mineral resources.

c. Waste Disposal: The coastal and ocean waters surrounding the United States have been used for disposing of municipal and industrial wastes for many years, particularly sewage sludge and dredged materials (Kester, et al., 1983). Recent legislation places restrictions on such practices and, in some cases, phases them out over the next few years. However, comparisons between land and ocean disposal options frequently indicate that marine disposal is less expensive and less environmentally damaging than land alternatives, which leads many to believe that marine waste disposal is likely to increase in the next 10 to 20 years, despite present public disapproval (Duedall, et al., 1985). Future pressures on land-based repositories may increase incentives to use subseabed geologic formations for permanent repositories, especially for containerized low volume and highly toxic wastes. Devising environmentally acceptable ocean waste disposal strategies depends on understanding the physical and chemical oceanic processes and how they affect sedimentation and mobility of contaminants.

Innovative engineered approaches to isolating and disposing of wastes in the ocean need to be tested and evaluated through pilot or demonstration projects in order to determine their effectiveness. Future use of the seabed for waste disposal will depend on socioeconomic pressures, innovative technologies that won't compromise the use of other marine resources, and better understanding of the processes of dispersal and deposition of waste particulates. Additionally, a comprehensive national policy for selecting long-term waste disposal strategies which includes evaluation and comparison of land- and ocean-based options and their impacts on the marine, terrestrial, and atmospheric components of the ecosystem would provide a framework for making wise choices about waste disposal. The surveying and mapping needs are those related to understanding seabed conditions and processes, but also being able to accurately monitor sites over long periods of time.

d. Communication Cables and Military Uses: Increasing use of the seabed for the installation of commercial submarine cable systems and a number of military applications is driven primarily by advances in fiber optics and digital transmission, as well as improvements in the technology capability for secure emplacement of various devices in or on the seabed (NTIA, 1984). Commercial communications cables constitute the majority of ocean cable installations. Military activities in the ocean are expected to continue indefinitely with cables, sensors and transducer systems likely to increase as their technological applications are improved.

Geological processes and the composition of the substrata are the most crucial physical conditions affecting emplacement, maintenance, and survivability of ocean cables and seabed military systems in the seabed. Improved geophysical survey equipment, sediment sampling, and in situ testing, along with more effective procedures for interpretation of geotechnical data, would yield benefits to both military and commercial operations in the seabed.

A major issue related to the expansion of military uses of the seabed is the conflict between military applications and commercial, recreational, and/or environmental interests. It is therefore important that potential conflicts with other uses be anticipated and that policies be developed for resolving them.

e. Biological Resources: Living resources associated with the seabed fall into one of two categories--commercially important fishery resources and organisms of special scientific interest or of potential importance as biotechnological or genetic resources. The United States is one of the world's largest consumers and importers of seafood products (O'Bannon, 1988). There is potential for expansion of the domestic fisheries industry into deeper waters to capture a larger share of this market. Although most experts believe that traditional fisheries are being harvested at or near maturity, some of the resources of the continental slope can be harvested by extending existing technology into deeper water. Many bacterial species found in chemically unusual marine environments are logical candidates to study for their ability to degrade toxic chemicals; and some marine benthic invertebrates are potential sources of pharmaceutical agents in the treatment of cancer, and other diseases (Felbeck and Somero, 1982; Roberts, 1987).

Research needs to be focused on improving our understanding of the bases of biological productivity, its variations, and the effects of human activities on these processes especially in deep water. Newer techniques based on remotely operated vehicles, better sensors, acoustics, and improved data interpretation may alleviate present assessment problems. Such fundamental knowledge of biological and living resource processes will contribute to expansion of American fisheries, the development of new biotechnology products, and to protecting the quality of marine environments.

f. Ocean Energy Systems: Ocean energy systems and related technologies are in very early stages of development and the commercial feasibility awaits more favorable economic conditions. The most likely candidate for development in the near future that will affect the seabed is ocean thermal energy conversion (OTEC), a process that harnesses the temperature differences between surface and deeper waters as energy; but other systems are also under study (Cohen, 1982; Baggott and Morris, 1985). The first commercial OTEC installations will probably be shore-mounted facilities on islands with the intake pipe extended to nearby deepwater sources. Moored OTEC facilities will require information on the physical properties of steeply sloping seafloors that border U.S. subtropical and tropical islands and have access to deep, cold water relatively close to their shorelines. In some configurations, the electrical energy would have to be transmitted to shore by seafloor cable, creating a need for detailed seafloor information along the cable route.

Commercial feasibility of any ocean energy systems depends on more favorable economic conditions than presently exist. The surveying and mapping needs are similar to many other existing and potential uses such as offshore oil and gas production platforms and pipelines. One important difference is that OTEC facilities are likely to traverse steeply sloping areas.

g. Cultural and Recreational Resources: Cultural and recreational resources of the include marine archaeology, treasure seeking and commercial salvage, recreation, and marine sanctuaries. It seems likely that new and improved seafloor exploration technology and availability of affordable submersibles will stimulate interest in both marine archaeology and submarine tourism.

The identification and protection of unique underwater areas and habitats in the waters of the U.S. has to date been a limited effort (Foster and Archer, 1988). In order to designate and manage a marine sanctuary, a substantial amount of information is needed on the resources and the physical environment of the area. Early identification of such areas would forestall potential conflict among competing uses by including sensitivity to environmental considerations in advance planning for the development of other resources.

3. SEABED CHARACTERISTICS AND PROCESSES

The EEZ seabed represents a diverse, poorly understood, difficult, and sensitive environment that differs fundamentally from coastal and terrestrial areas, where engineering practice and experience are more advanced. Some important features of the seabed and the processes that affect its utilization are discussed here.

a) Seabed Characteristics and External Effects: The U.S. EEZ embraces a vast range of seabed morphology, water depths, tectonic and transport processes, sediment types, and environmental conditions (McGregor and Lockwood, 1985). Topography varies from relatively flat on the shelf and lower continental rise to very rugged on steeper slopes and canyons. Depths vary from the shallow continental insular shelves, where surface waves affect the seabed, to regions where depths exceed 4,000 m. Included are passive and active tectonic margins and volcanic regions where a variety of tectonic processes, along with other environmental forces, such as currents, surface waves, tsunamis, earthquakes, and ice scouring affect the seabed and reshape and rework its sediments. Seabed materials include rock outcrops, boulders, coarse sands and gravels, biogenic sediments, carbonate reefs, phosphate deposits, silts, clays, gassy sediments, permafrost, hydrothermal crusts, and manganese nodules. These diverse conditions create a highly variable environment with important implications for expanded seabed utilization.

The Atlantic seacoast region is a passive margin with little tectonic activity, a wide shelf, and thick deposits of sediments. The active margin along the Pacific seacoast is quite different, with a generally narrow shelf, and dynamic tectonic processes that have resulted in greater physiographic variability than in other areas of the U.S. continental coast. Around the volcanic islands of Hawaii and the Pacific trust territories are narrow shelves consisting of coral reefs and volcanic aprons that extend to abyssal depths. Offshore of large rivers such as the Mississippi are thick deposits of underconsolidated and gassy sediments, canyons, diapirs, and large fan deposits of sediments in deeper water (Figure 2). Other important regional features include the area off the

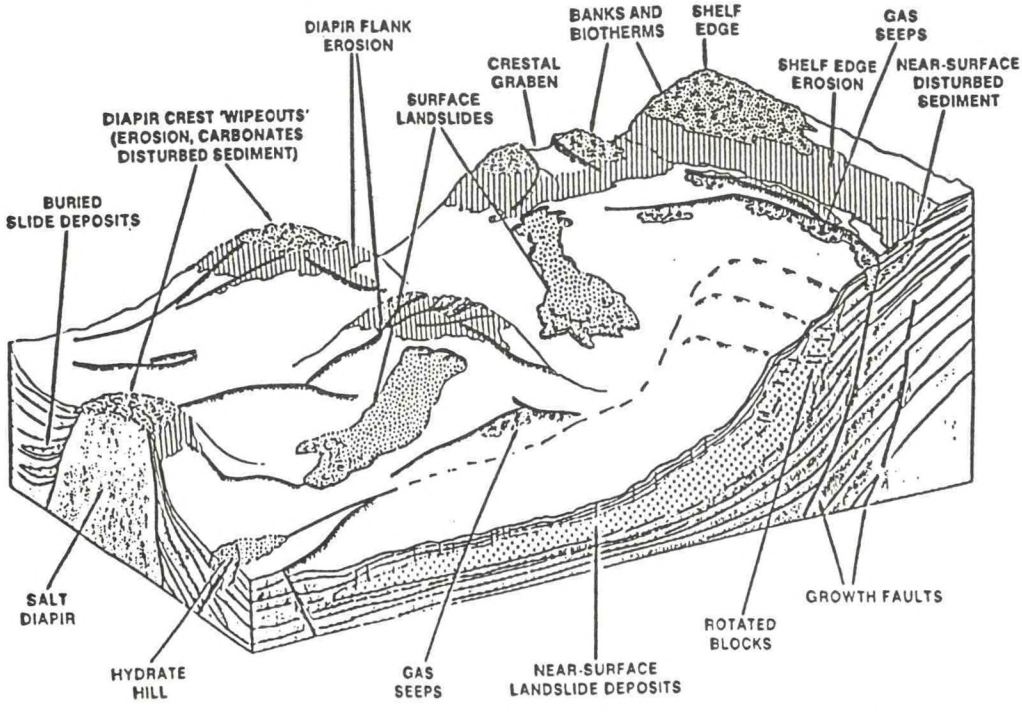

FIGURE 2. Principal geologic features of the outer continental shelf and upper continental slope offshore Louisiana and Texas. SOURCE: After Campbell et al., 1986.

western coast of Florida, where there are carbonate sediments, and the arctic regions of Alaska, where permafrost, deepwater gas hydrates, and ice packs affect the seabed.

Major environmental forces affecting the ocean floor include seismicity and active faulting at ridge crests and active margins; tsunamis, hurricanes and storm-related waves, bottom currents in deeper water; and ice keel gouging in the high latitudes. Earthquakes are a particular concern along the active margins of the west coast, Puerto Rico, Guam, the northern Marianas, and along the Aleutian trench in the North Pacific. The seismic history of arctic seas is poorly documented. The Atlantic coast is mostly inactive, although recent (1984)

earthquakes have been documented by the USGS Earthquake Information Center. The Gulf of Mexico historically has had only one earthquake of any magnitude. Normally stable slopes can fail when subjected to accelerations caused by earthquakes, and any structures, pipelines, or cables in the vicinity may be displaced or fail.

Tsunamis are long-period, open-ocean waves thought to be caused primarily by submarine landslides triggered by earthquakes or induced by shallow-focus-depth earthquakes or submarine volcanoes. Tsunamis are particularly dangerous because they are unpredictable, travel at great speeds, and build up very high waves when they shoal in shallow waters. The areas most susceptible to these waves are along the west coast, the Pacific islands, and Alaska.

Most hurricanes can be predicted well in advance with satellite remote sensing. Adequate data exists on the high winds, waves, currents, and storm surges associated with hurricanes. Surface waves affect the seabed in shallow water, where the water motion impinges directly on the seabed and can lead to seabed failures and erosion. Internal waves may play an important role in deeper water, but little data is available on these. In most of the EEZ, near-bottom currents exist at various scales of motion, duration, frequency, and magnitude. Currents result from tidal forcing, major oceanic-scale current systems (such as the Gulf Stream), wind setup, and storm surge. Episodic currents confirmed on the east coast continental rise are capable of suspending and transporting sediment by "benthic storms" that can occur several times a year (Hollister et al., 1984).

Ice gouging is an important concern in the Arctic. Enormous forces are imparted to the seabed when large ice masses, pushed by winds and currents, contact the seafloor. The depth of most gouges is of the order of 1 m or less, but scour depths exceeding 7 m have been documented (Barnes and Reimitz, 1974). These are active, seasonal processes that have important implications for seafloor structures, pipelines, and instruments.

b) Natural Seabed Processes: In addition to the forces already discussed, the seabed is shaped by the processes associated with the rise and fall of sea level during glacial and interglacial periods, the consequent sediment influx from continents, and changes in bottom current intensity. These forces create a dynamic and continually changing environment. Two broad categories of active seabed processes are particularly important to seabed utilization because of their widespread effects: mass wasting and slope deformation, and sediment dynamics (erosion, transport, and deposition).

Mass wasting is the downslope movement of sediment or rock, such as a submarine landslide. Typically, what occurs is catastrophic slumping or sliding along a well-defined failure surface within the sediment (Booth, et al.). However a full range of deformation processes can occur; very gradual (creep) deformations may eventually lead to more catastrophic failures, fluid-like debris flows, and turbidity currents (Figure 3). These

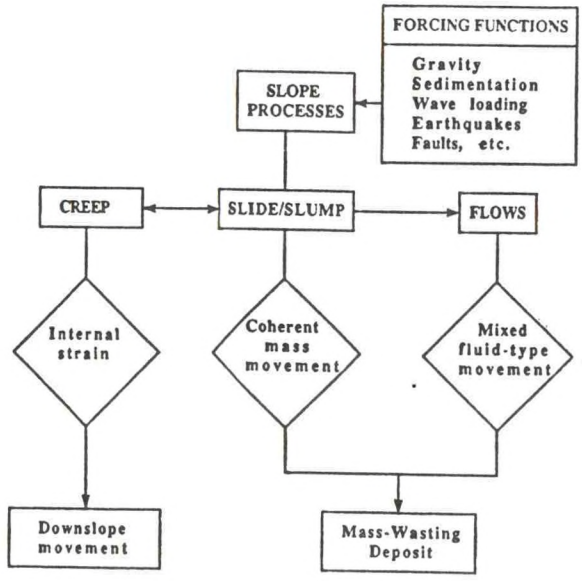

Figure 3. Interrelationships of slope deformation and failure processes. Slope processes can be viewed as a continuum ranging from very gradual downslope deformations (creep), submarine landslides that involve rapid movement of fairly coherent masses, and fluid-sediment flows. Any one type of process can lead to another depending on site conditions.

processes may encompass enormous masses of sediment and influence areas of more than 100 km^2 and are therefore important considerations in siting offshore facilities.

In addition to gravity, the primary causes of slope failure are earthquakes and associated faulting; changes in slope geometry resulting from oversteepening; or scour, wave loading, creep, loading by structures and construction, gassy sediments, and rapid sedimentation. Areas of potential slope instability are:

- deltas, which continually build by rapid sediment input;
- areas subject to storm wave influence; and
- the continental slope and upper continental rise.

Slope failures have been documented in many EEZ environments including the Mississippi River delta, Copper River (Alaska), the slopes off the Atlantic coast, in the Beaufort Sea, and off the west coast of the Bering Sea.

There are obvious implications of mass wasting for engineered installations on slopes. As oil and gas operations move to deeper water, the full range of downslope processes will need to be better understood in order to avoid potentially hazardous areas or to design structures that can withstand the resulting forces. Horizontal installations such as pipelines and cables are particularly vulnerable to mass wasting because they may traverse varied seabed conditions. If indeed some slopes are gradually being displaced downslope as a result of creep processes, there may be some problems of accurate position and depth determination related to siting of installations and monitoring of the seabed.

Sediment dynamics refers to the erosion, transport, and deposition resulting from interactions between the sediment and the moving waters directly above the sediment-water interface. In many areas, however, there is no clear interface, and in fact there is usually an active interchange between the water and sediment. Therefore, the definition of the seabed includes the benthic boundary layer, the zone composed of approximately the lower 10 m or less of water (with suspended sediments) and the upper 1 m of sediment. Knowledge of currents is crucial to understanding dispersal of pollutants; local scour around structures, buried pipelines, and cables; stability of moored arrays or other bottom-mounted installations; the fate of dredged materials; and the possibility that sediment suspended by bioturbation, mining, or excavation will be transported elsewhere.

c) Sediment Properties: Physical properties are the geological and engineering properties of sediments that must be understood in order to make calculations related to seabed processes and uses (Chaney and Fang, 1986). In general, physical properties of marine sediments (with the exception of carbonate and siliceous materials) are similar to those of water-saturated terrestrial soils. Thus, with some important modifications, most geotechnical principles developed for land apply to engineering analysis of the seabed. Special conditions that affect physical properties and seabed behavior are dynamic loading by waves, earthquakes, and sediment-structure interactions; high carbonate content; gas in sediments; high organic content; permafrost and freeze-thaw processes; ice-seabed interactions; and state of consolidation (compaction). Knowledge of compressibility, permeability (perviousness), and strength of marine sediments is important in analysis and design of structures for seabed applications and for other applications such as waste disposal on or in the seabed.

Most of the sediment varieties in the world's oceans can be found in the U.S. EEZ. For example, there are deposits rich in biogenic silica in the Bering Sea; organic-rich hemipelagic sediment along the Pacific coast; metal-bearing ferromanganese crusts and nodules off Hawaii, other Pacific islands, and the Blake Plateau; gas hydrate deposits in the Bering Sea and the Gulf of Mexico; and well-oxygenated abyssal lutites off Puerto Rico and the U.S. Pacific trust territories.

Biological processes can have important effects on the character and behavior of sediments. Physical and chemical alteration of sediments occur when benthic animals move about and feed, and in areas such as steep canyon walls burrowing animals can cause sediment instability. Knowledge of bioturbation processes is important to predicting sediment response to activities such as waste and dredge disposal, since bioturbation can reintroduce materials from sediments into the overlying water and possibly disperse them over large areas. Bioturbation generally acts to increase erodibility of sediment by maintaining a high water content and physically moving material toward the sediment surface where it can be moved about by bottom currents. However, an important counteracting consequence of feeding of sediment-dwelling animals is the packaging of small sediment

particles into large fecal pellets, which have different transport thresholds and hydrodynamic properties than the ambient sediments.

4. TECHNOLOGY AND INFORMATION NEEDS

A large body of information is needed for planning efficient use of the seabed including: oceanographic and meteorological data; data on sediment characteristics and engineering properties; knowledge of seafloor geologic processes; and information related to specific uses of the seafloor, including the need for improved environmental monitoring. Obtaining this data in a marine environment frequently requires complex and expensive technologies and techniques specially designed for ocean use. Since there is usually considerable commonality of information needs, and in order to optimize the efficiency of operations, the approach should consider the combined needs of the various disciplines. Only a brief summary of the major technology systems and information needs are discussed here.

a) Surveying, Mapping, and Positioning: The seafloor can be mapped using a wide variety of tools and techniques, at different scales and accuracies and for different purposes. There are four basic types of surveying and bottom mapping required to support development and protection of the seabed; water depth (bathymetry), seafloor imagery (mostly acoustic), subbottom profiling, and direct sampling of the sediments. Accurate navigation/positions of all mapping data is necessary for the data to be useful.

The acquisition of site-specific seafloor data for mapping is a fundamental necessity for development. Locations and time frames for needed data are determined by the specific development or engineering activity. For example, mapping in support of oil and gas development is dictated by exploration targets and production schedules. The survey tools and grids vary with the local characteristics of the area and the proposed activity, but for most of the anticipated uses there is overlap and commonality in the maps, scales, and resolutions required. Reconnaissance surveys provide a broad overview of regional geology and features resulting from long-term evolution of continental and island margins whereas higher resolution mapping (with higher positioning accuracy) is required for or site-specific surveys. Use of deep water areas (deeper than 300m) for resource extraction and activities such as telecommunications or military installations is increasing, and these areas are likely to become the principal location of development in the future. This frontier region poses considerable challenges to survey methodology and practice. Although regional reconnaissance surveys are in progress, resource distribution and bottom conditions of the deepwater areas are generally poorly documented.

Seabed mapping technologies include bathymetric survey systems, side-scan sonar systems, swath imaging and bathymetric (combined) systems, subbottom profiling systems, and direct sampling technologies. A summary of bottom mapping systems is presented in Table 2 and capabilities of acoustic mapping tools are described in more detail in Kosalos, 1984; Tyce, 1986; Davis et al., 1986; and Prior et al., 1988.

Table 2. Bottom Mapping Systems (adapted from Tyce, 1986)

Category	Multibeam bathymetry	Side-scan sonars		Side-scan sonars & subbottom profilers				Side-scan & bathymetry
System Name	Sea Beam	GLORIA II	ARGO/Klein	SeaMARC I	EDO 4075	Deep Tow	EG&G 990	SeaMARC II
Frequency (kHz) Pulse Length Pulse rep. (sec)	12/150 7 ms 1-22	6.2/6.8 2, 4 sec 20 40	100 0.1 ms 0.3	27/30 0.15-3.2 ms 0.5-4	100 0.1 ms 0.1-1	110 0.1-0.4 ms 0.1-1	59 0.1-0.5 ms 0.2-1	11/12 0.25-10 ms 1-16
Bandwidth (kHz) Beamwidth (deg)	0.14 2.7 x 2.7	0.1 2.5 x 30	10 1 x 40	0.31-6.7 1.7 x 50	10 1 x 25	2.5-10 0.75 x 60	2-10 1.2 x 40	0.1-4 2 x 40
Data type Cameras Other sensors	Digital -- --	Digital -- --	Analog TV & Still Navigation	Digital -- mag	Analog -- --	Analog TV & Still Many	Digital -- temp	Digital -- --
Tow depth Water depths Tow altitude	Hull mount > 10 km	30-60 m > 10 km	to 6 km 6 km 10-50 m	to 7 km 7 km 25-1250 m	to 5 km 5 km 10-100 m	to 7.5 km 7.5 km 10-150 m	to 6 km 6 km 10-200 m	50-100 m > 10 km
Cross-track resol Along-track resol	14-233 m 233 m	30 m 218 m	0.1-0.4 m 0.2-0.9 m	0.5-2.5 m 0.7-37 m	0.1-0.4 m 0.2-1.7 m	0.1-0.3m 0.1-2.0 m	0.3-1.3 m 0.2-4.2 m	5 m 175 m
Bathy. accuracy Swath width Survey speed	10-50 m 0.8 depth 15 knots	-- 14-60 km 10 knots	-- 0.1-0.7 km 1 knot	-- 1-5 km 2 knots	-- 0.1-0.8 km 2 knots	-- 0.1-1.5 km 1-2 knots	-- 0.2-1 km 2 knots	150 m (3%) 1-10 km 8 knots

The principal linkage between all survey and sampling measurements is position accuracy of the data. Historically, the accuracy of navigation systems has lagged those of survey and sampling systems. Navigation

systems can be characterized by the location of the reference systems: i.e. land-based, ship-based, seafloor-based, and satellite-based systems. Land-based navigation systems have long been standard for survey operations conducted within range of shore stations. The Loran C system has excellent repeatability of 15 m, and sufficient range (3000 nm) for most EEZ surveys, but has insufficient accuracy (0.25 nm) to support many survey needs. For accurate nearshore surveys, temporary installations are generally used. These employ user-passive hyperbolic radio transmission systems (Argo, Sylidis), or user-active radar transponder ranging systems (Falcon, Miniranger, Hi-Fix). These systems have accuracies on the order of 1 m, and have ranges of only 50 to 100 nm. Ship-based systems generally determine range and bearing to stationary acoustic beacons, benchmarks or structures on the seafloor, or aboard moving vehicles. The accuracy of these systems is a function of both the accuracy of the underwater acoustic transmission and reception, and of the ship's position determined through other means. Seafloor-based navigation systems generally consist of acoustic transponders, either on the seafloor or tethered some distance above. While limited in range by acoustic propagation to tens of kilometers, triangulation in range from bottom transponders produces navigation accuracy ranging from 1 m for near-bottom receivers to 50 m for surface receivers (such as ships).

Satellite-based navigation systems remain the standard for mid-ocean positioning of ships, and also hold the most promise for future improvements in nearshore ship navigation and positioning. The Global Positioning System (GPS), also known as NAVSTAR, uses range and time determinations from several of a series of polar orbiting satellites to establish position. When the entire "constellation" of GPS satellites is in orbit, fixes will be available at least once a second with accuracies on the order of 1 to 10 m.

A plan for reconnaissance-level mapping of the entire EEZ with Gloria and Sea Beam bathymetry has been coordinated by the Joint Ocean Mapping and Research (JOMAR) group of USGS/NOAA, and additional EEZ mapping in the 1990s is planned (NOAA, 1987). The relative roles of other government agencies, industry, and academia in setting priorities, as well as participating in coordinated surveys, remains to be addressed. A related issue is the need to balance efforts among high-resolution, site-specific surveys and ongoing reconnaissance. While the specific types of mapped data needed for each development activity require further definition, there is overlap and commonality in the areas, data types, scales, and resolutions required for many different anticipated uses. High-resolution data requirements for oil and gas production, cables and pipelines, military uses, and waste disposal should to the greatest extent possible be collaboratively defined so that multiobjective surveys can be coordinated to achieve cost-effective use of ship time and equipment.

The principal technical constraints to surveying and mapping the EEZ for development are now mainly operational, involving questions of rates of coverage, resolution, system efficiency, and cost-effectiveness. Some of the required technical developments include:

- rapidly traversing bottom vehicles capable of acoustic/in situ property cross correlation;
- deep-tow systems with multifrequency, multisensor packages in autonomous vehicles or improved towing and cable technology;
- multipurpose systems with vessels dedicated to routine multipurpose surveying with a wide range of tools aimed at extensive suites of seafloor data acquired in single traverses;
- multipurpose sensors from which simultaneous bathymetry, seafloor imagery, and subbottom profiles can be obtained;
- improvements in acoustic sources, arrays, variable and multifrequency profiling systems, together with real-time processing, to address difficult geologic terrain and the requirements for engineering data at greater depths below the seafloor;
- common, mutually compatible formats for digital recording and processing of data
- new geologic interpretation modes for effective use of survey data.

The principal nontechnical constraints to surveying and mapping of the EEZ are primarily organizational, involving questions of planning; prioritization of surveying technology resources; cooperation among different agencies, groups, and organizations; and data availability. Expense, different time frames for development, and the challenges of a largely unknown, difficult environment all dictate planning and organization of effort for successful and cost-effective mapping.

b) Geotechnical Data: Accurate characterization of a proposed development site requires meaningful measurements of seabed processes and sediment properties. Seafloor samples, using shallow drop-core or deep-penetration downhole samplers, are necessary to provide ground truth information for geophysical surveys performed as part of the mapping programs (McClelland and Ehlers, 1986). As exploration and production moved to depths greater than 300 m, needs emerged for new and improved technology to compensate for increased costs and risks of the deepwater environment.

During the past decade, there has been a major shift to in situ testing, which involves thrusting a sensor (such as a cone penetrometer or vane shear device) into the sediments to measure physical, geological, or engineering properties (Briand and Meyer, 1983; Silva and Wyland, 1987; Zuidberg, et al., 1986). This shift toward more in situ testing is the result of a number of factors. Economic incentives for offshore petroleum development provided the impetus to improve site investigation methods; major technological developments allowed more practical, reliable, and efficient in situ testing equipment; and investigators demonstrated the benefits of in situ test data for engineering analysis and design (Young et al., 1988). Geotechnical data acquisition systems are highly developed for water depths less than 200 m, whereas only moderate or little development has occurred for the Arctic or in water depths exceeding 300 m.

Deployment systems used for sampling or in situ testing can generally be divided into three broad categories: self-contained units, drilling rigs, and submersibles. Self-contained units are the simplest, least expensive, and require the least complex support equipment. Sampling and in situ testing can be performed with these systems and carried out from almost any vessel equipped with the appropriate winches. Various submersible systems--manned submersibles, remotely operated vehicles (ROVs), and autonomous underwater vehicles (AUVs)--can be used to deploy coring devices. It is expected that use of ROVs and eventually AUVs will increase, while use of manned submersibles will not. Operations conducted under ice may be one application with an increased role for manned submersibles, although risk to personnel has limited this use.

Development of the frontier regions of the seabed in the Arctic and in water depths exceeding 200 m will depend on further development of the following systems:

- instruments capable of providing data for analyzing long-term sediment stability;
- improved sampling and in situ testing devices for more difficult offshore environments;
- compact deployment systems that can operate in a rapid transit mode and that will automatically measure seafloor properties or sample the sediments.

A nontechnical issue for acquiring geoscience data is the need to develop a coordinated research and development plan involving different agencies and industry user groups and academia in a cooperative effort to develop improved systems for sampling and performing in situ and laboratory tests on seafloor sediments.

c) Seabed Monitoring: The environmental consequences of expansion of activities in the seabed of the are difficult to predict in advance. A monitoring program would establish environmental baseline information which could be used for such predictions. Monitoring of environmental impacts is particularly important in relation to use of the seabed for waste disposal, oil and gas exploration and production, and mining. Required monitoring will fall into three categories: (a) reference monitoring to determine the natural range and variability of environmental parameters of the EEZ seabed; (b) process-related monitoring to understand major EEZ seabed processes; and (c) use-related monitoring to evaluate the suitability of EEZ sites for specific uses and to determine their environmental consequences (NRC, 1989; Rhoads and Germano, 1986). Monitoring priorities and strategies should be established within the framework of a national EEZ program.

Monitoring on the scale of years to decades will be necessary to acquire data on seafloor process activity (Fredette, et al., 1986). Such data on seafloor behavior, processes, and causative factors is a key element in predictive site evaluations and will expand the usefulness of mapped data. Technology will, in a sense, "drive" environmental studies. As new measurement technologies are perfected so that they can be routinely used, new monitoring will be possible. Technology needs associated with monitoring programs include, a satisfactory method of measuring pollutants in the sediment and, the ability to quickly assess populations or organisms.

5. ISSUES AND RECOMMENDATIONS RELATING TO THE US/EEZ SEABED

The recent study by the National Academy of Sciences/Marine Board (NAS/MB, 1989) resulted in two major conclusions about the future uses of the seabed in the Exclusive Economic Zone (EEZ). First, it is highly probable that the present uses of this region are likely to increase in the next twenty years. These include exploration for and development of oil and gas resources, waste disposal, emplacement of cables for civilian and military purposes, harvesting of fisheries resources, recovery of certain hard minerals, and identification of cultural resources such as marine sanctuaries. Significant expansion of activities related to a broader spectrum of mineral mining, other biological resources, development of ocean energy systems, and recreational uses will probably become more important in the time frame beyond twenty years.

The second major conclusion of this study is that for all foreseeable uses of the EEZ seabed, improved coordination and increased joint planning are needed to implement effective and efficient programs for systematically mapping and surveying the EEZ, developing new or improved technology to support EEZ mapping, surveying and research programs, improving access to and sharing of EEZ data, developing approaches for multiple uses, and identifying and resolving potential conflicts between the various users. Such a strategy would provide the nation with the foundation for a coherent plan for developing its ocean territory.

Following are summaries of the findings and recommendations of the Committee on Seabed Utilization in the EEZ.

COORDINATION AND PLANNING

Economic and institutional pressures will lead to increasing use of the U.S. EEZ seabed for a variety of purposes. Additional planning efforts among federal and state governments, industry, academia, and representatives of public interest groups will lead to more efficient, orderly, equitable and environmentally sound development of EEZ resources.

Recommendations

1. Congress should enact legislation that creates a formal joint planning and coordination process that includes a lead agency mandated to develop a national EEZ plan, and an external commission composed of representatives of industry, academia, and public interest groups, and an internal interagency committee. The federal government should formulate a national management policy for EEZ uses that identifies the needs of specific user groups and determines ways of enhancing cooperation and efficiency of operations among the various agencies and industries and identifying and resolving potential conflicts among users.

2. As part of the planning and coordination process, federal agencies should pursue cooperative and joint agreements with coastal state governments in planning and implementing EEZ activities.

SPECIFIC USES

Certain Uses of the EEZ will require special policy action at the federal level in order to plan for future development. For example, development of mineral resources and use of the EEZ seabed for waste disposal are potential activities that are unlikely to proceed until more comprehensive national policies are devised. Other uses will also benefit from improved regulatory policies.

Recommendations

3. The U.S. Congress should ensure that a coherent policy is developed that addresses specific concerns of industry and coastal states with regard to economic and environmental issues affecting the development of EEZ mineral resources. Appropriate agencies should ensure development of the necessary science and technology for assessment, evaluation, and verification of critical hard mineral resources.

4. A comprehensive long-term national waste management policy based on an evaluation of waste disposal in all media, including land and ocean disposal options, should be formulated by Congress to provide a predictable frame work for planning and developing acceptable ocean waste disposal strategies.

RESEARCH AND TECHNOLOGY DEVELOPMENT

The seabed of the EEZ is a new frontier that includes a broad range of seafloor morphology, water depths, sediment types, and environmental conditions that affect its use. The complexity of the seabed requires multidisciplinary research efforts that are costly in terms of both technology and time to obtain and analyze data. The various potential uses of the EEZ share the need for reconnaissance survey data and for task and site-specific data. The mapping priorities and geographic areas of interest in the EEZ require further definition as a first step toward planning the efficient sharing of mapping activities, survey and ship time, and equipment.

Recommendations

5. Research activities in the EEZ should be coordinated through a designated agency to enhance cooperation and efficiency of operations among various agencies, industries, and academia, and promote basic research efforts that will increase our understanding of seabed processes.

6. As a part of the national plan, a formal government/industry/academia EEZ program should be established to set priorities for seabed surveying and mapping activities and promote the development of technologies for obtaining EEZ seabed data.

7. The agency designated to coordinate research activities should ensure that programs are set in place to develop the necessary technology for geotechnical and geological data acquisition in concert with the projected uses and needs.

8. Government should provide leadership in fostering communication and exchange of data among all agencies and other organizations conducting research in the EEZ.

ENVIRONMENTAL MONITORING

A clear need is emerging for a nationally coordinated effort in monitoring those portions of the EEZ seabed that may be effected by future uses. The required monitoring will fall into three categories: (a) reference monitoring to determine the natural range and variability of environmental parameters of the EEZ seabed, (b) process-related monitoring to understand major EEZ seabed processes, and (c) use-related monitoring to evaluate the suitability of EEZ sites for specific uses and resultant environmental consequences.

Recommendation

9. In conjunction with the joint planning and coordination process and the research efforts recommended above, a national EEZ monitoring program should be established with input from industry; federal, state, and local governments; academia; and public interest groups to determine EEZ monitoring priorities and strategies. Such a program should be based on the framework of projected uses of the seabed and should include long-term reference monitoring, seabed process-related monitoring, and use-related monitoring at specific sites. It should also incorporate the capability to respond to detrimental impacts.

PROTECTION OF UNIQUE AREAS

Identification and protection of unique underwater areas and habitats under the National Marine Sanctuaries Program has to date been a limited effort. In order to designate and subsequently manage a marine sanctuary, a substantial amount of information is needed on the resources and physical environment of the area.

Recommendation

10. Federally sponsored activities should include a marine sanctuary reconnaissance component for discovery and identification of unique areas of the seafloor deserving long-term protection. Designations should occur in advance of resource development to forestall conflict among competing uses.

6. COMMENTS RELATING TO MARINE SURVEYING AND POSITIONING NEEDS

Expansion of research and development activities to deepwater and Arctic frontier areas presents new and exciting challenges for accurate navigation, for precision positioning--both vertically as well as laterally, for bathymetric and subbottom mapping, and for monitoring of seabed processes and seabed installations. The study on seabed utilization (NAS/Marine Board, 1989) has identified several areas for technological development of surveying and positioning systems to assist in seabed applications. This study pointed out quite clearly that the one common information need for essentially all seabed uses is mapping of the seabed, including the subbottom strata. Because of the complexity and expense of operating in the ocean environment, it seems logical that all potential users of such systems - governmental agencies, industry, and academia - should join forces and coordinate efforts to improve systems and to operate them in an efficient manner so that information can be shared. The JOMAR program (NOAA, 1987) is an excellent example and good start but certainly more can be done to encourage cooperative programs. Several of the findings and recommendations that resulted from the NRC/Marine Board study were oriented toward these goals--not only for surveying and mapping but for other technological needs. In terms of the relation between seabed utilization and surveying, mapping and positioning systems there are three main issues that need to be considered: the use of the seabed for the location of permanent position markers, operation of systems to study and monitor seabed processes, and the use of systems for specific applications. Some comments and suggestions are offered here.

a) Seabed Mounted Systems: One of the potential problems of using the seabed for siting of positioning systems is that the seabed is often not fixed. This is especially true on some submarine slopes that may be experiencing gradual downslope deformations (possibly of the order of 10's of centimeters per year) and others that may be subjected to mass wasting processes such as debris flows and submarine landslides. Not all slopes are vulnerable to these downslope processes but certainly this factor needs to be considered in the deployment of instruments resting on or in the seabed. Another factor is that many marine sediments are in a very "loose" or soft condition and therefore very compressible. In some cases the sediment column may be compressing due to the natural overburden conditions and in others the effect of loading from the bottom installation may cause additional settlement of the system. Therefore both the lateral and vertical movements of bottom supported systems should be evaluated for each site.

b) Seabed Processes and Seabed Monitoring: We still have much to learn about processes within the seabed--especially in the frontier areas. The research community needs both reconnaissance type mapping data to look at regional conditions and precise information at particular sites. Although bathymetric data and side-scan imaging often provide insights on seabed processes, it is usually also necessary to have detailed data on subbottom conditions. The ideal system would have the capability to simultaneously map and "image" the seafloor, and map the configuration of subbottom strata. Another pressing need is to be able to precisely monitor the behavior and deformations of and within the seabed over long periods of time (several years). In some cases it is sufficient to determine relative movements but in others (such as those involving very large masses of sediment) we need to know the absolute lateral and vertical displacements. The accuracy needed for some studies in frontier deepwater areas is of the order of 5-10 centimeters.

c) Systems for Specific Uses: As mentioned earlier, there are a wide range of accuracies required for the many existing and potential uses of the seabed. Even for a given use, there may be more than one required accuracy depending on the specific application for the data. For example in deepwater areas the multibeam bathymetric maps and mid-range side scan data may be sufficient for preliminary site evaluations but more accurate data is necessary for designing and constructing an oil production platform. While specific uses may require some special data, there is often overlap and commonality in terms of data types, scales, and resolutions required for many of the applications. Data requirements should be collaboratively defined so that multiobjective surveys can be coordinated to achieve cost-effective use of ship time and equipment.

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OFFSHORE EXPANSION PROJECT AT THE TOKYO INTERNATIONAL AIRPORT

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Features of the Project

The Tokyo International Airport (known as Haneda Airport), located at the mouth of the Tama River in Tokyo Bay, is the most important airport in the Japanese domestic airline network. Annual passengers passing through the Tokyo International Airport reached about 40 millions in 1990 and show continuous increase every year. The value is approximately half the annual number of people who fly on Japanese domestic airlines. With increase in passengers, the airport has become rather congested, which surpasses its capacity. Under present conditions, however, it is impossible to increase the airport's capacity to cope with the increasing demand without essential expansion of the present airport.

The Tokyo International Airport Offshore Expansion Project, hence, has been planned and implemented by the Ministry of Transport, Japanese Government for providing answers to this serious situation. The project has been made by expanding the present airport onto the reclaimed land just off there and transferring many of its functions. The reclamation has been undertaken by the Tokyo Metropolitan Government for waste disposal. That is, the airport will be situated on the waste disposal ground which was not originally intended to be particularly in use for airport construction.

The completion of the project will expand the area of the airport nearly threefold to approximately 1,100 hectares and will provide three new runways, new aprons, large passenger terminals, and cargo handling facilities. As the results of that, landing and takeoff capacity will increase to 230,000 and passenger handling capacity to 85 millions a year, which can meet the growing demand for air transport and to ensure that Haneda will effectively operate as the hub airport in the Japanese domestic airline network. The objectives of the project are not only to increase the capacity of the airport but to improve surface access to the airport, to ease the problem of jet noise for contributing greatly to environmental improvement of the neighboring community, and to utilize waste disposal areas effectively.

The project has been carried out in three stages as shown in Figure 1 and summarized in Table 1 to keep pace with the reclamation plan. The first stage of construction started in January 1984 and finished in March 1988 with completion of the new A-runway. The new A-runway started its operation on July 2nd, 1988. Currently under construction as the second stage are aprons, taxiways, passenger and cargo terminal buildings, hangars, and other airport facilities in the west terminal areas, bridges, and the access traffic network including a monorail and highways to be extended to the new terminal. The work is being actively executed with the target set for completion by around March 1993. The third stage of construction will encompass the

construction of the new B- and the new C-runways, new aprons and a terminal building in the east terminal area. A part of construction on the third stage already began in 1990, before the completion of the second stage of construction.

Challenging Very Much Soft Ground

The airport construction site consists of the non-uniform artificial ground. A 468-hectare waste disposal area will be set up just adjacent to the present airport, where dredged sludge, discarded construction materials, and other solid waste have been dumped since 1971. A part of the dump has already been formed into reclaimed land. In the offing of the existing reclaimed area, the work for extending reclaimed area of 341 hectares, using the waste materials are under way.

Figure 2 shows the soil profiles at the west terminal area, revealing that layer thicknesses vary greatly from location to location. The reclaimed layers were made by removal of earth from the alluvial sand layer (As1) followed by being dumped with ultra-soft dredged sludge (Ac1 layer), and then with construction waste soil (Bs layer). The water content ratio of the Ac1 layer reaches 200%; the ground before improvement is so soft that even a man cannot stand on it. The site on Ac1 layer is prone to major differential settlement and is not appropriate for construction of airport facilities whose surface has to be kept strictly flat.

Such poor foundation conditions,

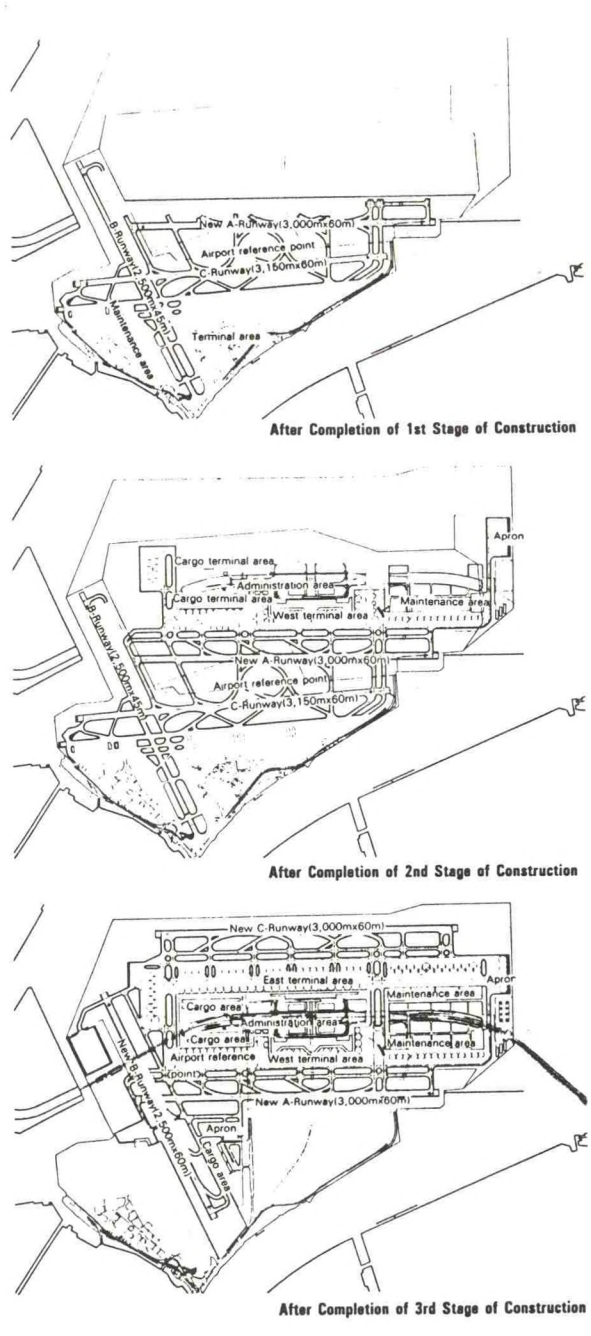


Figure 1 Plan of the project.

Table 1 Summary of the stage plan.

Scope	Before the expansion in the offshore development	First stage of the Plan (start of the use: July, 1988)	Second stage of the Plan	Third stage of the Plan
Runway	(B-Runway) 2,500x45m (C-Runway) 3,150x60m	New A-Runway 3,000x60m (B-Runway) 2,500x45m (C-Runway) 3,150x60m	New A-Runway 3,000x60m (B-Runway) 2,500x45m (C-Runway) 3,150x60m	New A-Runway 3,000x60m New B-Runway 2,500x60m New C-Runway 3,000x60m
Area	408 ha	586 ha	About 900 ha	About 1,100 ha
Runway capacity	About 160,000 takeoffs/landings per year	About 180,000 takeoffs/landings per year	About 180,000 takeoffs/landings per year	About 230,000 takeoffs/landings per year

therefore, has to be overcome with proper soil stabilization methods. The kind of stabilization method employed is determined by comparing various methods as to their cost, period of work, workability, etc. as shown in Figure 3. Generally, the vertical drain (paper drain, pack drain, and sand drain) methods are used for a site where settlement through consolidation is to be promoted. The deep mixing method and the quicklime method are also used for a site where the ground has to get adequate strength for operating large construction machines as well as for the foundation of structures.

With regard to vertical drains, efforts are made to obtain information to be used for the design and execution of the drains, concerning radically changing soil layers and their consolidation characteristics, conducting such field tests as automatic ram sound tests and three-component cone penetration tests densely over a broad area as a supplement to borings. As to the performance of very long paper drains, field tests have been undertaken and resistance factors with regard to well resistance and mat resistance have been evaluated.

Burying Underground Structures

It is necessary to provide various public utilities for operating an airport. Most of them in the airport are introduced through underground tunnels, as they are called "public utility tunnel." Drainage channels are also spread over the airport like capillaries in order to eliminate rainfall and sewage as soon as possible. Moreover, access roads are also installed under the ground at many areas in the airport. Such underground structures have been designed in consideration of differential settlement and earthquakes. In installing underground structures, open-cut excavation and earth retaining walls are applied. For open-cut excavation, very careful measurement control and information-oriented execution using the back analysis method are chosen to accomplish rapid work in the very soft ground safely.

Spreading Pavement

Since considerable residual settlement is unavoidable even after soil improvement, the type of pavement of

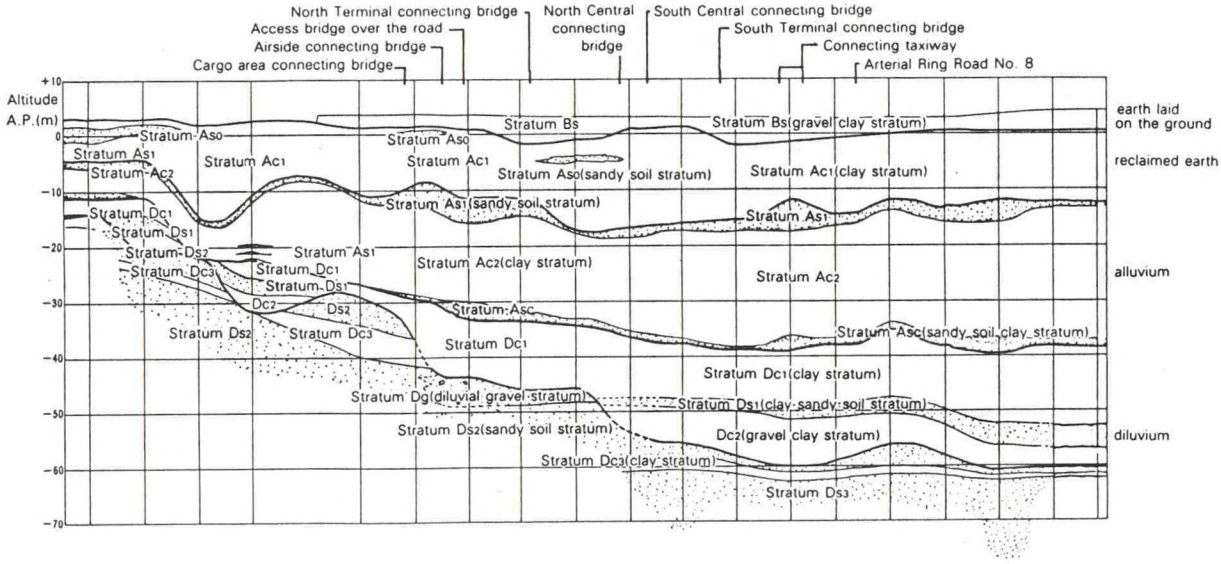


Figure 2 Soil profile at the second stage area.

runways and aprons whose surface smoothness is essential was carefully selected. In the design on pavement, furthermore, differential settlement should also be taken into account. Before the design of the pavement, field tests on various types of pavement structure have been undertaken. On the basis of the test results, it was decided that the new A-runway be provided with a special asphalt pavement structure called a sandwich pavement. The sandwich pavement, shown in Figure 4, consists of asphalt and the substrata of crushed stone and hydraulic mechanically stabilized slag. This is a type of flexible pavement permitting settlement to some extent but has relatively high rigidity which enables to disperse aircraft loadings.

For designing the aprons of about 100-hectare on the second stage, careful consideration was made as to differential settlement and future maintenance and repair. Field model tests of aprons, more than 20 types of pavement structure, have been undertaken to establish the design method and maintenance and repair methods as shown in Figure 5. As the results, prestressed concrete pavement, normal concrete pavement, steel fiber reinforced concrete pavement, and asphalt concrete pavement were adopted respectively according as the degree of forecast differential settlement and the frequency of operation at each apron.

Erecting Bridges

Seven bridges are laid across the Metropolitan Expressway running in the north-south direction at the center of the expanded airport to link the east and the west terminal areas. Since these bridges are located in the center zone of the airport, their aesthetic impression was taken into full consideration. From this point of view, the terminal area was divided into two zones, the center zone for

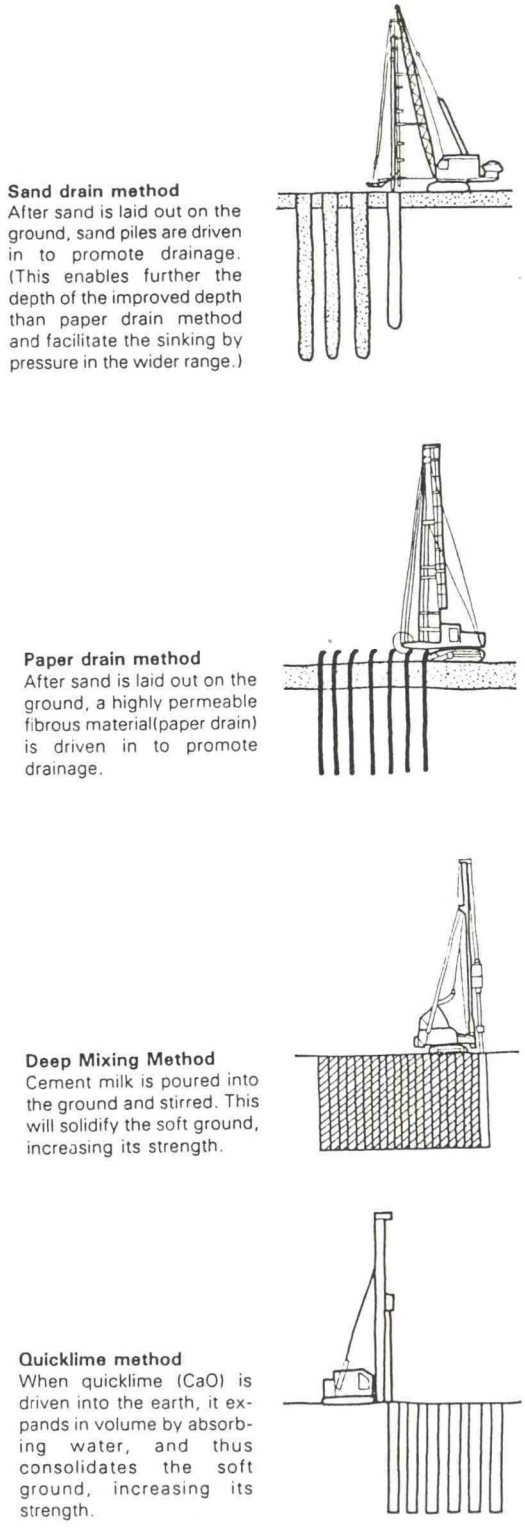


Figure 3 Ground stabilization methods.

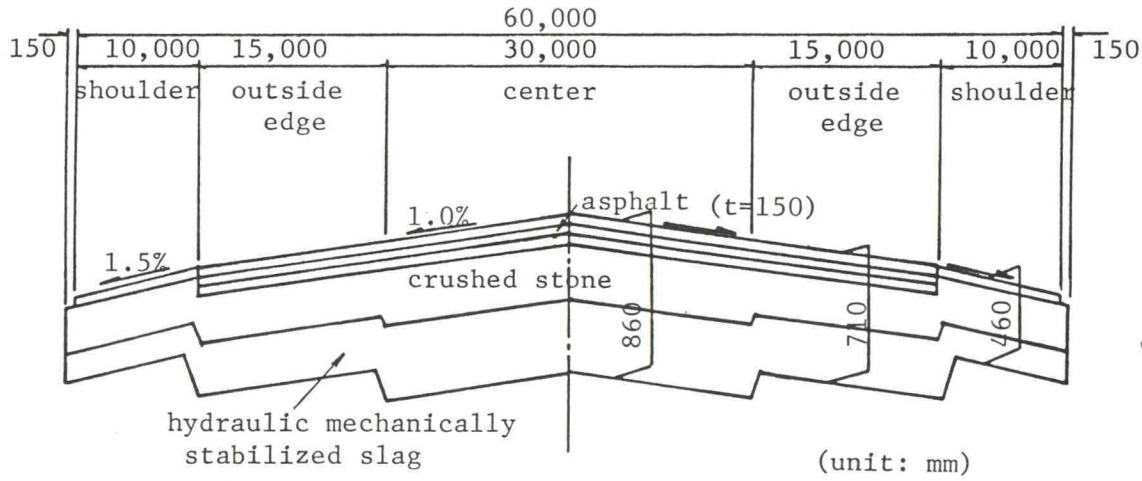
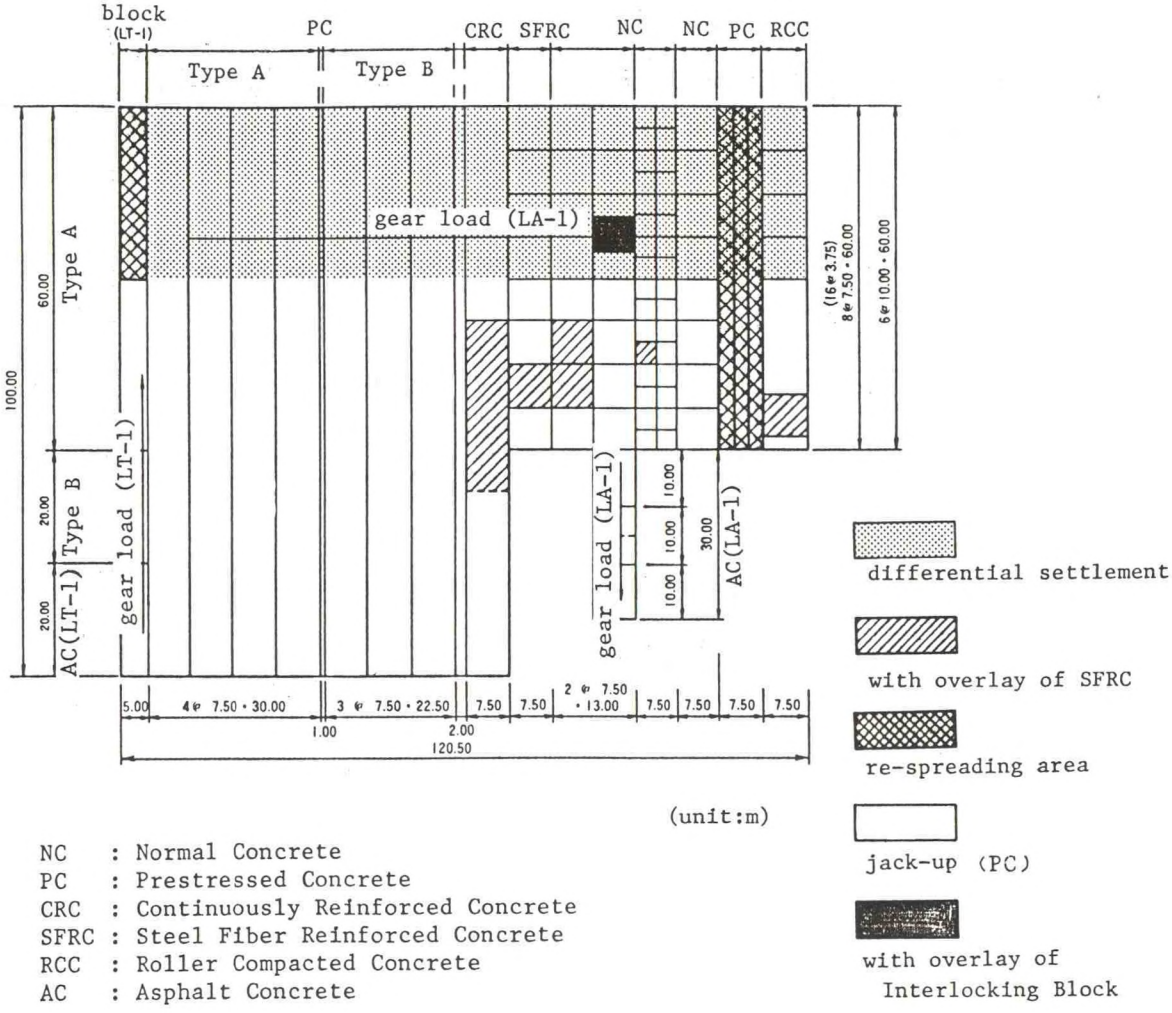
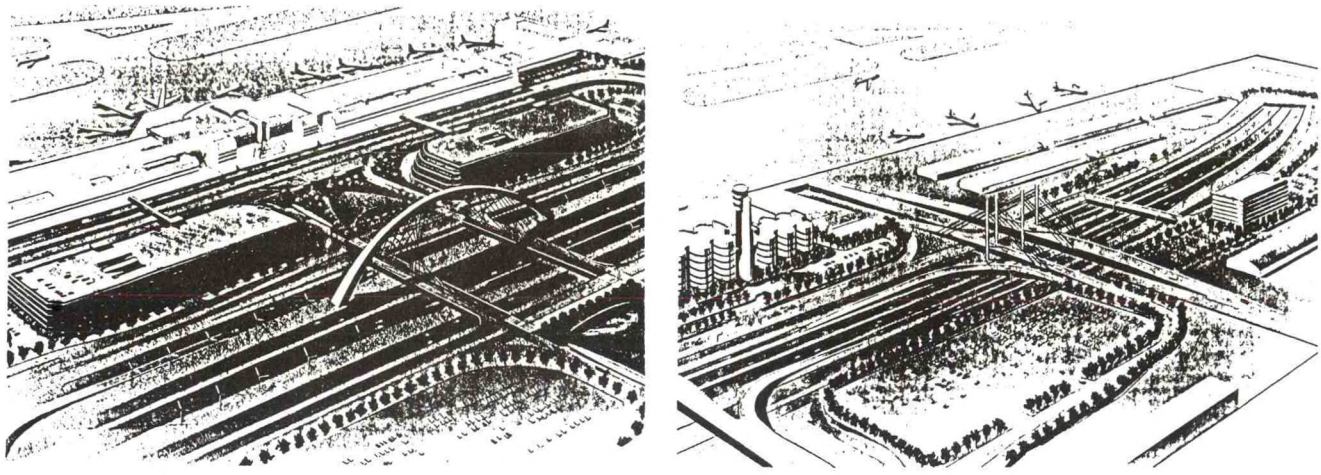


Figure 4 Cross section of the new A-runway.



NC : Normal Concrete
PC : Prestressed Concrete
CRC : Continuously Reinforced Concrete
SFRC : Steel Fiber Reinforced Concrete
RCC : Roller Compacted Concrete
AC : Asphalt Concrete

Figure 5 Field tests on various types of apron pavement.



(a) Center zone (b) North-gate zone

Figure 6 Bridges at the center and the north-gate zones.

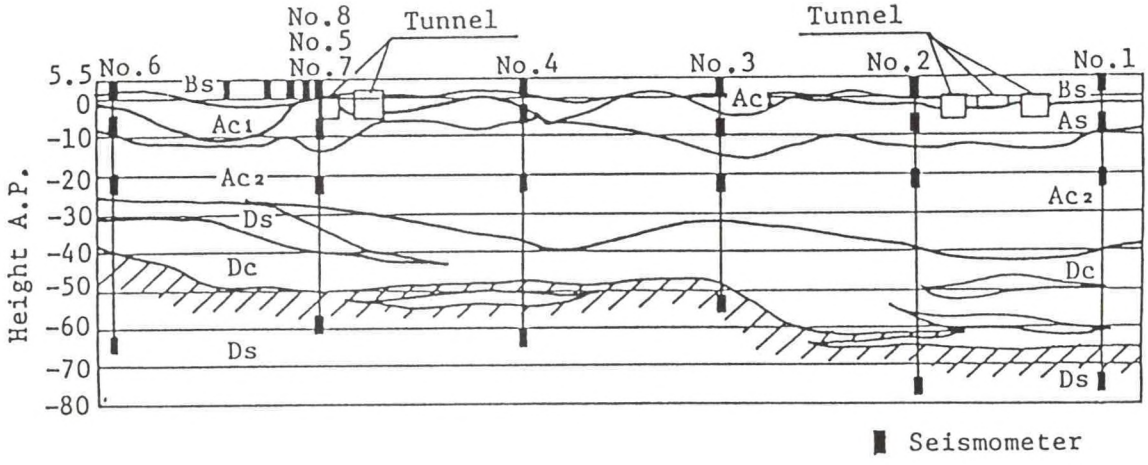


Figure 7 Arrangement of earthquake observation points.

passengers and the north-gate zone for freight, control and operation, and maintenance, and the desirable image and design of each zone was elaborated. The design concept for these seven bridges is "simply structural aesthetic." On the basis of the concept, all the bridges were decided to be made with slender box-sectioned steel girder. The corners of the towers and the main girders are shaped round by cold forming in order to obtain soft impression. Furthermore, these bridges will be constructed with all-field-welding procedure including round shaped corners so that the surfaces of members are very smooth and beautiful.

Two bridges in each zone are particularly exhibiting symbolic quality; the Airside Bridge and the

Access Bridge in the north gate zone and the Central North and South Bridges in the central zone. These bridges should express high technological and sharp characteristics as the symbol of an airport itself which is full of high technology as shown in Figure 6. The Airside Bridge and the Access Bridge, both are cable-stayed bridges, have the same configuration, and appear in double silhouette. The Central Bridges are very unique with an arch-shaped tower suspending respective girder and are exhibiting both structural rationality and a symbolic quality.

Facing Earthquakes

Most of the airport facilities are extended over long distance and vast area so that their behaviors during earthquakes can be very complex. Thus, the strong motion observation by using seismic array is necessary for establishing a reliable earthquake resistant design on those facilities. To contribute to the progress of an earthquake resistant design method for soft ground, a high-density earthquake observation network has been installed, and efforts are continuing to reveal the behaviors of runways and underground structures during earthquakes.

The instrument array at the airport is one of the most extensive observation network in the world. The seismic array there consists of eight local stations along and around the new A-runway as shown in Figure 7 and three local stations at the underground access road tunnels; each station monitors the ground motions and the pore pressures during earthquakes. When the level of acceleration exceeds a pre-set level for triggering, the recording automatically starts at the observation center.

OSAKA BAY PHOENIX PROJECT

Fumikata Iwatani
Osaka Bay Regional Offshore Environmental Improvement Center

What is the phoenix project?

Here discharges a lot of wastes in big cities like metropolitan area and Kinki area according to the concentration of population and industry. It is difficult, however, to dispose of wastes to the final disposal sites because the land utilization in big cities is promoted with high speed.

Therefore, in order to dispose of domestic waste, the coastal municipalities construct final disposal sites at sea, and inland municipalities dispose of their waste out of their region. On the other hand, the industrial wastes, the lack of the final disposal sites, flow widely, and this phenomenon is the cause of illeagal dumping. It is a very serious problem to ensure final disposal sites in big cities.

In Tokyo and Osaka bay areas, they have filled up sea by their waste, and recently especially there increases the case which they use wastes as filling up materials when arranging the port areas. Under these conditions, we must construct final disposal sites and arranging the port planning at the same time.

In order to solve these problems, the plan which arrange the port planning and provide final disposal sites has been advised as "Phoenix Project" by the Ministry of Health and Welfare and the Ministry of Transportation.

For this plan, "The law of Regional Offshore Environmental Improvement Center"was enacted in 1981, and some rules concerning the law were regulated.

In addition, "Phoenix" has two meanings. One is the Egyptian myth. Phoenix is a bird which said to live five or six hundred years and to burn itself on a funeral pile, and rise again from the ashes, fresh and beautiful for another long life. The other is the name of a plant. Phoenix is a subtropical plant and belongs to the palm family. The reason why we call our plan "Phoenix Project" is we want to rebirth the land with full green.

The history of Osaka bay phoenix project

(1)The Ministry of Transportation announced an idea for the construction of regional waste sea walls in August 1966.

(2)The Ministry of Health and Welfare announced an idea for the regional waste disposal plan in August 1967.

(3)The Ministry of Health and Welfare and the Ministry of Tansportation put their plan togather and announced the plan as "Phoenix Project".

(4)The National Diet passed "Law of regional offshore environmental improvement center" in June 1981.

(5)Based on the law, the Minister of Health and Welfare designated the regional waste disposal area, and the Minister of Transportation designated the harbors for the regional offshore land reclamation sites in January 1982. The area is shown in fig. 1.

(6)Osaka Bay Regional Offshore Environmental Improvement Center was formally established in March 1982.

(7)Osaka Bay Center announced the master plan in March 1985.

(8)The master plan was approved by the Minister of Health and Welfare, and Minister of Transportation in December 1985.

(9)The center began to construct Amagasaki offshore final disposal site in November 1987, and it was completed in January 1990.

(10)The other final disposal site "Izumiotsu was begun to construct in June 1988 and is now under construction.

The outline of the Law of Regional Offshore Environmental Improvement Center

(1)Public organization called the Regional Offshore Environmental Improvement Center is responsible for carrying out the phoenix project, that is, planning, construction and operation of the coastal landfill sites of waste.

(2)The center has two purposes : final disposal of waste at the coastal landfill site and improving the port and harbor facilities by landfilling.

(3)The center disposes of waste discharged in broad area(more than two prefectures).

(4)The center is invested by the concerning local governments and port authorities. The center is established after the approvement of the Minister of Health and Welfare and Minister of Transportation.

(5)The center's bussiness are as follows:

① construction and operation of sea walls entrusted by the port authorities

② construction and operation of landfill facilities other than sea walls for disposal of domestic waste entrusted by the local governments

③ construction and operation of landfill facilities other than sea walls for disposal of industrial waste, surplus soil discharged by construction activities and dredged sand

(6)The center shall make the master plan, which shall be approved by the Minister of Health and Welfare and the Minister of Transportation before construction of the facilities.

(7)The National Government can subsidize the construction cost.

The outline of the master plan

(1)Landfill sites

Off-Izumiotsu 203 ha, 30 million m³

Off-Amagasaki 113 ha, 15 million m³

The sites are shown in fig. 2.

(2)Loading facilities (shipment base)

Harima	1,700 ton/day
Kobe	6,700 ton/day
Amagasaki	12,000 ton/day
Osaka	12,000 ton/day
Sakai	9,900 ton/day
Izumiotsu	5,000 ton/day
Wakayama	2,100 ton/day
Tsuna	110 ton/day

We construct loading facilities and waste is carried by barges from each loading facility to landfill site.

The reason why we construct these facilities is to prevent the concentration of the trucks which load wastes.

These facilities are shown in fig. 2.

(3)Area discharging waste

149 municipalities in six prefectures

population 17 million

area 8,900 km²

(4)Volume and kind of disposal waste

domestic waste	4.3	million m³
industrial waste	12.0	million m³
surplus soil	21.9	million m³
dredged sand	6.8	million m³
total	45.0	million m³

(5)Landfilling period

from 1989 to 1994

(6)Construction cost

142 billion yen

The outline of the landfill sites

We have two final disposal sites, Izumiotsu and Amagasaki. Fig. 3. shows their outline.

In each site, we have two kinds of disposal area; impermeable water controlled area and stabilized solid-fill area.

We dispose of cinder, sludge, slag, smoke dust and domestic waste in the impermeable controlled area, and the other wastes such as waste plastic, waste rubber, waste metal, waste glass and ceramic are disposed of in the stabilized solid-fill area.

Countermeasures for environmental Prevention

(1)Sea wall structure of the disposal site

Considering the water depth and soil conditions of the project sites, and construction execution feasibility and economic factors, a caisson type sea wall is being

employed. For the construction of the impermeable water controlled area, considering practicability, execution feasibility and economics, it was concluded that steel sheet piling was the best option, with the steel sheeting being driven in behind the sea wall down to the clay layer. A cross section of the sea wall construction is shown in fig. 4. The steel sheet piles construction is shown in fig. 5.

(2)Water level control

Maintaining the inner water level of the impermeable controlled area at the average low tide level helps to improve the impermeability effect. In the actual method, the sea wall will be closed to maintain the water in the site at the average low tide level.

During the shore filling operation, the inner water level will always be monitored, and as the water level rises, the inner water will be treated by the waste water treatment facility and then discharged into the ocean.

(3)Waste water treatment system

As a processed waste disposal site, the shore-fill disposal will be conducted in areas sectioned off by sea walls. The displaced water, created within the site by the shore-fill, will be treated by the waste water treatment facility. In addition, as the filling process continues and sea water has been displaced, the surface water will be collected and treated.

This water treatment system is as follows.

①Pretreating equipment

After removing the floating debris from the displaced water created by the shore filling within the site by pumping through a screen, pH will be adjusted.

②Biological treatment equipment

A contact aeration type organic membrane treatment will be employed. By utilizing the micro-organisms on the surface of the fillers, dissolution of the organic matter in the waste water and removal of the nitrogen constituent can be effectively carried out. This plays the central role in the waste water treatment system.

③Coagulating sedimentation equipment

The polluting substances in the water to be created are removed through the addition of coagulating chemicals and by gravitational precipitation. The slightly acidic coagulation precipitation treatment is especially effective in the removal of COD and SS components. After sterilizing, the treated water is discharged into the ocean.

④Sludge treatment equipment

Sludge generated by the treatment of the waste water is concentrated, and after accumulation, a high molecular coagulant is added and it is then disposed of by burring in the shore-fill area(controlled area).

The quality of the raw and treated water are indicated in the waste water treatment facility flow sheet in fig. 6.

Acceptable standard

In accordance with the law, and in consideration of preserving the environment, the acceptable standards have been established. These standards have also been established to ensure the proper treatment of the wastes and to reduce the amount of the wastes processed.

As a general principle, acceptable wastes must be nontoxic and nonhazardous.

Combustible wastes must first be incinirated and noncombustlble materials must be crushed (standard tables are omitted here).

Land use after lanffilling

Reclaimed land will be divided into three zones; port zone, urban zone and green zone according to the demand to the verious site. The land use is shown in fig. 7.

Thus, the wastes are expected to rebirth the land, improve the urban environment and also create the new seacoast environment.

Fig. 1 Regional waste disposal area and related harbors

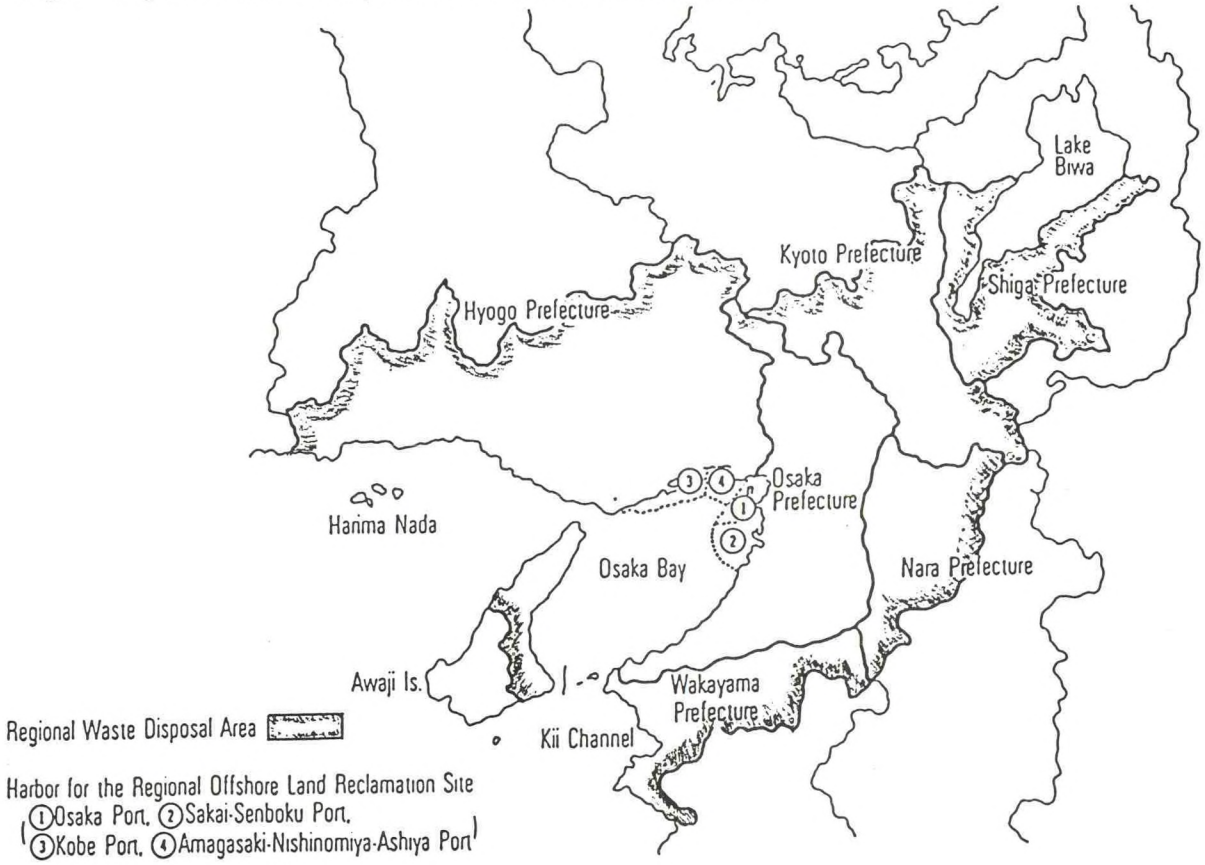


Fig. 2 Disposal sites, and loading facilities and their area

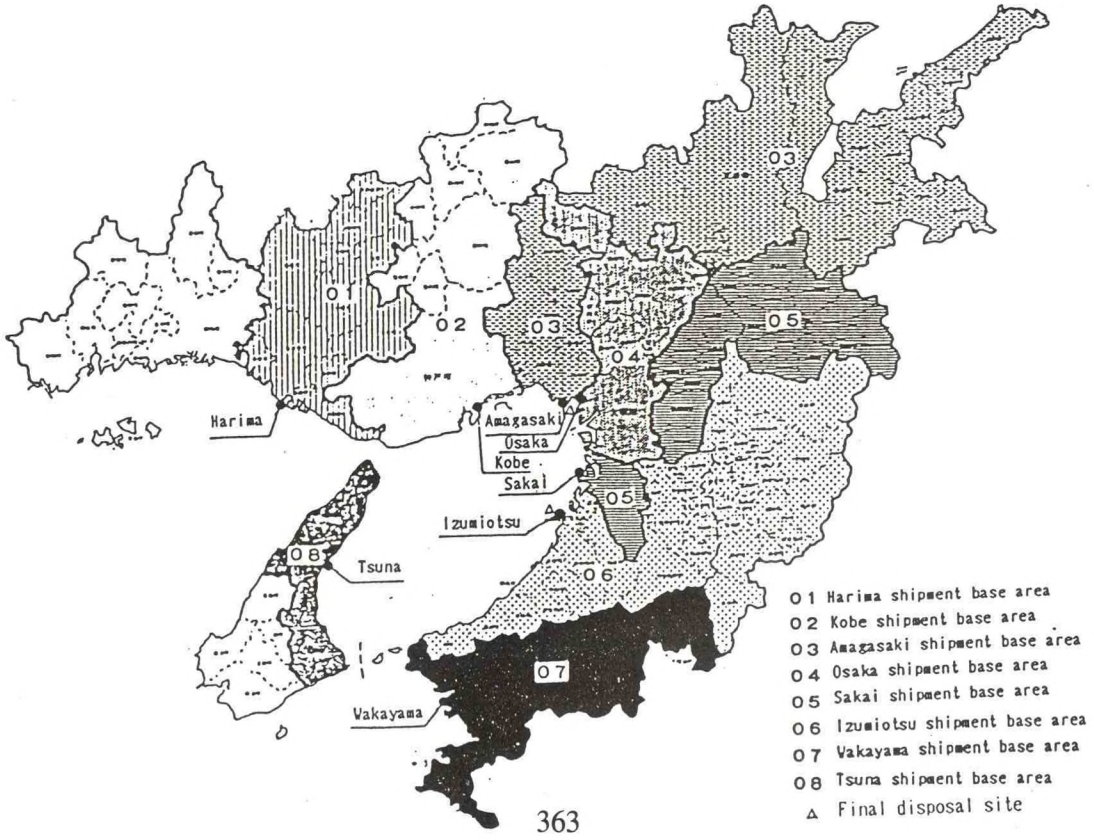


Fig. 3 The outline of the landfill sites

Izumiotsu offshore disposal site

(1) The location of landfill site and volume

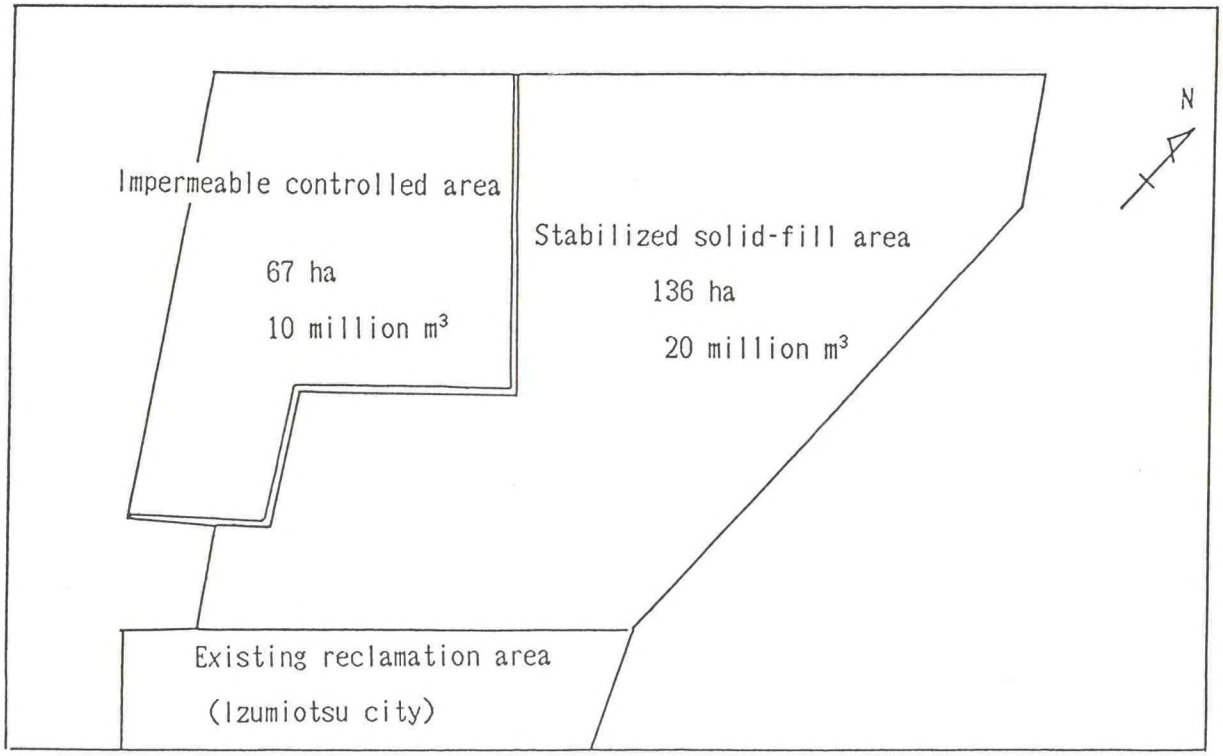
location	area	volume
Sakai-senboku port Izumiotsu city	203 ha	30 million m^3

(2) Volume and kind of disposal waste

(million m^3)

kind	domestic waste	industrial waste	surplus soil	dredged sand	total
volume	3.1	8.4	14	4.5	30

(3) Landfill site



Amagasaki offshore disposal site

(1) The location of landfill site and volume

location	area	volume
Amagasaki-Nisinomiya -Asiya port Amagasaki city	113 ha	15 million m^3

(2) Volume and kind of disposal waste

(million m^3)

kind	domestic waste	industrial waste	surplus soil	dredged sand	total
Volume	1.2	3.6	7.9	2.3	15

(3) Landfill site

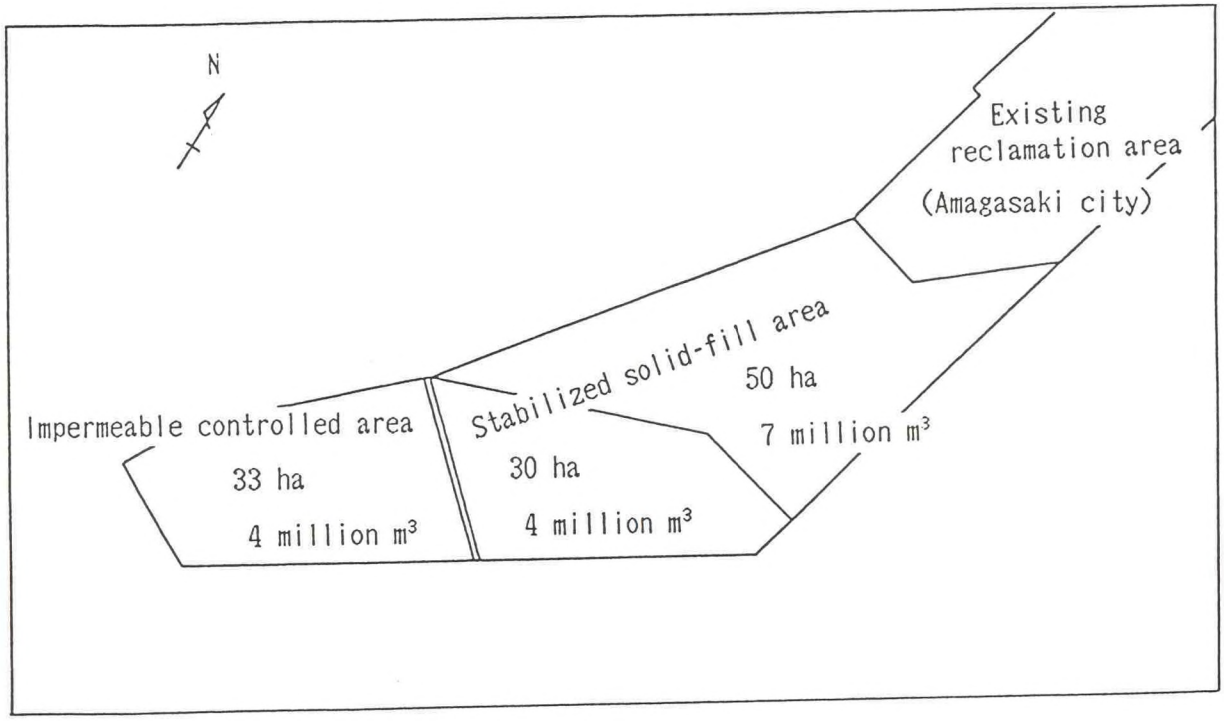


Fig. 4 Sea wall construction

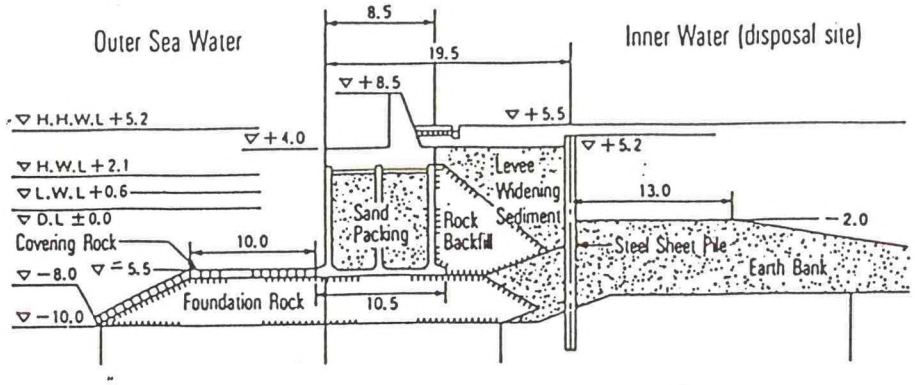


Fig. 5 Steel sheet pile construction

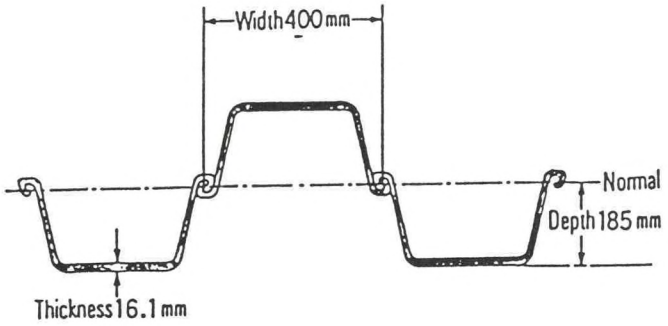


Fig. 6 Waste water treatment facility flow sheet

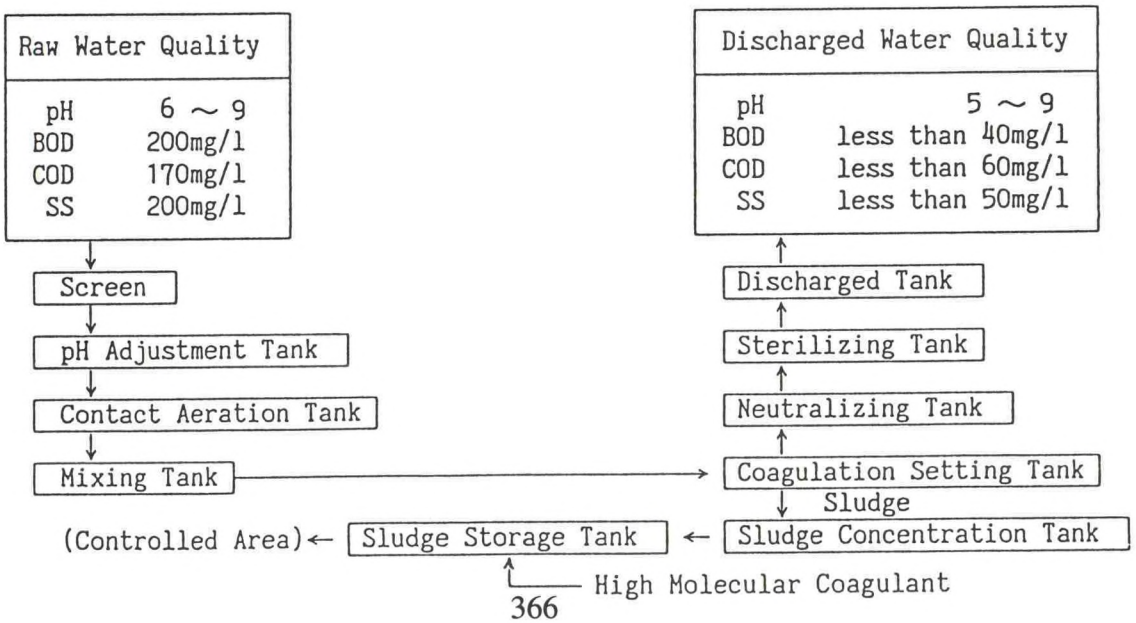
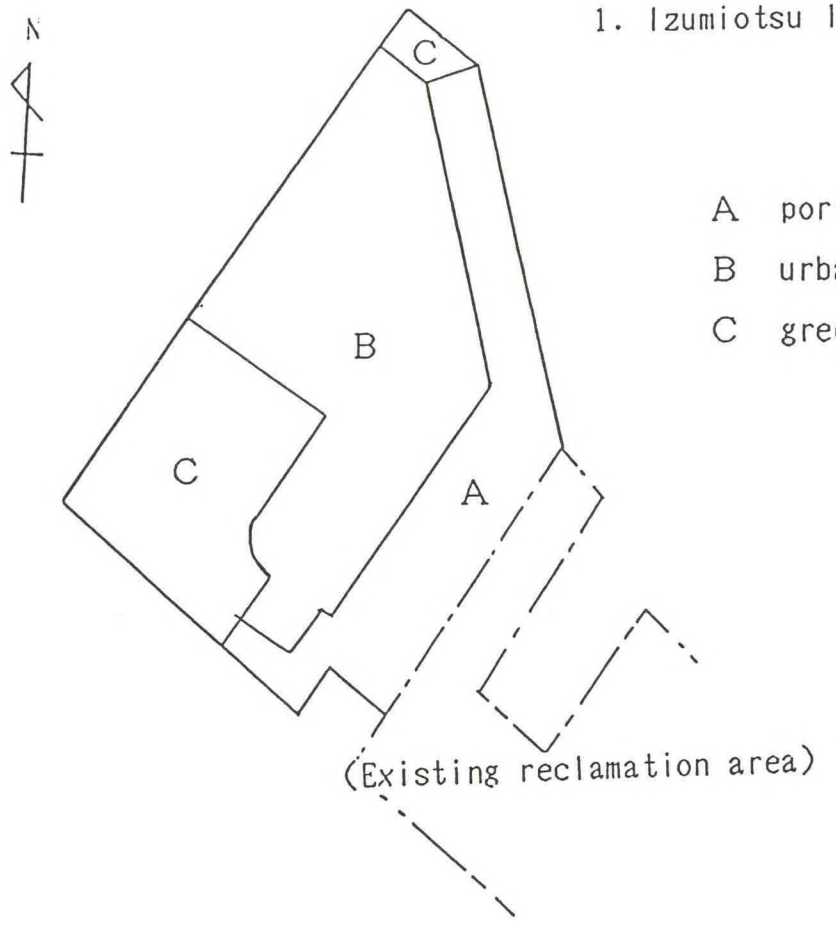


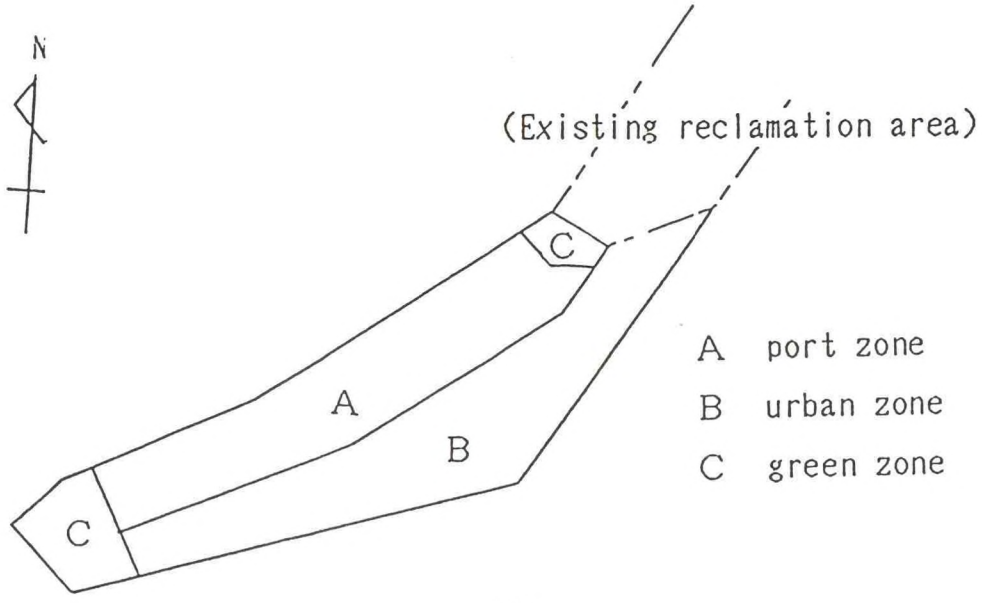
Fig. 7 Land use after landfilling



1. Izumiotsu landfill site

A	port zone	58 ha
B	urban zone	95 ha
C	green zone	50 ha

2. Amagasaki landfill site



A	port zone	43 ha
B	urban zone	57 ha
C	green zone	13 ha

SHORE PROTECTION BY STRUCTURES

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Ministry of Construction

Introduction

Because of the geographical conditions of Japan, its population and property are largely concentrated in coastal zones. These areas are subject to harsh natural conditions, and are often struck by disasters resulting from storm surges, tsunamis and beach erosion. In order to protect people and property from these natural disasters, the Ministry of Construction of Japan has been promoting the improvement of shore protection facilities through its shore protection works.

This article discusses the historical development of shore protection works under the theme of "shore protection by structures," taking into account recent changes in the philosophy of shore protection as well as in the needs of the people with respect to coastal areas. In addition, as examples of future shore protection works, projects aiming to conserve and develop coastal zones will be introduced.

I. Characteristics of Japan's Coastal Regions and Shore Protection Works

Japan consists of four major islands, Hokkaido, Honshu, Shikoku and Kyushu, and about 5,000 islands around these major bodies of land. Japan is surrounded by sea, and, at 34,000 km in length, the complex coastal line is considerably long for a country of Japan's area. A large part of the national land is mountainous, and the area of plain, 110,000 km^2, is only 28% of the total area of Japan, which is 380,000 km^2. Most of the plain consists of alluvial plains near the mouths of rivers. Because of these configurations, most of Japan's population and property are concentrated in the coastal areas. The area inundated by high seas is only 5,500 km^2, 1.5% of the national land, and the population in the area inundated by high seas is 11 million, or 9.3% of the total population.

The coastal areas of Japan are subject to severe natural conditions, such as typhoons, low atmospheric pressure, winter storms, and earthquakes. Damage is often caused by storm surges, high waves, tsunamis and beach erosion. Japan is within the path of typhoon routes; therefore extensive damage is not uncommon. Substantial damage was caused by these major storms: the Muroto Typhoon in 1934 (approx. 3,000 dead and missing and 90,000 houses damaged), Makurazaki Typhoon in 1945 (approx. 3,000 dead and missing and 116,000 houses damaged), and Ise Bay Typhoon in 1959 (approx. 5,000 dead and missing and 157,000 houses damaged). Also, Japan is located in an earthquake-prone area, and due to its complex shorelines, much damage has been caused by tsunamis. The most notable recorded cases of this type of damage have been the Sanriku-oki earthquake tsunami in 1933, which left approximately 3,000 dead; the Chilean earthquake tsunami in 1960, which left approximately 140 dead; and the more recent Nihonkai-chubu earthquake tsunami in 1983, which resulted in approximately 100 fatalities. It is Japan's task to protect human lives and property in coastal areas from these natural disasters. Accordingly, various types

of shore protection works are being advanced to provide this necessary protection.

Judging from the condition of the areas near coastal zones, the area adjacent to 16,000 km of seacoast (47% of the total length) requires shore protection. The seacoasts of Japan fall under the jurisdiction of the Ministry of Construction, the Agricultural Structure Improvement Bureau of the Ministry of Agriculture, Forestry and Fisheries, the Fisheries Agency and the Ministry of Transport. The length of seacoast under the jurisdiction of the Ministry of Construction is 16,000 km, or approximately 48% of the total coastline. Of this, 6,000 km and adjacent areas requires shore protection. In Seacoast Conservation Areas, shore protection works guarding against storm surges and waves, shore protection works guarding against erosion, and coastal environment improvement works are being advanced to protect human lives and property, as well as to promote the utilization of coastal areas. There, structures such as sea walls, piers, detached breakwaters and artificial beaches are being constructed. In the budget for shore protection works in fiscal year 1990, the total amount of moneys budgeted by these three ministries and one agency was ¥172.3 billion, of which ¥56.2 billion was budgeted by the Ministry of Construction alone.

II. Change in the Coastal Improvement Methods

1. Line defense method

Shore protection in Japan can be traced back many years. In the 1940s and 1950s the coastal zones of Japan were subjected to tsunamis and storm surges resulting in significant damage. Therefore, from the 1950s through the 1960s there was an urgent need for the shore protection works to cover the long Seacoast Conservation Area throughout Japan, even though the budget is limited. Therefore, "coastal defense by unifacility (line defense)" using three-face armored coastal dikes at shorelines was adopted with the aim of national land conservation.

These coastal dikes, while effective, separated people from the sea. As the living standard of the people improved, their need for a better coastal environment grew. In response to this need, coastal environment improvement works were begun in fiscal year 1973. The improvement of areas where people can come in contact with the sea, as well as the protection of the national land itself, has been promoted by these projects.

2. Zonal defense method

Beaches perform the function of protecting national land by attenuating the incoming waves and preventing or mitigating damages. Another important function that they serve is enabling multipurpose utilization of the combined land and sea area so that people can come into direct contact with the sea for recreational and economic purposes. Accordingly, it is desirable to facilitate the functions of the beach in coastal improvement. In the 1980s, "zonal defense" was introduced as a philosophy for shore protection (Fig. 1).

In this method, external forces complexly affecting the coast are dispersed by multiple protection facilities such as detached breakwaters, gently sloping coastal dikes and revetments, as well as through beach nourishment. The life span of these facilities is improved, and at the same time, the level of usage of the shore itself is raised. In order to create new coastal areas with the zonal defense methods, the development and actual use of detached breakwaters, gently sloping coastal dikes and revetments, and beach nourishment are being promoted. Also, the development of new technologies based on

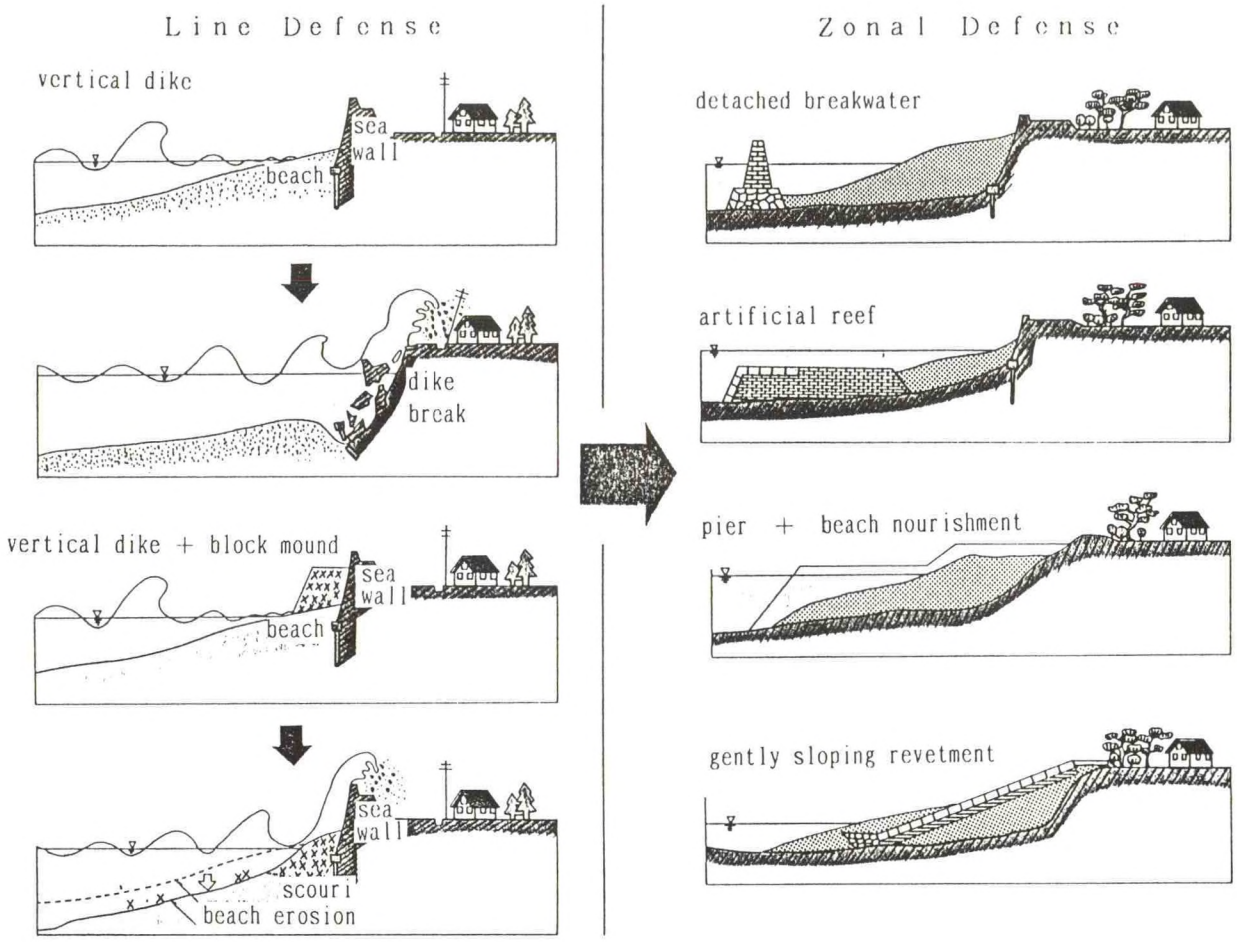

Fig. 1. Changes in shore protection

new construction procedures for artificial reefs and headlands is being advanced to create stable beaches.

Below, shore protection facilities of the zonal defense method are explained.

(1) Gently sloping coastal dikes and revetments

Many problems, environmental and scenic, have arisen regarding the use of conventional vertical-type coastal dikes and revetments. These facilities reduce people's access to the beach and the actual usage of the shore itself, and may hide the sea from the area behind the beach. First of all, with these structures, scouring due to strong reflected waves tends to develop, and problems occur with the increase in the wave overtopping rate. To resolve these problems, new structures such as gently sloping coastal dikes and revetments are being utilized. Without reducing the shore protection efficiency, these structures promote harmony between people and the sea and create a pleasant environment in terms of scenic views.

Reducing the slope of the seaside surface by 30% makes it possible to achieve a lower wave run-up height

than with use of a vertical type of revetment. Reduction of the slope of the surface also decreases the reflection ratio and the amount of erosion, thus enabling maintenance of a constant shoreline.

(2) Detached breakwaters

With the installation of detached breakwaters, effects on shore protection are observed. The major effects that have been noted are wave dissipation effects and accumulation effects, which accumulate beach materials behind detached breakwaters. When accumulation takes place, wave dissipation effects are added due to the reduction of the depth behind the detached breakwaters.

(3) Artificial reefs (Fig. 2)

Artificial reefs are constructed using rubble or crushed stones, thereby securing the wave-control functions of coral reefs in the subtropical coasts. Since the structures are located underneath the water level, they do not obstruct the view. The functions of artificial reefs can be expected to include wave height attenuation by wave breaking and control of literal transport such as by detached breakwaters.

(4) Headlands (Fig. 3)

The principle that shores surrounded by natural headlands can maintain stable coasts for a long time is applied here. When a group of artificial headlands are constructed on relatively long erosive coasts, the areas between adjacent headlands are made into pocket beaches. Thus, the wave energy is dissipated, and the stability of beaches is gained.

III. Shore Protection in the Future

In the latter half of the 1980s, the value of "waterfront" property, which had not been highly prized previously, was recognized. Construction of offices, business facilities and houses was soon begun in these waterfront areas. Areas in various parts of Japan with good natural environmental conditions, in the meantime, began to advance regional development projects centering around resort development. In response to these activities involving shore protection works, national land conservation by zonal defense based on the basic concept of recreation and the maintenance of broad, pleasant shore areas is being steadily promoted. At the same time, there is increasing demand for shore protection works to support projects that would benefit such regional development in response to the needs of the respective areas.

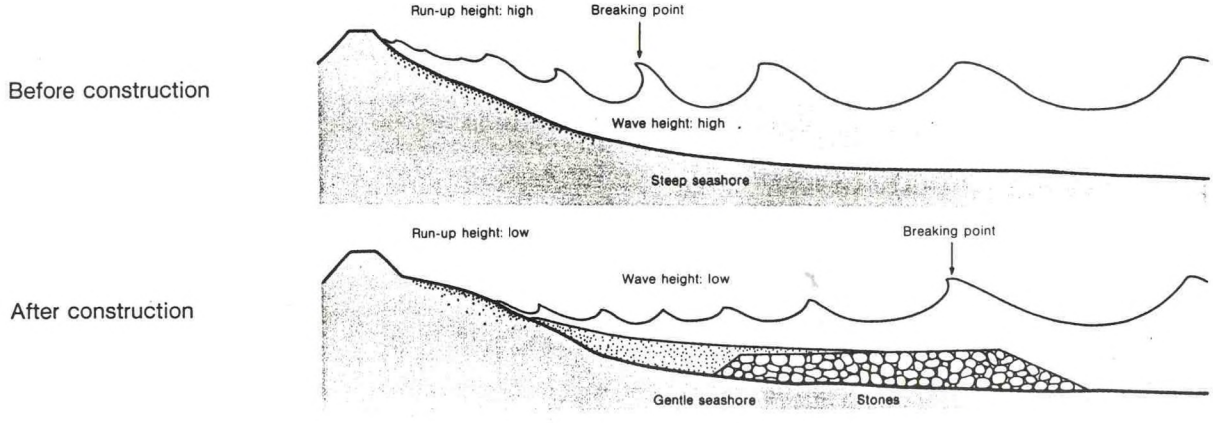

Fig. 2. Artificial reef

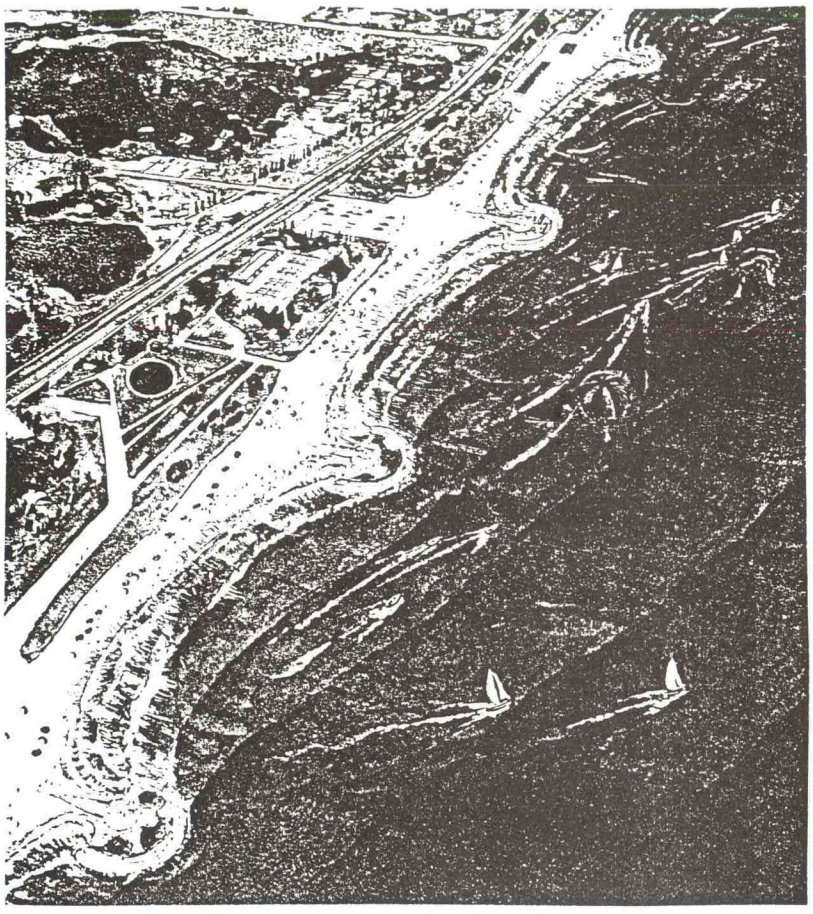

Fig. 3. Headland

In the interest of shore protection and coastal utilization, the Ministry of Construction intends to create large calm sea zones that stabilize shore areas by introducing new types of structures. It plans to utilize the areas and waterfronts created in conjunction with shore protection activities for several purposes, and to advance the coastal zone development projects. As part of these projects, the Ministry of Construction is working to implement the Marine Multipurpose Zone (MMZ) concept, which advances intensive use of the coastal zone facing the open sea by installing large-scale offshore breakwaters at deep sea, and to promote artificial barrier construction.

The following are two examples of shore protection projects that will be implemented in the future.

1. The Marine Multipurpose Zone (MMZ) project and large-scale offshore breakwaters

(1) Outline of MMZ project

The Marine Multipurpose Zone (MMZ) project is one of the future shore protection concepts. By constructing large-scale offshore breakwaters with the function of dissipating wave energy at a depth of 10-20m, a wide and calm sea area is created between the structures and the shoreline. Also, we can use the coastal zone facing the newly created calm area for a variety of purposes. A conceptual drawing of the MMZ project is shown in Fig. 4. The predicted effects are shown below.

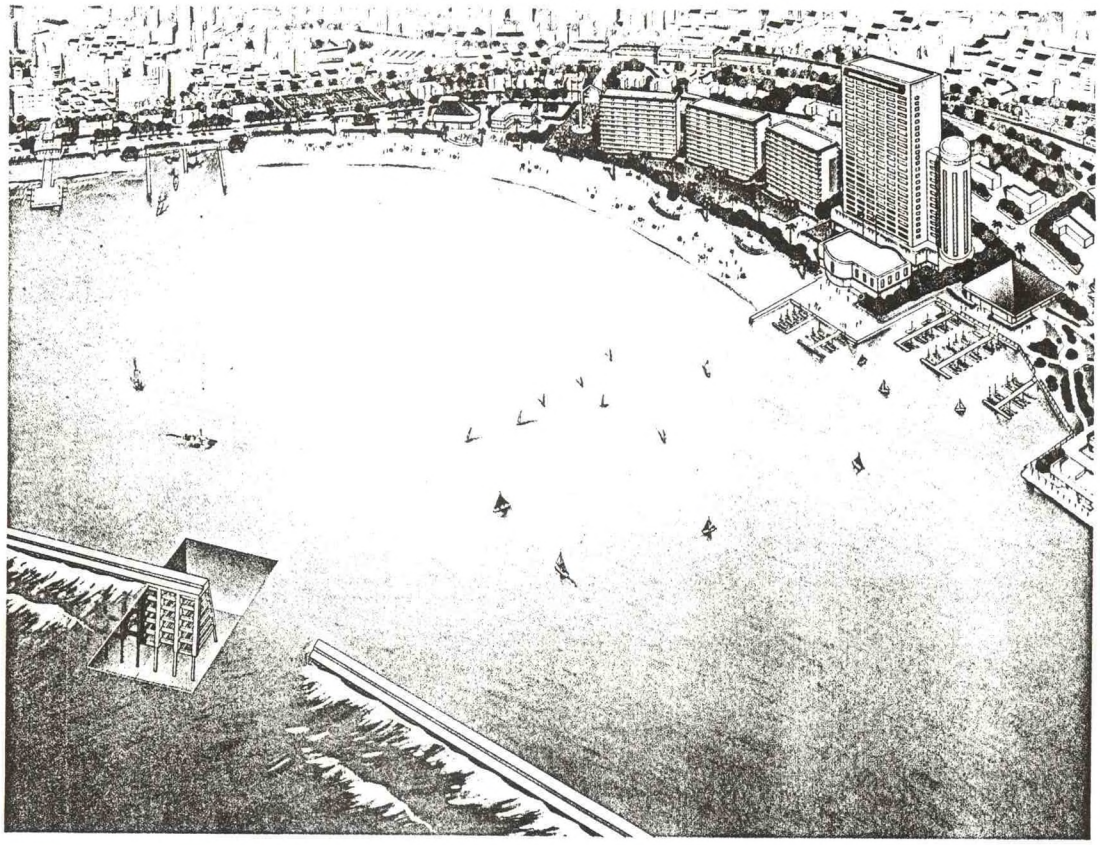

Fig. 4. Image of MMZ project

1) Large-scale offshore breakwaters dissipate the wave energy and stabilize the beach. The permeable structures function to maintain good water quality.
2) These structures create a calm sea area which can be utilized for purposes such as marine sports and marine culture. These structures are expected to provide an artificial environment for fish.
3) The beach stabilized by these structures is widened by the progress of the shoreline. Multipurpose use of this area is greatly promoted, and a good waterfront environment is created.
4) The land area created by the progress of the shoreline has the characteristics of a waterfront in that it can be used for a residential area, roads, parks and a recreation area.

(2) Research and development of large-scale offshore breakwaters and the effort to implement the MMZ concept in actual projects

The Ministry of Construction has been conducting research and development for the MMZ project under a program entitled "Development of Offshore Technology for the Creation of a Marine Multipurpose Zone (MMZ)" in collaboration with the government, academia, and the private sector since fiscal year 1986.

The research project has three main themes: "development of offshore breakwaters," "development of materials and maintenance technologies" and "protection and utilization of marine space." In the project, as shown in Fig. 5, studies on offshore breakwaters of several types, such as the slit type and the embedded steel-

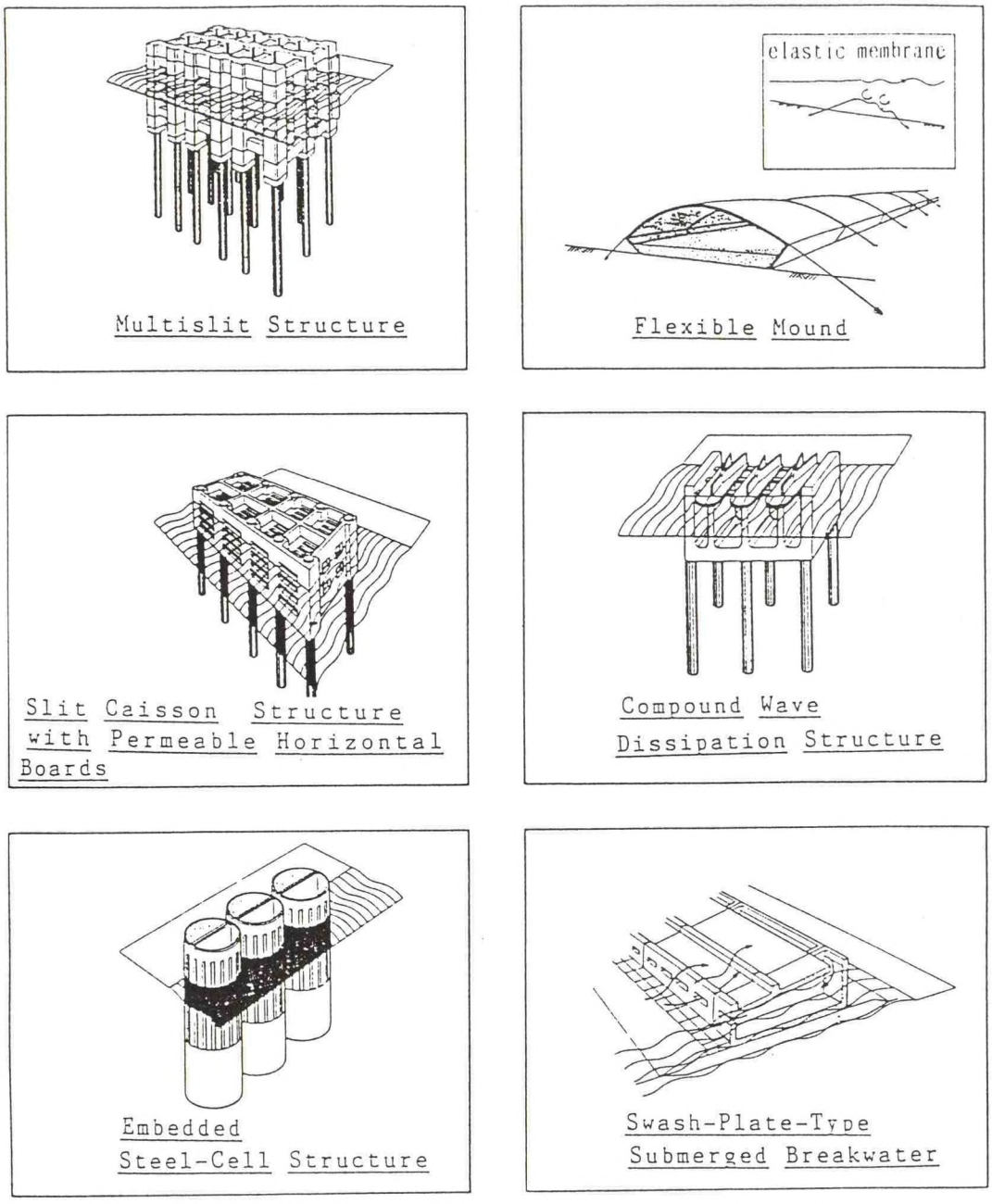

Fig. 5. Offshore breakwaters under consideration

cell type, are being carried out.

To evaluate the effectiveness of offshore breakwaters in a real coast, an experimental slit-type offshore breakwater (Pile and Block Structure: PBS) is being constructed at the Suruga Coast in Shizuoka Prefecture. Work began in fiscal year 1987, and as of fiscal year 1990, one PBS offshore breakwater was completed; the second breakwater is now being constructed. Calming of waves due to the installation of the structure has been observed at the beach, and the shoreline has gradually advanced. The installation is also expected to be beneficial in attracting fish.

The Ministry of Construction will

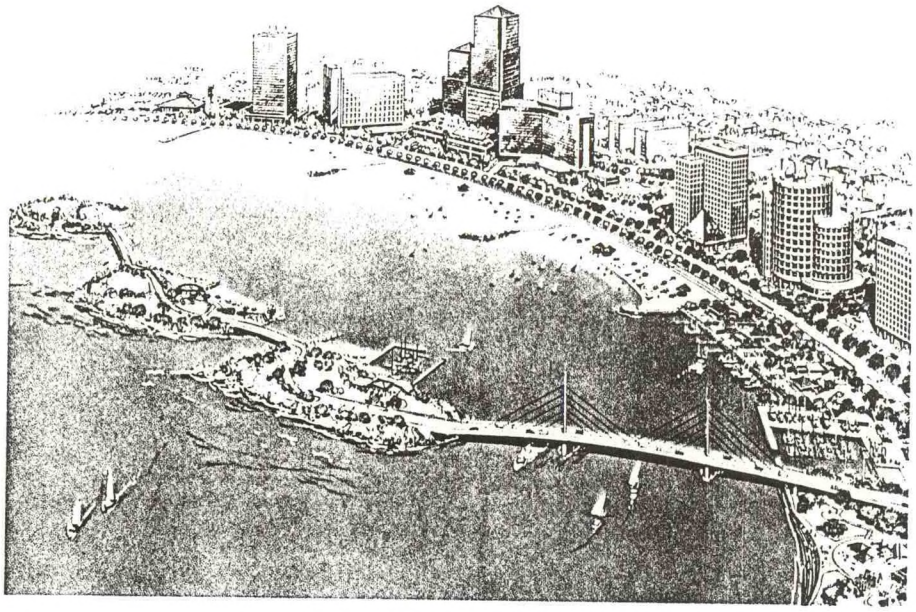

Fig. 6. Image of artificial barrier project

implement the MMZ project as part of its shore protection works in or after 1991. For the time being, it will continue the experimental construction at the Suruga Coast and will select the sites for installation of offshore breakwaters in the coastal zone facing the open sea. On-site investigation and evaluation of effects will be continued.

2. The artificial barrier project

Artificial barriers are islandlike multipurpose shore protection facilities which can be constructed off a seacoast that is in need of shore protection facilities. The artificial barriers can calm waves and stabilize the beaches as well as protect human lives and property from storm surges, tsunamis and beach erosion. In addition, they produce new calm sea areas between the barriers and the land area, and create waterfront environments with amenities that people can enjoy, along with space suitable for marine recreation. The surface of artificial barriers will also be used for housing, roads, parks and recreation facilities, and the soil from construction sites can be effectively used for the construction. Figure 6 shows a conceptual drawing of an artificial barrier project.

The name "artificial barrier" was derived from the barrier islands, which are long natural islands off the east coast of the United States and in the Gulf of Mexico. Here, calm sea areas and comfortable urban space are created by the barrier islands. On the outer side of the barrier islands, waterfronts facing the open sea develop, and two types of coastal zone utilization are being advanced. The islands are utilized for multiple

purposes such as housing, roads, parks and recreational facilities.

The Ministry of Construction will begin conducting studies for the advancement of the artificial barrier project at the Oharai Coast in Ibaraki Prefecture and at the Tanoura Coast in Ohita Prefecture in fiscal year 1991. It plans to construct artificial barriers at these coasts, so that the safety of the national land can be ensured. Creation of comfortable coastal zones can also be expected.

Conclusions

Thus far, the shore protection works advanced by the Ministry of Construction and changes in their basic philosophy have been introduced with a focus on structures. At present, the "zonal defense method" is adopted as the basic philosophy, and improvement projects aiming to create places that bring humans into contact with the sea are being carried out in coastal areas throughout Japan. Also, preparations are being made to implement coastal zone development projects based on the MMZ project and artificial barrier project advanced by the Ministry of Construction, in or around fiscal year 1991.

Today, efforts are being made to improve living standards and the surrounding environment so that people can truly experience a richer quality of life. By creating "coastal space with safety and amenities," shore protection works are expected to lead to the development of pleasant areas where people can gather and relax, while safeguarding human life and property in the areas behind the seacoast. To meet the needs of Japan's people, the Ministry of Construction will strive to translate these concepts into reality.

Integrated Shore Protection System in Japan

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1. Introduction

Japan consists of four main islands of Hokkaido, Honshu, Shikoku, and Kyushu from north to south, and it has other various size islands as many as 3600. The total length of her coastline is approximately 34,000 km, extremely long despite the small land area. She is a mountainous country and the area of available lands is no more than 35 percent of the total area. For this reason, the available spaces for economic and social activities are limited and concentrated along the coastal region.

On the other hand, the natural conditions around Japan are too severe. The coasts and the people living along the coastal region have been exposed to the menace of attacks of the large waves due to the typhoon in autumn, the strong monsoon in winter, and the passage of a low atmospheric pressure in all seasons, and moreover by the storm surge and tsunami as shown in Figure 1, by which, in fact, a large number of lives and properties were lost in the past.

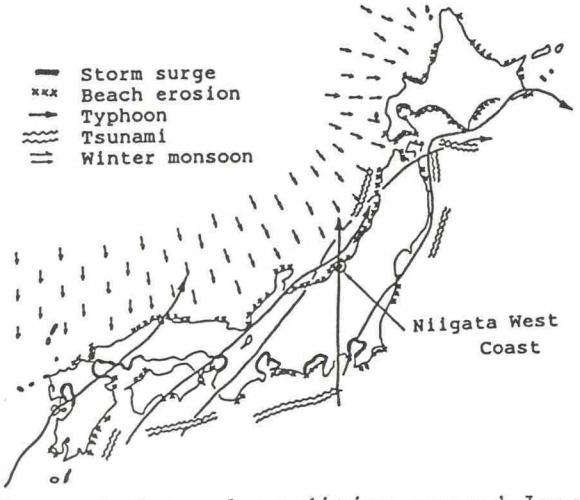

Figure 1 Natural condition around Japan

As a result, we have not taken an advantage of the coast up to the resent time, or rather have been forced to make strong efforts on the coastal protection works. Especially against the beach erosion which spread chronically all over the country after the war, the shore protection works have been conducted purposely and sometimes urgently as required. At present, about 67 percent of the total coastline that needs some protective measures has been somehow protected. However, we cannot neglect the fact that we have put the most emphasis on increasing the extension of the protected coastlines by adopting economical countermeasures. These structures keep the people living the hinterland away from the waterfront.

Recently there are high demands for other ways of coastal protection, which enables the coasts to have more safety and preserve a beautiful view and to be utilized for various purposes including recreation.

2. Shore Protection Works after the War

Japanese land is mountainous, and the most Japanese rivers are short and fast flowing. Even the longest, the Shinano River, is a mere 367 km from source to mouth. A localized torrential downpour in the Pacific Ocean side area in a rainy season and the thaw melting snow in the Japan Sea side area in the spring consequently floods a river. Hence, a river improvement has been a matter of major concern historically. Thanks for the rapid development of river improvement works such as construction of flood channels and dams, damages by floods had been gradually reduced.

On the other hand, such river

improvement works brought about extreme decrease of sand discharged from the rivers. Also, a large amount of sand was excavated from the river bed to utilize it as the construction material for concrete structures. In addition to that, especially in a period from 1955 to 1964, the ports began to be constructed on sandy beaches in earnest on an unprecedented scale in number and size. Furthermore, there were a rapid development of coastal regions by land reclamations.

To the matters worse, large-scale destructions of nature happened concentratedly and continuously during this period. Those are the Toyamaru typhoon (Sep. 1954), the Kanogawa typhoon (Sep. 1958), the Isewan typhoon (Sep. 1959), the Chile Earthquake tsunami (May 1960), and the Second Muroto typhoon (Sep. 1961), etc. Particularly the Isewan typhoon, which hit Ise Bay of the central Japan, brought a tremendous damage of 5,101 killed and completely and partially destroyed houses of 153,893.

Due to the combined effects of the above mentioned factors, the beach erosion problem became much more chronically serious in the whole country of Japan.

In a early stage of beach erosion, planned and employed measures were to construct jetties or to place wave breaking works in front of a seawall. The jetties have a function to obstruct the long shore sediment transport by waves, which prevents the sand being washed away and promotes the sand accretion. They, however, cannot bring their functions into full play for the off-shoreward sand transport by the normally incident large waves.

Since around 1970, detached breakwaters have been constructed as a general countermeasure for the beach erosion. When the bottom sediments could be expected to be supplied from offshore to onshore side of the detached breakwater, the island type with gaps between adjacent units was adopted. When it could not, the continuous type without gaps was adopted. In the former case, the sand deposited behind it forming a tombolo or a salient which occasionally reduced the rate of longshore sand transport. As the result, the detached breakwaters were rapidly and widely applied.

In the following undertaking of the shore protection works, it was necessary for the nearly defenseless coast to extend the protected coastline as fast as possible. Many coasts in Japan were protected by most of detached breakwaters, jetties, embankments or seawalls, and wave breaking works. However, as the economic power of Japan was still meager and the budget was limited in that time, cross sections were designed as economical as possible. These countermeasures were not such fundamental ones as to take the decrease of sand supplement from the rivers into account. Anyhow, the further erosion reaching to the hinterland had been stopped, but many sandy beaches disappeared.

As the space for sea bathing, which has been the most popular marine leisure in Japan since the old time, decreased little by little in 1960's, people wanted to create a suitable place for it. Then, artificial beaches were planned and began to be constructed in many locations. Figure 2 shows the locations of artificial beaches at present. Since there were not enough volume of sand in Japan, it was hard to continuously nourish the artificial beach. Therefore, it was basically important in design to take some facilities into consideration in order to keep the sand inside the beach from being washed away. This was the nearly same technique as those developed as the countermeasures of beach erosion. That is to say, the detached breakwaters and jetties have been constructed to stabilize the artificial beach. It must be said that the purpose of the artificial beach is to make an offer a recreation zone for people, but not to protect the hinterland from huge waves.

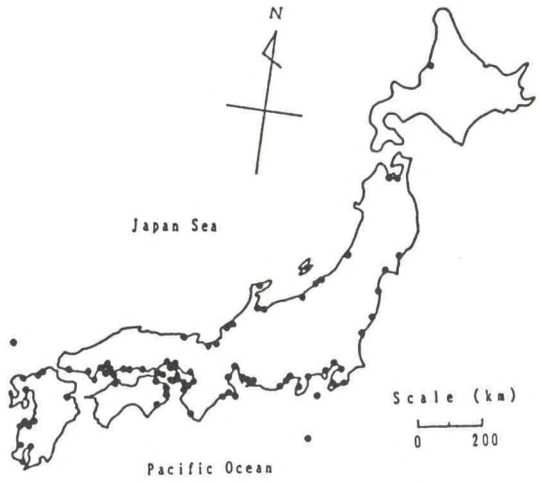

Figure 2 Locations of Artificial beaches

3. Integrated Shore Protection System

The construction of shore protection facilities have been proceeded up to this time. There are, however, some consciousness of problem in the present protection system as follows;

(1) The views of coastal regions are worse than what it was. The demand for a better quality of protection got greater along with improvement of a living standard, and multipurpose use of valuable coastal zone came to be required.

(2) Many artificial beaches have been created to take back the lost beaches. Total length of these beaches, however, is still very short compared with the long Japanese coastline. Moreover, they are not designed from a standpoint of prevention of coastal disasters.

(3) Figure 3 shows the elapsed years since the construction of structures. More than half of facilities were constructed more than 20 years ago. The facilities have been becoming superannuated year by year.

(4) In Japan, there was no severe coastal disaster in last quarter century. This is mainly due to an uplift of coastal improvement level. At the same time, however, it is an actual fact that the large typhoon has not attacked the Japanese coast during about last 30 years. It was quite strange. Therefore, it can be said that the present protection system has not been tested yet by a full-scale power of nature.

To solve some of the above stated problems, it is necessary to strengthen the shore protection facilities. For example, to guarantee more safety of life, the shore protection facilities should be designed for a longer return period. The quantity of overtopping against the seawall must be much less what we design now. It needs to enlarge the cross section of coastal structures because of higher top level. The strengthening of facilities, however, will diminish the people's desire for more effective utilization and better view of coast. This contradiction motivates us to develop a new shore protection system which must have two conflicting functions, that is to say, a prevention of coastal disaster in a huge storm and an acceptance of people to the beach in a calm. Now, a new system, namely a Integrated Shore Protection System (ISPS), is going to be applied to the eroded beach.

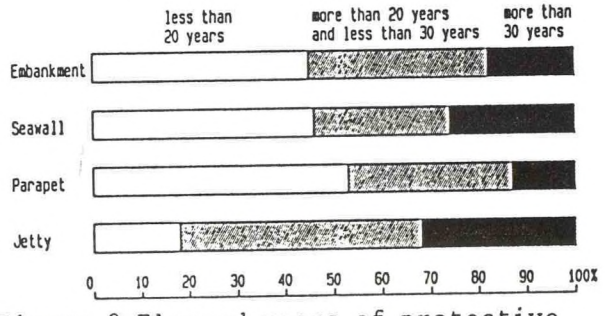

Figure 3 Elapsed years of protective structure around ports (in 1987)

The ISPS is the combined system of an offshore structure, a sandy beach and a seawall which brings each protective function into full play as a whole. That is to say, the ISPS works such that the detached breakwater with a low level crown height or submerged breakwater placed at the offshore front-line first suppresses the waves, secondly the natural or artificial sand beach breaks the waves propagating onshore, finally a step-type seawall, having the structure with easy access to the beach, absorbs the rest of the wave energy (see Figure 4). Since a portion of the protective functions is allotted to each of three facilities, the total system has remarkable features. It can avoid blocking the people's approach to a sand beach and spoiling a beautiful view. We can also take a longer return period of the objective forces at designing facilities.

Figure 4 shows the conceptual comparison between the usual system and the ISPS. The former is, so to speak, a line defence which extends in the longshore direction along a coast. Contradictory to this, the latter is a

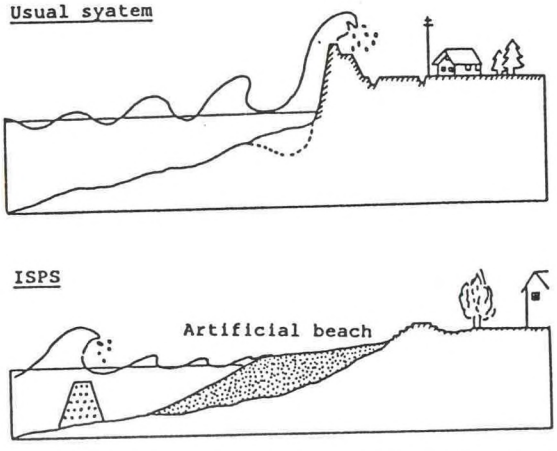

Figure 4 Conceptual comparison between the usual system and the ISPS

plane defence with the parallel arrangement of plural number of facilities in the cross-shore direction. The crown height of seawall can be made lower in the latter system.

There are many technical difficulties remain to be solved from now so as to make the coasts what people currently desire to be. In the next chapter, an application of the ISPS to the Niigata West Coast(see Figure 1) will be shown.

4. Application of ISPS to the Niigata West Coast

4.1 Background

Niigata Prefecture has a wide sandy beach facing to the Japan sea. The beach was formed by voluminous depositional materials discharged from the Sinano River as shown in Figure 5. The Shinano River has a length of 367 km, ranking first in Japan, and a drainage area of 12,050 km². The left side beach of the Sinano River, extending approximately 6 km long, is referred to as the Niigata West Coast in this paper.

During this half a century, however, the beach has suffered severe erosion. That is due to the Sinano River Improvement Works including the river diversion works, the large scale of West Jetty Construction Works at the river mouth and the subsidence of ground in this area. As the river used to cause frequent floods in the Niigata city located around the mouth of river, a short-cut of the main stream to the Japan Sea, named The Ohkouzu Channel, was opened at the site 50.9 km upstream from

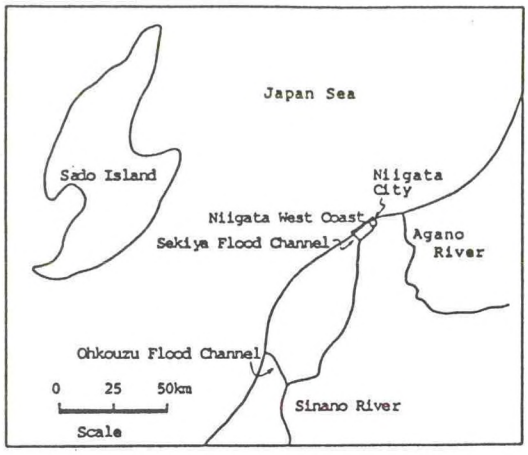

Figure 5 Location of Niigata West Coast

the mouth in 1927. Then, the drainage area decreased down to 1,420 km². A construction of the second short-cut, name of the Sekiya Channel, started in 1964 at the location of about 8 km upstream from the river mouth and was completed in 1975.

Figure 6 shows the history of the Sinano River Improvement Works and the shoreline recession at the Niigata West Coast. The shoreline has recessed as much as 350 m at maximum at the location of E from the position of relatively stable era in 1889. The scale of recession is one of the largest case in Japan.

To protect the Niigata West Coast from erosion, technical study of protection measures and construction of detached breakwaters based on it have been conducted since around 1945. At the

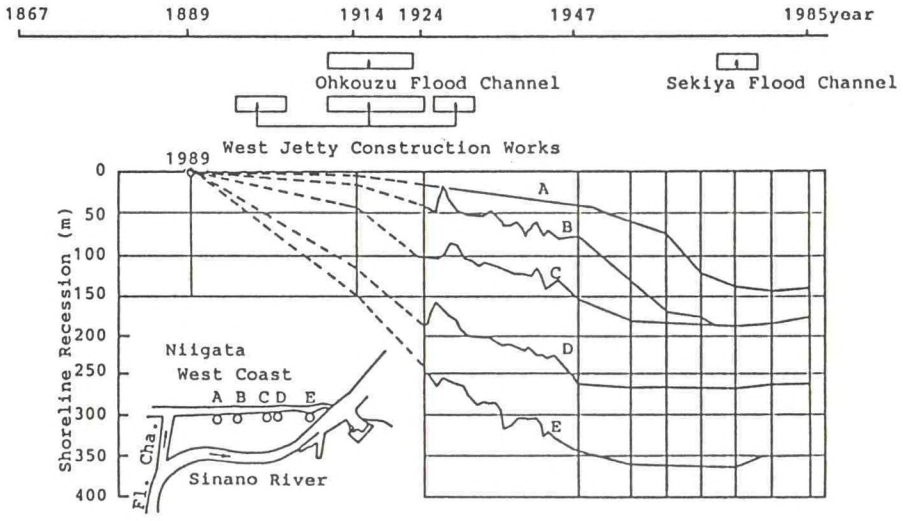

Figure 6 History of the river improvement works and shoreline changes

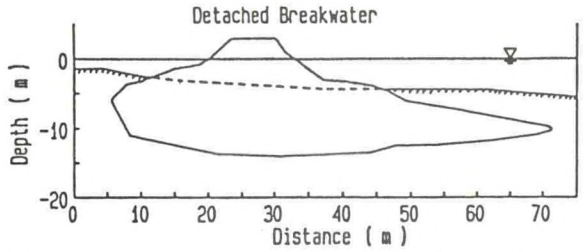

Figure 7 Deformed detached breakwater

initial stage, scour at the toe of the detached breakwater resulted in a severe subsidence and concrete blocks had to be repeatedly supplied to maintain the cope level. These endeavors have made up the detached breakwaters in the present form, in which the crown height is more or less +3 m above the low water level. Figure 7 shows the cross section of the present detached breakwater disclosed by cross hall elastic wave prospecting in 1985 (Miyamoto et al., 1986). The blocks settled about 10 m deep at maximum under the seabed.

The present detached breakwaters seem to make barely the shoreline to be stable. However, the seabed in front of them is still being eroded due to the shortage of supplied sand from the Sinano River. Figure 8 shows the change of beach profile along the typical surveyed lines. Although there existed the subsidence of ground of about 2 m in this area, it has almost stopped at present. However, the erosion over a wide area in the offshore will never stop. The increase of water depth in front of the detached breakwater will come to make the coming waves higher. Thus, if the detached breakwaters will breakdown due to the seabed erosion, a large-scale shoreline recession should occur. According to an estimation, the detached breakwaters will loss the function to protect the beach enough from erosion even after several years.

To cope with the present difficulties, the reinforcement and raising works of breakwaters seem to be no longer effective. It is necessary to construct new facilities at the offshore side of eroded area to stabilize the coast for a long term.

At the same time, there are strong demands to use the seaside for recreation and relaxation. Many citizens now cannot but hope the restoration of the vast sandy beach such as in the past. Then, it was decided to apply the ISPS to this beach at first.

4.2. Technical Investigation concerning to the ISPS

An important point to protect the West Coast is to prevent the erosion in front of the newly placed protective facility such as seen in present detached breakwater. For this purpose the protective facility should be a low-reflection type as much as possible. We consequently designed a submerged breakwater modeled on a bar formed in a natural beach. Such a structure would be able to diminish the scour of bottom topography around it and also protect the hinterland.

The largest three requirements for the function of submerged breakwater are the following items.

1) It must prevent the erosion in front of the present detached breakwaters by decreasing the transmission of incident waves.

2) It must not promote the scour and erosion on the offshore side seabed by having lower reflection.

3) It should be stable against subsidence.

At first to study the required condition of transmitted waves, a relationship between the wave condition

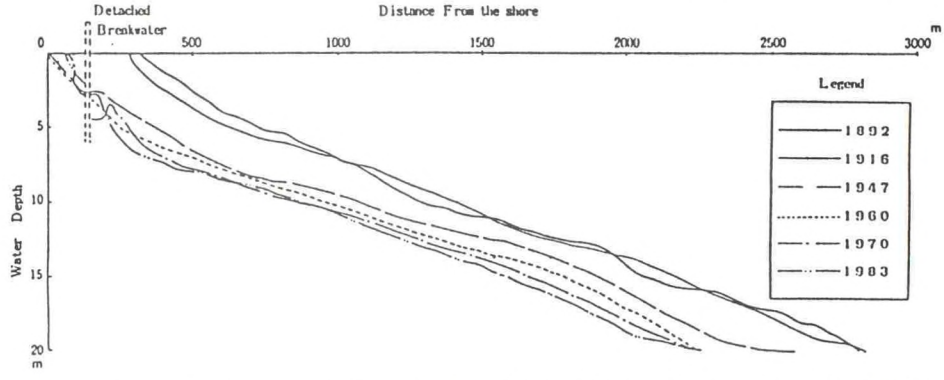

Figure 8 Changes of beach profile at typical surveyed line

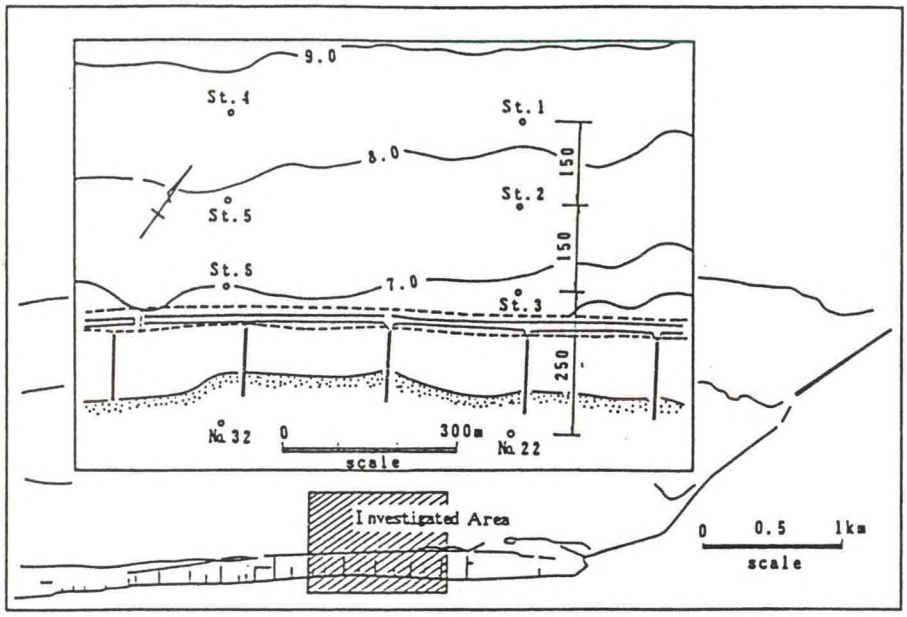

Figure 9 Location of observation points

and the critical condition of seabed changes was analyzed based on the field data measured at the points shown in Figure 9 (Arai et al., 1987). At St.1 to St.6 in the figure, sand recorders to detect the elevation changes were installed. The characteristic of bottom level changes were then correlated with wave data as shown in Figure 11. In the figure, erosion, accretion and no change are indicated by different symbols. The critical condition of sand movement is expressed;

$$Ho/Lo = a(d/Lo)^{n}(\sinh 2\ h/L)(Ho/H), \quad (1)$$

where Ho and Lo are the wave height and length in deep water, and H and L are the wave height and wave length at the water depth of h, respectively, and d is the grain size of sand. According to Sato and Tanaka (see, Sato and Ozasa, 1978), n is 1/3, and a is 1.35 for the critical condition of surface movements, which is also shown in Figure 10. The present results of observation seems to coincide if a=1.0 as shown in the figure. Taking n=1/3 and a=1.0 in equation (1), we can have the critical wave height for the seabed change for each period of wave. At the water depth of about 8 meters in the back of the submerged breakwater, the critical wave height is about 1 meter for the typical wave period of 8.0 second under stormy weather. Then, there will be no major topographical changes at that site if we can reduce the transmitted wave height to be less than 1.

At present, the seabed in front of the present detached breakwater is eroded most extensively and the amount of erosion decreases as it goes offshore. This erosion is due to the reflected waves by the breakwater. To avoid the similar erosion in front of the newly constructed submerged breakwater, we would intend to take the reflection coefficient of this structure as 0.2. That is because the two-dimensional movable bed experiment conducted by Saeki et al. (1985) shows that the scour will not occur in front of the breakwater when the reflection coefficient is less than 0.2.

Based on the above investigation, we

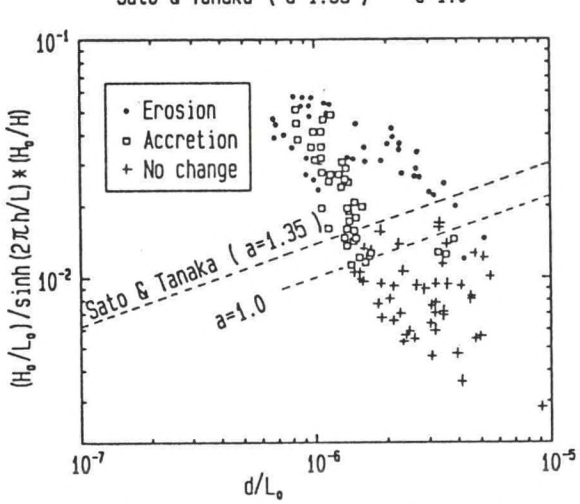

Figure 10 Deformation limit of sea bed

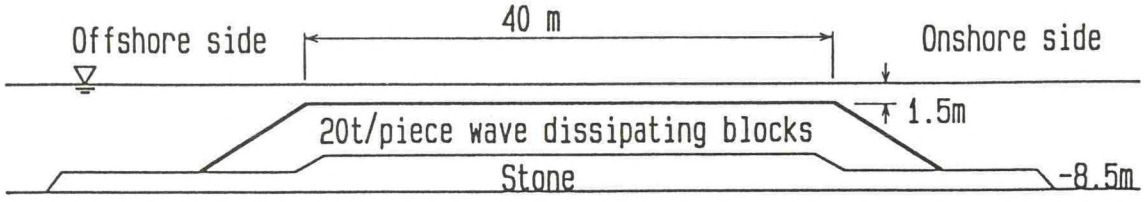

Figure 11 Cross section of submerged breakwater

decided to set two criteria for the submerged breakwater. That is, the transmission and the reflection coefficients are about 0.4 and 0.2, respectively, against the representative wave (Ho=3.0 m, T=8.0 sec).

In general, the transmission coefficient becomes smaller with the smaller ratio of depth at the top to wave height($h/H_{1/3}$) and the larger ratio of top width to wave length($B/L_{1/3}$). On the other hand, the reflection coefficient becomes smaller with the larger value of $h/H_{1/3}$. To insure the desirable coefficients of transmission and reflection as well as to pursue to be economical, the Niigata Port Construction Office (1988) conducted two dimensional model experiments on the transmission and reflection coefficients. Based on the result, it was decided that the top level of submerged breakwater is C.D.L.-1.5 m and the top width is 40 m. The designed cross section is shown in Figure 11.

Furthermore, to examine a location of submerged breakwaters, the topographical change for several cases had been predicted by combining a hydraulic experiment and a numerical simulation (Irie and Kuriyama, 1988). Based on the result of estimation, it was determined to place the submerged breakwater at the water depth of 8.0 m which is 400 m offshore from the present detached breakwater as shown in Figure 12. In addition, it is necessary to place jetties of 200 m long for reducing the longshore current due to wave set-up in the back of the submerged breakwater.

The construction works of the submerged breakwater and the jetties started in 1988. At present, one jetty of 200 m long has been already built up. The second one is 160 m long now, which is under construction. The submerged breakwater has partly built up for the section of 200 m long with the top crown width of 20 m, which will be made longer and wider up to the designed scale by

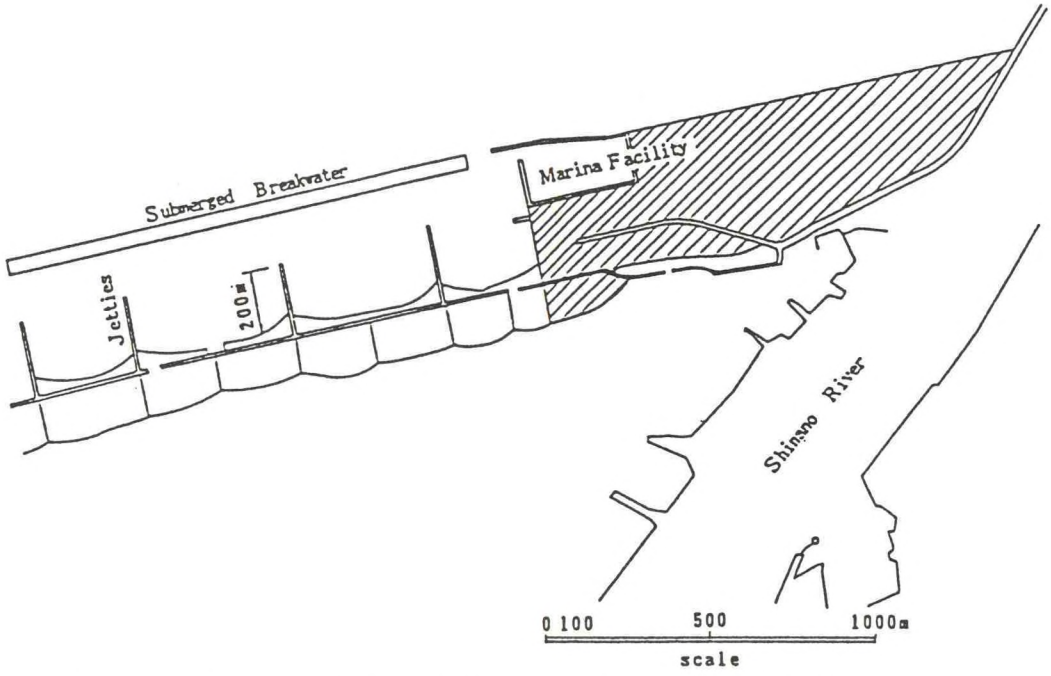

Figure 12 Costruction site of submerged breakwater

1994. After that, it is planned to supply the large amount of sand to nourish the eroded beach in the onshore-side area of present detached breakwater. Finally, the present detached breakwater will be removed to complete the ISPS.

However, there are quite a few problems to be solved technically for carrying out this plan. For instance, in order that a sand beach should work as a protection measure with the submerged breakwater and the jetties, if circumstances required, we may need to devise some measures that prevents the sand from flowing out in storms. For this reason, we need to develop, to some degree, quantitative prediction methods of beach deformation due to the cross-shore sand transport. It is, however, still hard to be established despite the current advanced numerical simulation techniques by a computer. At the Port and Harbour Research Institute, research has been directed toward finding the relationship between beach deformation and exerting forces in a storm based on the data obtained at the Hazaki Oceanographical Research Facility (Katoh and Yanagishima, 1988; Katoh and Yanagishima, 1990).

As this project is the first application of the ISPS to the actual beach in a large scale, we have already started to carry out the follow-up survey of wide scope on waves, currents, topographical changes around structures and so on, and will continue for a long term beyond the end of project.

5. Summary

As Japan has a long coastline and is exposed to severe natural conditions such as typhoons, we have been forced to make strong efforts on the coastal protection works to prevent the coastal disasters. We have constructed the detached breakwaters, the jetties, the seawalls and so on as quickly as possible under the limited financial condition. As a result, these structures keep the people away from the waterfront. In order to restore the beautiful sandy beach such as in the past, we are going to develop a new shore protection system, namely Integrated Shore Protection System (ISPS), which has two conflicting functions, that is to say, a prevention of coastal disaster in a huge storm and an acceptance of people to the beach in a calm. The ISPS is the combined system of a offshore structure, a sandy beach and a seawall with a low level of crown height, which brings each protective function into full play as a whole.

In the Niigata West Coast where one of the largest erosion in Japan has occurred, the ISPS is about to be carried out into a construction stage by supporting with enough technical investigation. We will conduct it properly, as trying to solve the technical problems and checking the effect of facilities step by step, by doing a sufficient and continuous follow-up study.

It is expected that fundamental techniques obtained in this project will be developed into application of this method at the coasts facing open sea before long, and that we will be able to put into practice the shore protection works with more excellent functions and greater views in the future.

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RESULTS OF THE FIELD EXPERIMENT OF THE FLOATING OFFSHORE PLATFORM "POSEIDON"

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1. INTRODUCTION

Many kinds of the conceptions of the ocean development have recently been presented for the effective utilization of the ocean space. [1] [2] Those conceptions can be realized by the social and economic necessity, achievement of the technology and the strong will of corporations. The Kansai international airport which is now been under construction is a typical example of the ocean space utilization using the reclaim method of construction satisfying the conditions mentioned above. On the other hand, we can choose the method using the floating body in order to generate the utilizable space in the ocean. The large-scale floating platform has never been carried out so far. However, this method of construction can truly be one of the powerful methods from the point of view that it has an advantage concerning environmental assessment and there are special sea area where the reclaimed construction cannot be adopted.

The Ship Research Institute has been making the research to confirm the technological possibility of the utilization of the ocean space using the huge floating offshore platform. The individual element technologies have been assured by the model experiment in the basin and the theoretical calculation during this research. The achievement that the structures moored for a long period of time at sea are safe enough to realize the utilization of ocean space using the floating offshore platform is essentially indispensable. Therefore, the field test using the proto-type floating offshore platform had been planed to validate the applicability of the element technologies which have been stored so far concerning the floating offshore platform. The outline of this experiment has been described in the previous UJNR report. [3]

The full-scale structure named "POSEIDON" was too small to use for the purpose of the utilization of the ocean space, but an unprecedented long field test in the world has been carried out from September, 1986 to July, 1990. The full-scale structure has been safely moored for about 4 years. This achievement is the most valuable results than any other results which will be shown in later chapter.

This paper deals with some of that experimental results.

2. ENVIRONMENTAL CONDITIONS

Although data concerning environmental conditions have been originally measured to investigate the experimental conditions at the test field, some new findings applicable to the similar field test obtained during the enormous data analyses.

2.1 Wind spectrum at the test field[4]

It is often required according to the recent ship classification rule to make a computer simulation for one hour or more using the varying wind as the external force in the dynamic analysis of the mooring system. The spectrum formula proposed by Davenport[5] or Hino[6] has been used as the varying wind velocity spectrum. Thus, it is very interesting to check the wind velocity spectrum measured on the "POSEIDON".

The spectrum analysis of the varying wind velocity has been carried out using the data measured for continuous 43 hours

during the seasonal strong wind in winter. The analyzed time interval is one hour with 30 minutes time lag. The estimation of the spectrum has been done by AR model for the total of 87 cases. Figure 1 shows the one of the examples and also shows the result using the data length of 10 minutes. The analyzed spectrum using the latter data found to be almost the same as the Davenport or Hino's spectrum. However, there is a distinct difference between the analyzed spectrum and theirs. The characteristics of the spectrum from the measured data and the new formula representing the varying wind velocity spectrum on the basis of the physical assumption has been obtained.

The spectrum of the varying wind velocity obtained from the new formula shows the good agreement with the measured data as shown in Figure 2. The peak frequency of the spectrum moves toward the low frequency range as the mean wind velocity and the intensity of turbulence get larger. On the contrary, the spectrum presented by Davenport or Hino can never represent this tendency. It is hopeful that the validation of universality concerning the new formula should be checked using measured data of wind velocity on the sea in the another test field.

2.2 The characteristics of wave spectrum[7]

It was a quite valuable result that the directional wave spectrum has been measured by the installation of the line array of three ultrasonic wave height meters. The reliability of it for the wave period less than 9 second becomes worse because of the long distance between arrays. There are not so much of data of directional wave spectrum with a sufficient accuracy.

The frequency spectrum shall be discussed first. Figure 3 shows the change of frequency spectrum in every 2 hours chosen from the data measured for continuous 23 hours in the growth process of waves. This Figure shows that the energy equilibrium area which exists in the high frequency range of spectrum is proportional to the -4th power of frequency. This area moves toward the low frequency range with the growth of waves. The energy around the peak frequency rapidly increases where the growth of waves reaches the top. It is commonly accepted that spectrum in such area is proportional to -5th power of frequency proposed by Phillips[8] and it has been generalized to be involved in the presentation of Pierson-Moskowitz type of spectrum. However, -4th power rule has been demonstrated theoretically by Toba[9]. This detection that observed data have been found to support Toba's theory is one of variable results

Secondly, directional function of wave spectrum shall be investigated. Spreading parameters at peak frequency Smax have been evaluated by using measured data in order to compare them with the experimental formula presented by Mitsuyasu[10]. As shown in Figure 4 measured data have opposite tendency. The characteristics of S with respect to the frequency have also been investigated. The results are shown in Figure 5. The change rate of S obtained from the measured data is not so rapid as the equations presented by Goda et al.[11], and thus analyzed S rather agrees well with the result of Izumimiya[12]. It is considered to be a shallow water effect that S becomes larger in the low frequency range.

2.3 The characteristics of current

The geographical effect on the current is strong in comparison with the wind and waves, thus the general characteristics have never been found. However, it has been turned out that the current of which direction goes along with the local coastline is superior as shown in Figure 6 and the main cause of the current seems to be side current deriving from Tsushima ocean current. Thus, it can be said to be necessary that the at least one year field observation is necessary in order to grasp the characteristics of the current at the installation site of the offshore structure.

3. BEHAVIOR OF THE STRUCTURE

The behavior of the floating offshore structure in the disturbance such as wind, waves and current is the key of the research among the element technologies which have been studied so far. The validity of the method of estimating the external force by theory has been verified through the behavior of the structure, although the external forces corresponding to those disturbances have not been measured directly.

The behaviors of the structure can be divided as follows in order of large period.

(1) Steady drift and tilt
(2) Slow drift motion by wind
(3) Low frequency motion by waves
(4) Oscillation with the wave period

"POSEIDON" moves and tilts due to the steady force or steady wave drift force resulted from the steady component of wind and current and balances with the mooring force and static restoring force. These are considered to be represented as the mean value in certain period of time unless a rapid change of the sea conditions occurs. The steady environmental data, steady drift and steady tilt have been obtained as the mean value of the measured data at regular time. Steady external forces have been calculated according to the ordinary method of estimation. The estimation of steady drift agrees well with the measured data as shown in the Figure 7.

Figure 8 shows the time history of wind speed, of pressure difference in the direction of sway and of the motion when the wind load is dominant (mean wind velocity:13.8m/s, significant wave height:0.3m). It is found that those three items have mutually excellent correlation. The coherency between wind velocity and wind pressure difference or wind pressure difference and the motion in the direction of sway, are shown in Figure 9. It means that those three items seem to have a linear relation in the period range of more than 160 second. That is to say,"POSEIDON" moves slowly balancing quasi-statically itself with wind pressure.

The low frequency motion with the period from 60 to 90 second due to waves surely occurs as shown in Figure 10. The ratio of maxima out of the N extreme values to the standard deviation is shown in Figure 11. The measured data exist between the theory of Longuet-Higgins[14] with $\varepsilon=0$ and that of Kato[15]. The latter gives the upper limit to the measured data. Therefore, the maximum expected values of low frequency motion due to waves can be estimated using this method.

It has been reported in the previous UJNR meeting that the motion of "POSEIDON" with the wave period agree well with the theoretical calculation. The previous calculation has been made on the assumption of the long crested waves instead of considering the directional spreading of waves. The theoretical calculation of the transfer function for short crested irregular waves agree well with measured data as shown in Figure 12. The lateral motion shown in Figure 13 occurring when the principal wave direction equals to 0 degree can be explicable by taking account of the wave directionality.

As above mentioned, the measured behaviour of the floating structure at sea have agreed well with theoretical calculation which has been developed so far. The applicability of those methods to the full-scale structure proved to be fine in the wide range of frequency. It is especially fruitful that the slow drift motion due to the slowly varying wind speed and by waves has been confirmed

4. MOORING LINE TENSION[16]

The mooring line tension is divided into the steady component including the initial tension and the oscillating component. Furthermore, the latter consists of the long period of oscillation due to slow drift motion and the short period of oscillation which equals with the wave period. The component of the long period of oscillation can be estimated rather accurately from the shift of the mooring

point using the quasi-static theory of catenary. The calculation method of the short period of oscillation with an enough accuracy considering the effect of slow drift motion has been presented, which improves the simple method of Shimada et al.[17] calculating the dynamic effect. Figure 14 and 15 show the measured data and the results of calculation respectively.

The mooring line tension is originally a phenomenon with the strong non-linearity, thus there is no existing theory which estimates the maximum of the tension. The Figure 16 shows the ratio of the maxima out of N extreme values to the standard deviation in the drift direction of surge. The measured data surpass the theory of Longuet-Higgins shown by the solid line. This tendency gets stronger with the wave height and its upper limit ratio of the measured data to the theory is approximately 3 times.

5. STRUCTURAL STRAINS

5.1 Structural strains by solar radiation[18]

In the course of analyzing data for strains, it turned out that the maximum strains by solar radiation is by far larger than that by the waves concerning the bending strains in the girder, thus checking this item cannot be overlooked in the design of the huge offshore platforms.

Applying the theory or experimental formulae which have been well established in the fields of meteorology, architecture and air conditioning, the method of estimating the solar radiation and the thermal distribution of the structure with simplicity and also with sufficient accuracy has been presented. Thus its validity has been verified comparing with the measured data.

Figure 17 shows the comparison of the estimated values with the measured one on a typical fine day. It can be said that the estimation is quite sufficient with an accuracy although it differs a little bit with the measured in winter time.

Thermal distribution on the structure should be obtained by solving the heat conduction equation with regard to walled body considering solar radiation, atmospheric temperature, relative humidity and wind velocity around the structure.

Figure 18 shows the comparison of the estimated values with measured one at a certain position as an example. The tendency of how the estimation agrees with the measured one is almost the same even for other positions.

As for the effect of the external disturbances on the distribution of the temperature, the wind around the structure turned out to be the most, especially in the low velocity range and the second was the atmospheric temperature.

The calculation of stress distribution acting on the structural members using the obtained temperature distribution should be possible.

5.2 Estimation of fatigue damage on strength members

The estimation of fatigue damage on the strength members has been carried out by simply changing the measured data of long period of time during the experiment for strain into that for stress.

Figure 19 shows the calculation results for all through the experiment period of time. The pattern of the fatigue damage of which is large in winter and is small in summer, is repeated every year. The accumulated damage of the brace is about 0.04 in a year, thus the fatigue life span is estimated as approximately 25 years.

It has been found that the fatigue damage is proportional to the 3rd power of the standard deviation of varying strain. The accuracy of the estimation of the fatigue damage depend greatly on that of transfer function of strain with respect to waves, on that of wave spectrum in the range of frequency where transfer function of strain has significant values, and also on that of S-N diagram.

The method of the reasonable estimation on the design stage has now been investigated to be presented

6. CONCLUSION

The results of the field test using the floating offshore platform "POSEIDON" has been presented. There are other results concerning the maintenance such as the investigation of the corrosion for the structure and the mooring chain, that of the marine growth and 11 columns with the anti-corrosive paints. Those results shall be published some other time.

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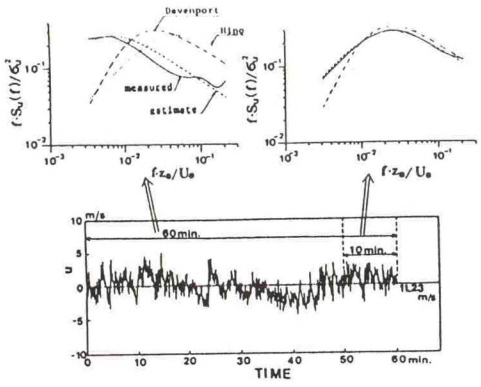

Fig. 1 Influence of measurement time on varying wind velocity spectrum

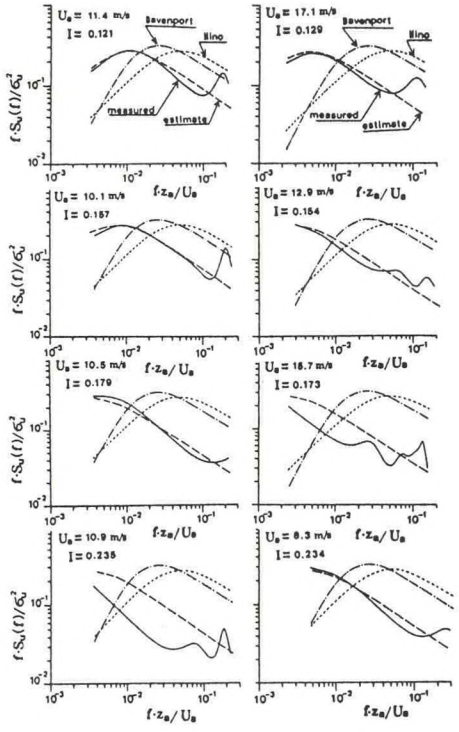

Fig. 2 Varying wind velocity spectra

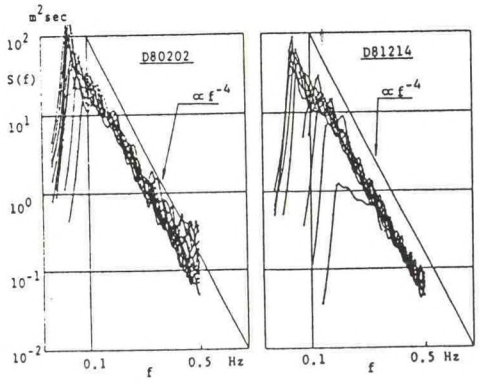

Fig. 3 Change of frequency spectra in every 2 hours

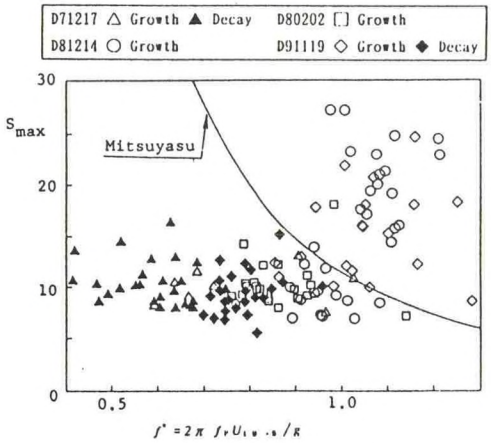

Fig. 4 Relation between Smax and non-dimensional frequency f*

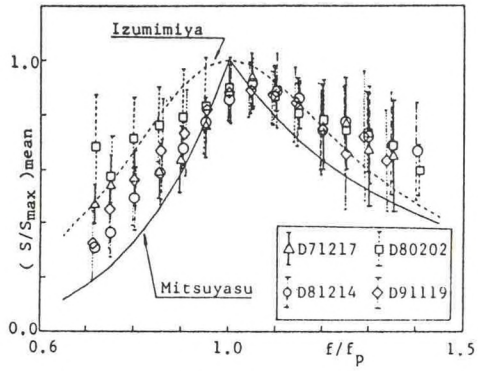

Fig. 5 Change of the spreading parameter S

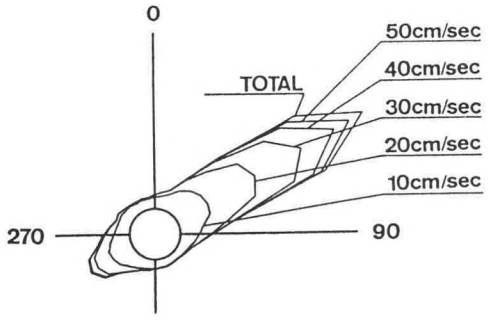

Fig. 6 Distribution of current direction and velocity

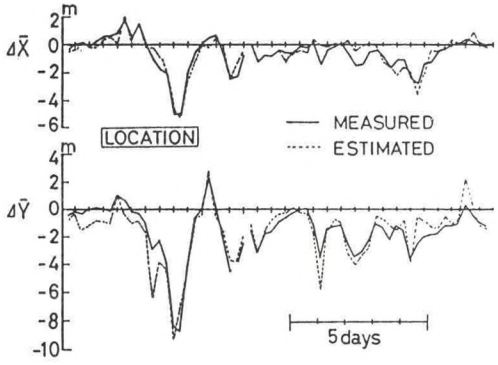

Fig. 7 Steady drift of POSEIDON

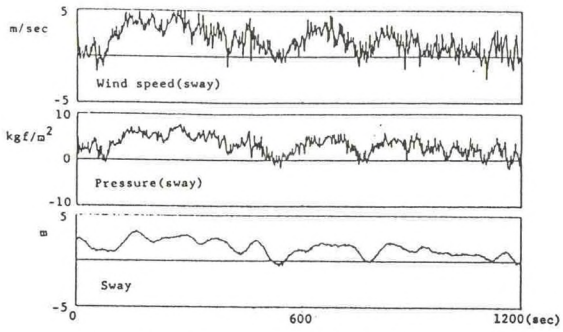

Fig. 8 Time history of wind, pressure difference and sway

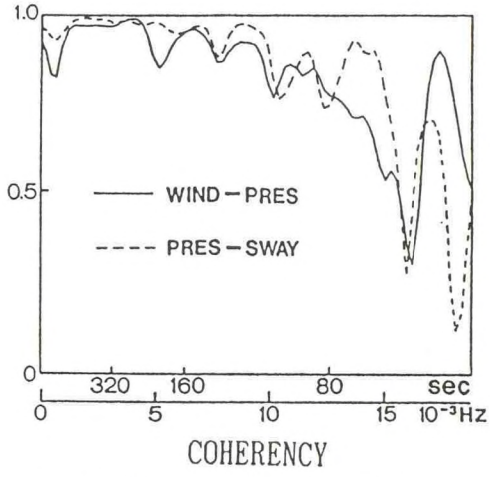

Fig. 9 Coherency between wind velocity and wind pressure or wind pressure and sway

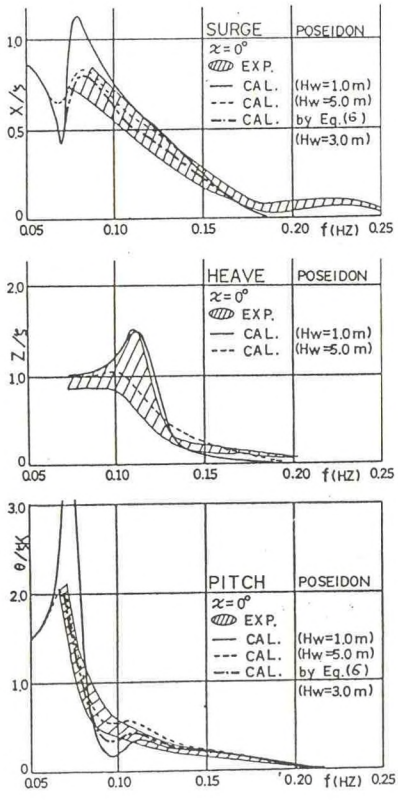

Fig. 12 Transfer function of full-scale structure

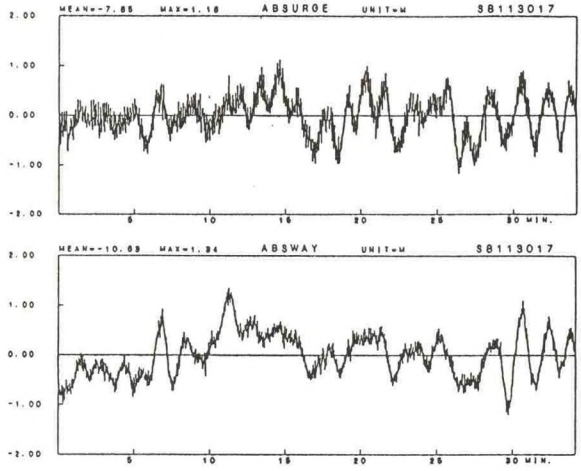

Fig. 10 An example of measured low frequency motion

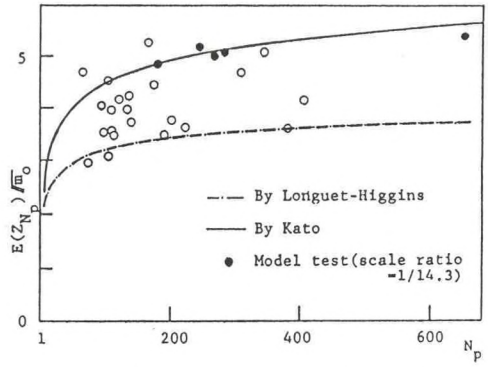

Fig. 11 The ratio of maxima out of the N extreme values to the standard deviation

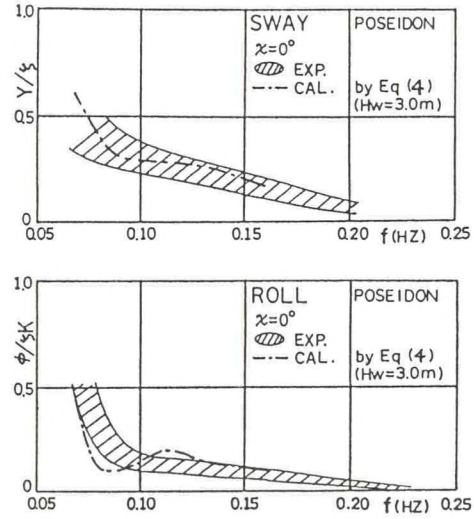

Fig. 13 Transfer function of lateral motion in the case of head sea

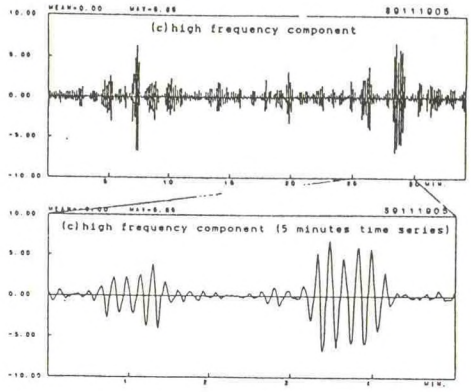

Fig. 14 Measured mooring line tension

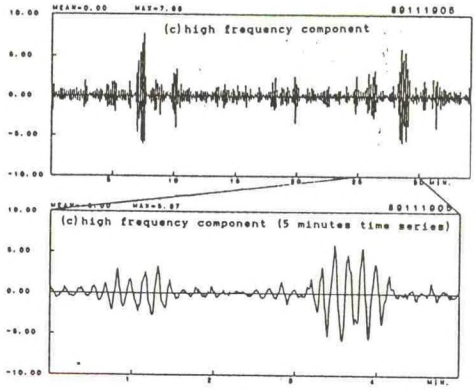

Fig. 15 Calculated mooring line tension

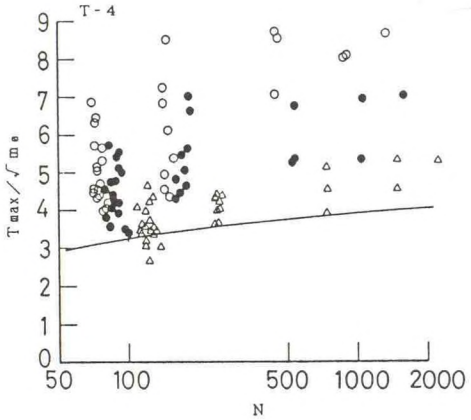

Fig. 16 The ratio of maxima out of the N extreme values to the standard deviation

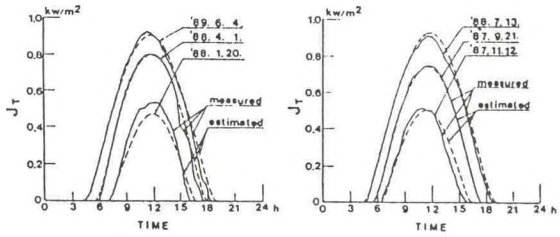

Fig. 17 Comparison of total solar radiation between measurement and estimation

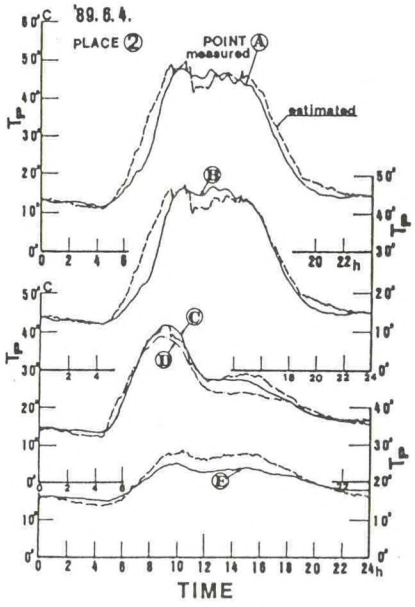

Fig. 18 Comparison of the plate temperature between measurement and estimation at point 2

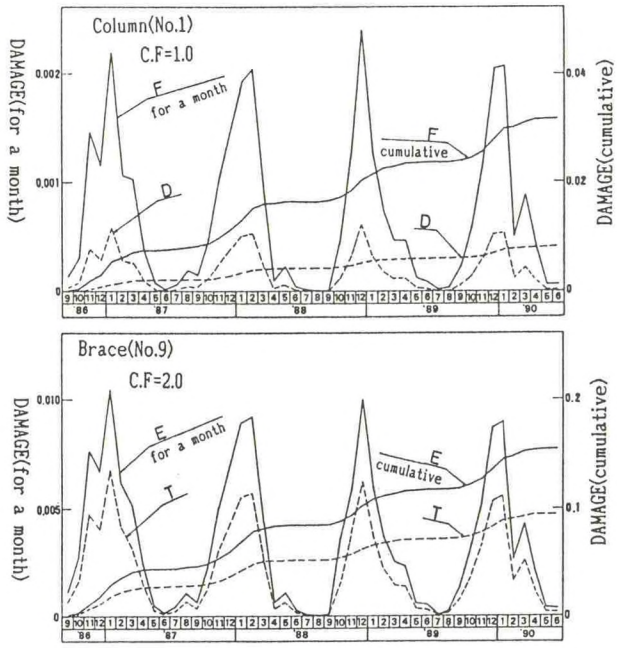

Fig. 19 Estimated histories of fatigue damage

The Present State and Future View of Floating Facilities in Coastal Zone

Shigeru Ueda[1)]
Yasutoshi Yoshimoto[2)]
Hiroaki Nakada[3)]

ABSTRACT

Recently, development in the coastal zone is actively promoted to create comfortable area and space where the port and harbour is placed in the heart of the area. These projects are promoted by a local government and the third party, and Ministry of Transport cooperates for promoting the projects and pays special attention on the planning and the safety of facilities.

Among those projects, there are some facilities which consist of floating structures. These floating structures should be moored even in storms such as typhoons, and they make large motions and large mooring forces are induced. As for the operation, motions of floating structures must be less than the allowances to secure the safety and comfortableness of customers.

This paper describes the present state and future view and the design criteria of floating facilities with introducing some instances. Description is made on the Design Manual for Floating Facilities which was recently compiled.

1. INTRODUCTION

Recently, development in the coastal zone is promoted so actively to create comfortable area and space. The object of the development of coastal zone is to create the comfortable, favorable and attractive port and harbour area with full of amenities placing the port and harbour area as the basis of citizen life looking forward the 21th century. The port and harbour area has

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been developed as the basis of transportation and traffic where the facilities concerned have been constructed functionally, however in future, facilities such as residences, shopping centers, convention halls, exhibition halls and parks including amusement parks, athletic fields and fishing parks are going to be located organically and be formed a basis of citizen life.

The projects above mentioned are promoted by the local governments and/or the third sectors which are semi-public organizations and private developers, and Ministry of Transport cooperates for promoting the projects and pays special attention on the safety of facilities.

Among the facilities constructed for those projects, there are floating structures which are used for museums, exhibition halls, marine restaurants and convention halls. For instance, there are several facilities consist of ships which are used to be passenger and/or freight ships such as the **Hikawa Maru** moored in the basin in front of the Yamashita Park in the Port of Yokohama and used for a restaurant. **Oriana** in the Port of Beppu which is used to be a passenger ship placed on the British-American and British-Australian Line, both **Soya** in the Port of Tokyo and **Fuji** in the Port of Nagoya which are used to be observation ships for the Antarctic Region, **Brazil Maru** in the Port of Toba which is used to be a passenger ship placed on the Brazilian Line carrying immigrants, and **Hakkoda Maru** in the Port of Aomori and **Masyu Maru** in the Port of Hakodate which are used to be Aomori-Hakodate ferryboats are the representative of those facilities. On the other hand, there are several floating facilities which are newly constructed to meet the purpose such as **Marine Pavilion** which was exhibited for the Yokohama Exotic Show and **Floating Island** which is placed in the Sakaigahama Marine Park. Those facilities such as large sized floating berths at the sites of soft soil condition and floating piers for pleasure boats in marinas accommodating growing of demand of marine leisure are expected to be constructed in future.

Special features of floating structures are specified as follows. Firstly, floating structures shall be moored for long terms at the same site. As major structural type of port and harbour facilities are gravity type or pile type, which do not make motions with accordance of the action of waves and wind. Furthermore, as ships in a port are recommended to leave a port if it threatens of storm, ships are not equipped enough devices to survive storms as moored in a port. Secondly, ships which are used as passenger and/or freight ships will be moored at the fixed place and will

Table-1 Floating Structures Constructed up to This Moment

No	Name	Opened	Purpose	Location	Properties	Capacity
1	Hikawa Maru	1961	Restaurant	Yokohama	12,000GT, 163m	331p.
2	Kanawa	1962	Restaurant	Hiroshima	27m	
3	Hiroshima	1965	Restaurant	Hiroshima	21m	
4	Show Boat	1969	Theater	Ishikawa	54m	459p.
5	Scandinavia Maru	1970	Hotel	Numazu	5,105GT, 127m	113p.
6	Hoo Maru	1973	Restaurant	Matsushima	16m	24p.
7	Hoo Maru	1973	Restaurant	Matsushima	16m	56p.
8	Brasil Maru	1974	Restaurant	Toba	10,216GT, 156m	2,000p.
9	Aquapolis	1975	Exhibition	Okinawa	104×100×32m	
10	Ryugu	1976	Restaurant	Nojiri Lake	25m	150p.
11	Shioji	1978	Restaurant	Toba	180GT, 39m	102p.
12	Soya	1979	Museum	Tokyo	2,734GT, 83m	
13	Aquarium ship	1982	Aquarium Ship	Amakusa	50m	1,500p.
14	Manbo	1983	Restaurant	Saga	22m	250p.
15	Sun Urashima	1984	Restaurant	Toba	350GT, 26m	160p.
16	(Restaurant)	1985	Restaurant	Tamano	28m×20m	100p.
17	(Floating Pier)	1985	Restaurant	Toya Lake	28m	120p.
18	Fuji	1985	Museum	Nagoya	5,250GT, 100m	521p.
19	Prince Willem	1985	Exhibition	Nagasaki	1,460GT, 73m	300p.
20	Oriana	1987	Restaurant	Beppu	41,920GT, 245m	6,650p.
22	(Floating Pier)	1987	Mooring	Inawashiro	12×10.4×2m	
23	Marine Pavilion	1989	Exhibition	Yokohama	40×34.6×5m	
24	Floating Island	1989	Exhibition	Onomichi	130×40×5m	

Notice: Blank in the column of the capacity means unknown

be used in common. Therefore, it is required for facilities to have equipments for the safety of customers, fire preventing and emergency escape with difference to those equipped for ordinary ships.

2. PRESENT STATE OF FLOATING FACILITIES

(1) Outline

Major floating facilities constructed up to this point are listed in **Table-1.** Such description as 12,000GT in the column of properties means that

facilities are used to be ships. Floating facilities are mostly used for restaurants, exhibition halls and museums. In special, those facilities which make use of ships exhibit the accommodation such as guest rooms, bridges, engine rooms, and deluxe furnitures and ornaments. As for the observation ships for the Antarctic Region such as **Soya** and **Fuji** do not only exhibition of cabins and accommodations, but also displaying panels dealing the object and significance of the observation of the Antarctic Region, the history of the exploration and observation of the Antarctic Region, details of Antarctic exploration by internal and external exploration party, nature and creature of the Antarctic Region, and materials and equipments for the observation and exploration. These facilities are, so to speak, Antarct.c museums.

Floating structures have been mostly constructed in bays or lakes or at the sites where the basins are well sheltered from ocean waves by a number of islands and/or peninsulas. Therefore, wave force acting to floating structures is not so strong and wind speed is also decreased even in typhoons screened by islands and mountains around the site. But, the view of the ocean from the floating structure is screened by surrounding islands and mountains or inland seas. If floating structures located facing to the ocean such as Oriana so as to observe the horizon, design wave for 50 years return period becomes 3.3m of significant wave height, 7s of significant wave period, and design mean wind speed is 33.9m/s even located in the Seto Inland Sea. Therefore, design of mooring facilities is most important for the safety of the floating structure. Because of the diversity of citizen demand, some floating structure may be constructed in such a open sea. **Photographs 1 and 8** show instances floating structures and their mooring facilities constructed up to this moment.

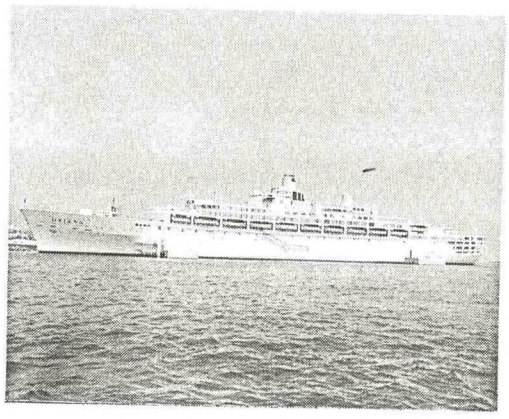

Photo.1 Oriana

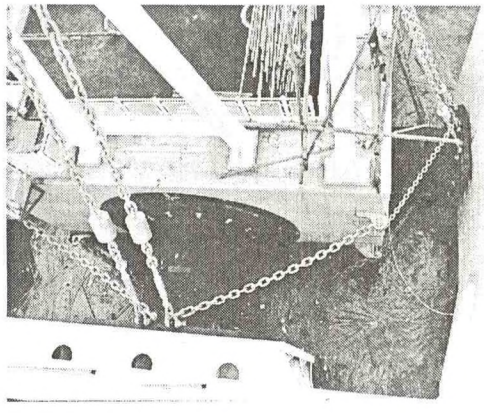

Photo.2 Fender of Oriana

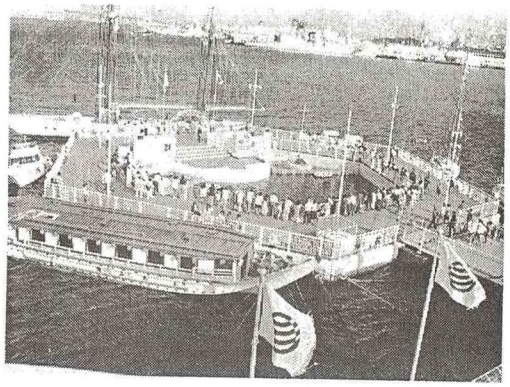

Photo.3 Marine Pabvilion

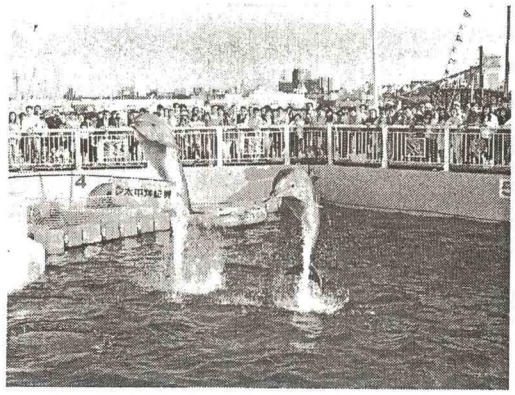

Photo.4 Show at Marine Pavilion



Photo.5 Soya

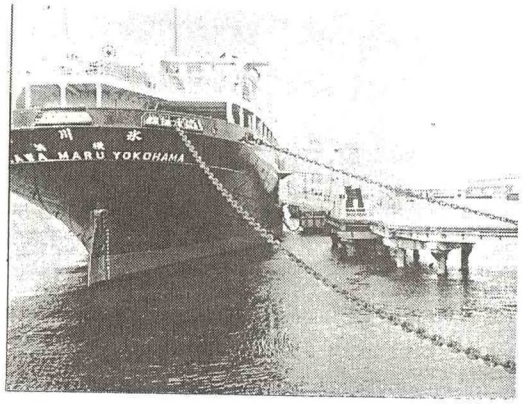

Photo.6 Hikawamaru

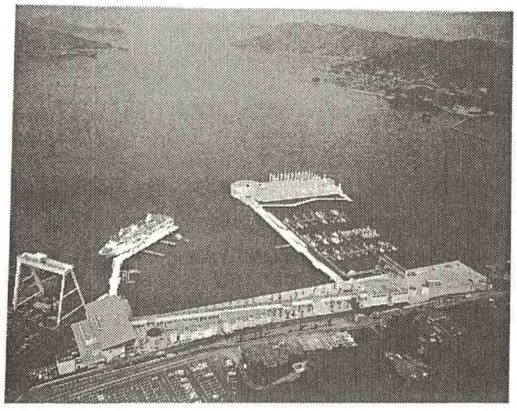

Photo.7 Floating Island

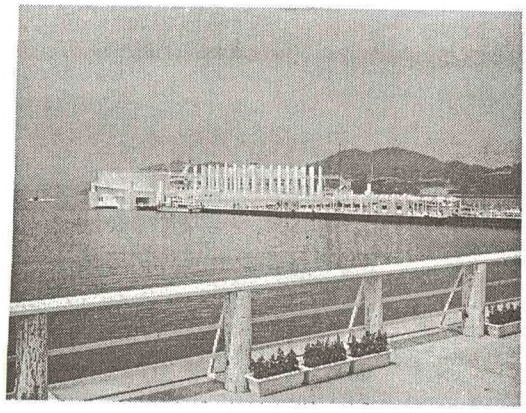

Photo.8 Floating Island

(2) Design Condition of Major Floating Facilities

Table-2 lists design conditions of major floating facilities such as **Oriana(Beppu), Fuji(Nagoya), Soya(Tokyo), Hakkoda Maru(Aomori)** and **Floating Island(Sakaigahama Marine Park).**

On the design of those floating facilities, much attention shall be paid on the examination on the safety of the mooring facilities. The procedures of the examination are specified as follows.

1) Estimate the wind speed for the required return period related to the life time of the floating structure by use of data observed at the weather bureau in the neighbourhood of the location, or by use of data obtained from hindcating.
2) Estimate deep water wave condition for the required return period, then, estimate the wave condition at the location considering refraction and diffraction of waves according to the topographical condition.
3) Calculate wind force and wave force acting to the structure, and also radiation forces induced by motions of the floating structures.
4) Determine the load deflection characteristics of the mooring facilities.
5) Calculate motions of the floating structure and mooring forces.
6) Design of the mooring facilities in conformity with to meet the safety requirement.
7) Detail design of floating structures.

There are some differences of design way between each floating facilities listed in **Table-2.** Points of differences are specified as follows.

1) Return period of wind speed
2) Which of mean wind speed or the maximum instantaneous wind speed is adopted as design wind speed.
3) Treatment of gusty wind.
4) Interaction of wind and waves.
5) Treatment of irregular waves.
6) Non-linear load-deflection characteristics of mooring facilities.

As for items above mentioned, details will be described in the section of Design Manual of Floating Facilities.

Devices and materials used for mooring facilities are mooring dolphins, rubber fenders, chains, anchors, sinkers, mooring ropes(wire ropes, synthetic ropes such as nylon ropes). As rubber fenders and mooring ropes have non-linear load-deflection characteristics, the properties of mooring facilities shuold be determined

Table-2 Design Conditions of Major Floating Facilities

	Oriana	Fuji	Soya	Hakkoda Maru	Floating Is
Design Wind Speed	33.9m/s(50 year return, corrected to sea wind)	Ordinary : 16m/s Special : 60m/s	Maximum Inst Wind Speed 50m/s	30m/s or 23m/s S, W, N, E ESE, SSE 100 year return	28m/s 100 year return
Design Wave	$T_{1/3}$ $H_{1/3}$ NNE 6.0s, 2.1m N E 7.0s, 2.5m ENE 7.0s, 3.3m E 7.0s, 3.3m ESE 6.2s, 2.9m S E 4.7s, 1.9m	$T_{1/3}$ $H_{1/3}$ Ordinary: 1.4s, 0.5m Special : 3.0s, 0.6m	$T_{1/3}$ $H_{1/3}$ 6.0s, 3.0m	$T_{1/3}$ $H_{1/3}$ N 7.3s, 0.8m NNE 7.3s, 0.8m N E 7.3s, 0.8m 100 year return N 6.7s, 1.0m NNE 6.7s, 1.0m N E 6.7s, 0.9m 10 year return	$T_{1/3}$ $H_{1/3}$ 4.0s, 1.5m
Seismic Coeff.	K_h=0.1	K_h=0.2	K_h=0.2		
Tidal Level	HHWL 3.40m HWL 2.10m LWL 0.00m	HHWL 5.35m HWL 2.60m LWL 0.00m	LWL 0.00m	HHWL 1.50m HWL 0.80m LWL 0.00m	HHWL 4.95m HWL 4.12m LWL 0.00m
Type of Mooring Facility	Dolphins Rubber Fenders	Dolphins Rubber Fenders Chains Nylon Ropes	Dolphins Rubber Fenders	Rubber Fendres Nylon Ropes	Chains Sinkers
Properties of Mooring Facility	Buckling Type 1,250H～3,000H	Buckling Type 300H×4,500L Nylon ϕ58 Nylon ϕ65	Buckling Type 300H×2,500L	Hyperbolic Type 2,500H×4,500L Nylon ϕ75～80	Chain Grade#2 ϕ76 Grade#2 ϕ78

taking account of deflection due to both stationary forces and variable forces of wind and waves acting to floating facilities simultaneously.

(3) Administrative Organization and Regulations Concerned

Items should be examined and procedures should be taken in order to promote the construction of floating facilities which are used for such as a museum and/or a sight-seeing spot are specified as follows. Here, the administrative organization means a division and/or a section in charge, however, it differs in each local government. Among items should be examined, those which concern to the safety of the body of floating structures themselves and mooring facilities are applied the Port and Harbour Law and/or the Ship Safety Law. These items concern to the safety of the floating structures are examined by the committee organized by the **Coastal Development Institute of Technology** and/or by the **Nippon Kaiji Kyokai(NK)**. And the items concern to the safety of navigation in the neighbouring basin of floating facilities is examined by the committee organized by the **Japan Association for Preventing Marine Accidents.**

1) Business
*Composition of share holders, *Demand estimation,
*Payability
2) Space utilization
*Demand of space, *influence to ship navigation
(Port and Harbour Section)
3) Traffics related
*parking area(permission by Port and Harbour Section or City Planning Section),
*traffic arrangement (Port and Harbour Section, City Planning Section or Police)
4) Safety of facility
*Safety of the facility itself(Port and Harbour Law, Ship Safety Law:Port and Harbour Section),
*Influence to relative facilities
(Port and Harbour Section)
5) Effect to environment
*Landscape, *Field of view sight,
*Fishery resources, *Current
6) Procedures relative
*Permission for exclusive use of water area of the Port and Harbour area (Para.1 of Art.37 of the Port and Harbour Law:Port and Harbour Section)
*Occupation of shore protection facility(Art.7 and 8 of the Coast Law:Port and Harbour Section)
*Permission for use of port facilities:
(Port and Harbour Section)
7) Adjustment with Fisheries:(Local government)
8) Adjustment with Local Business:(Local Government)
9) Fire Defense and Accidents Preventing
*Para.1 of Art.17 of the Fire Defense Law(Fire Defense and Accidents Preventing Section)
*High Pressure Gas Regulation
(Fire Defense and Accidents Preventing Section)
*Liquid Propane Gas Law for Proper Dealing
10) Environmental Sanitation
*Food Hygiene Law, *Entertainment Facilities Law
*Water Pollution Preventing Law,
*Seto Inland Provisional Law,
*Filthy Water Disposition Law,
*Water Supply Law, *Air Pollution Prevention Law
11) Miscellaneous
*Adjustment with port planning,
*Adjustment with organizations concerned,
*Large Scale Retail Shop Law

3. Design Manual FOR Floating Facilities

(1) Purpose of the Design Manual for Floating Facilities

Construction, improvement or maintenance of floating type port facilities and their mooring facilities, and mooring facilities of restaurant ships and other moored ships specified by Government Ordinance shall be in conformity with the technical standards

established by the Ministry of Transport Ordinance. The "Technical Standards for Port and Harbour Facilities with Commentary" (hereafter the Technical Standard) was published in 1979 and revised 1989 based on the Circular Notice of the Director General, Bureau of Ports and Harbours, Ministry of Transport, concerning the technical standards for port and harbour facilities, and complementary comments to it. The Design Manual for Floating Structures specify items which is not dealt in the Technical Standard and is compiled to be referred in designing, planning and examining of floating type port facilities and the mooring facilities, and mooring facilities of restaurant ships and other moored ships.

(2) Limit of Application

The manual shall be applied for those floating facilities and their mooring facilities listed below.

1) Floating berths, car parking ships, warehouse ships, and other floating type port facilities(where, mooring buoys, small pontoons, floating breakwaters, floating oil storage facilities are excluded because of no additional established items more than the description in the Technical Standard.
2) Mooring facilities for restaurant ships, museum ships and other moored ships which are limited to those facilities applied to the Ship Safety Law.

(3) Application of Law

a. Port and Harbour Law

In case of the planning of the construction of floating type facilities in the port area where the port planning is established according to the Para.3 of Art.3 of the Port and Harbor Law, the planning shall be applied to the port planning. And also, in case of the construction of floating facilities occupying the basin, following procedures shall be taken according to the Port and Harbour Law. On the other hand, in case of in the Coastal Preservation Area the permission from the coast administration authority according to the Art.8 of the Coast Law, and in case of in a river the permission from the river administration authority according to the Art. 23 of the River Law. However, some local governments regulate the occupation of basin. As for fishery ports, the Fishery Port Law shall be applied excluding those port applied the Port and Harbour Law.

1) Port Area: permission from the port authority according to the Art.37 of the Port and Harbour Law(including the neighbouring area to the port area)
2) Official Noticed Area: permission from the governor of the local government according to the Art.56 of the Port and Harbour Law
3) Basin excluding above mentioned: notice to the governor of the local government according to the Para.3 of the Art.56 of the Port and Harbour

Law(including rivers, lakes and marshes and private basin)

b. Ship Safety Law

A Ship prescribed in the Ship Safety Law is a structure which is floating and may load goods and/or men to achieve social and economic role for the sake of a man. On this meaning, moored ships shall be applied to the Ship Safety Law. Where, moored ships are those listed below which are used by a number of passengers and used for purposes, where as for ships with double or more layer decks the place to be used shall be enclosed.

Purposes of moored ships are theaters, cinema theaters, entertainment halls, town halls, assembly halls, cabarets, coffeehouses, night clubs, recreation halls, dance halls, assignation houses, restaurants, eating houses, markets, shops, exhibition halls, hotels, inns, libraries, museums, art museums, car parks, gymnasiums, swimming pools, athletic grounds or play grounds, offices, aquariums, and observatory.

(4) Selection of the Location

The location of floating structures shall be selected properly taking account the conditions of occupation of the basin inside the port area, effect to ship navigation and environment in the neighbourhood, meteorological and marine conditions such as wind, waves, current and so on.

(5) Design of Floating Facilities

a. Basic conception of design

Design of floating facilities shall be made in principal according to the Port and Harbour Law, and examination on the function and the safety of the floating facilities shall be made. Design of floating structures is broadly classified into design of the main body of floating structures and the mooring facilities, as aiming at the parts.

b. Design conditions

Following items shall be considered as design conditions of floating facilities, and examination shall be made on the function and the safety of floating facilities.

1) Waves
2) Sea level(tide, storm surge, tsunami)
3) Current(tide current, tsunami flow)
4) Wind
5) Soil conditions
6) Surcharge
7) Earthquakes, littoral drift, drift ice

Here, the return period for design wind and waves shall be properly determined considering the importance and the life time of floating facilities. The return period is the average number of years for an occurrence of phenomenon excess the design level. For instance, if a

phenomenon of a certain level shall occur once per ten years in average, the return period is 10 years. The return period is a function of encounter probability. For instance, if the life time of floating facilities is 20 years, for 0.642 of the encounter probability the return period is 30 years, where, for 0.332 of the encounter probability the return period is 50 years.

The probability wind speed is estimated by use of data observed at the weather bureau in the neighbourhood of the location. Data shall be obtained for enough long period, and yearly maximum ten minutes mean wind speeds are analysed fitting data to the appropriate extreme function and estimate the wind speed for the required return period. As wind speed and waves are vary irregularly, it is recommended to consider gustiness of wind and irregularity of waves as well as paying attention to the load-deflection characteristics of the mooring facilities.

It is recommended to avoid the location where tsunami may occur so frequent, however, if there is apprehension of tsunami, calculate the current speed of tsunami and examine the safety of the mooring facilities.

c. Stability of floating facilities

Stability of floating facilities shall be examined with consideration of reaction force from the connecting bridges, surcharge and leakage at certain blocks. As for surcharge, examination on the inclination and the free board shall be made with consideration of the eccentricity of loads.

d. Analysis of motions of moored floating facilities

Analysis of motions of moored floating facilities shall be made in accordance with the appropriate method with consideration of the irregularity of loads and the non-linear load-deflection characteristics of mooring facilities. In special, if the load-deflection characteristics is non-linear and/or asymmetry, it is recommended to do numerical simulation to estimate the motions of floating facilities. The results of the numerical simulation shall be statistically analysed to estimate the maximum expected values of the motions and mooring forces of floating facilities. There are different two type of load-deflection characteristics of rubber fenders which are so called buckling type fenders (exhibit constant reaction force against about 20% to 40% of deflection to the height) and hyperbolic type (exhibit hyperbolic load-deflection characteristics). Buckling type fenders exhibit hysteresis on unloading. The load-deflection characteristics which shall be used for numerical simulations is determined based on the published performance diagram in a catalogue issued by a fender manufacturer with consideration of the variation of the load-deflection characteristics due to individual differences, temperature, repetition of loading, bi-axial loading, dynamic response, creep and deterioration.

Table-3 Deviation of Fender Characteristics
(Deviation of Reaction Force against the Same Deflection)

Individual Difference	0.9 – 1.10
Deterioration	1.0 – 1.05
Dynamic Response	1.0 – 1.10
Creep	Fender reaction force caused by stationary loads shall be less than the fender reaction force against 10% of deflection
Repetition of Loading	0.8-0.9(ten times of repetition with the intensity equivalent to the fender reaction force against 40% of deflection
Bi-axial Loading	Loading with 10% of shear force against compression
Temperature	0.95 – 1.25 (corresponding to 50℃ – 0℃)

Table-4 Combinations of Design Load
for Analysing Motions of Floating Facilities

Items of Conditions	Ordinary	Special Cases		
		Storm	Earthquake	Tsunami
Wind	○	○		
Waves	○	○		
Current	○	○		○
Tidal Level	HWL, LWL	HWL, LWL		○
Storm Surge		○		
Temperature	○		○	
Earthquake			○	

Table-3 lists the standard of deviation for each item. On the analysis of motions of floating facilities, loads and the combinations listed in **Table-4** shall be considered.

e. Structural intensity of floating facilities

Materials such as pre-stressed concrete, reinforced concrete, steel and hybrid structure of steel and concrete are may be used for construction of floating facilities. The materials shall be selected considering

Table-5 Combinations of Design Load for Examining the Structural Intensity

Items of Conditions	Storm	Earthquake	Tsunami
Dead Weight	○	○	○
Surcharge	○	○	○
Snow, Stikked Ice	△	△	△
Wheal Load		△	△
Hydro-static Load, Buoyancy	○	○	○
Wave Force	○		
Radiation Force	○	○	○
Curren Force	△		○
Wind Force	△		
Earthquake Load		○	
Tsunami			○
Ice Ppessure	△	△	△
Mooring Force	○	○	○
Collision Force	△		

○:shall be considered, △:considered occasionally

of the characteristics and the economics. On the examination of the structural intensity of floating facilities, such loads as dead weight, hydrostatic pressure, buoyancy, wave force, wind force, wheel road, earthquake load, reaction force of fenders and mooing forces with consideration of loads and the combinations listed in **Table-5.**

f. Design of the mooring facilities

The type of mooring facilities shall be selected with consideration of such items as size of floating facilities, water depth, materials and length of chains and/or mooring ropes and so on, with or without intermediate sinkers and soil condition of the sea bed. Generally, the chain system and/or the wire system may be employed in relatively deep sea, and the intermediate buoy system and the intermediate sinker system, dolphins, piers and bollards and bitts may be employed in relatively shallow water. The combination system of wire and chain was employed in deep sea for instance. Anchors and sinkers are used in the chain and the wire systems. Piles, rubber fenders, mooring ropes are used for dolphins, piers, bollards and bitts. In special, as chains may hinder navigation and mooring of ships, piles may be used in the sheltered calm basin.

The type of mooring facilities shall be selected in

conformity with following items and criteria.

1) To be safe and efficient on the ordinary conditions for cargo handling and boarding and unboarding of passengers.
2) To be safe against the special conditions such as typhoons or earthquakes.
3) Water depth, construction cost, precedent.

Description is made in the Design Manual for Floating Facilities, how to determine the properties of the mooring systems for the chain system and the dolphin with fender system. And an instance of design of mooring facilities of **Oriana** is described in **Chapter 4.** On the other hand, as for the dolphin with fender system, examination on the safety of the dolphin against earthquake loads shall be made and the method of examination by use of the seismic coefficient method, the response spectrum method and the numerical simulation method are explained in the Design Manual for Floating Facilities.

On the detail design of mooring facilities, the allowable load of mooring ropes, chains, rubber fenders, holding power and the required safety factors of anchors and sinkers, the thickness allowance against corrosion and abrasion, design load for dolphins are prescribed in the Design Manual for Floating Facilities. Following items are the extraction.

* Allowable load of chains, wire ropes and synthetic ropes are specified as follows.

chains:	1/3 of breaking load(proof load)
wire ropes:	1/3 of breaking load
synthetic ropes:	1/5 of breaking load

* Allowable deflection of rubber fenders is the subtraction of a certain amount $\mathbf{d_f}$ from the rated deflection $\mathbf{d_r}$. $\mathbf{d_f}$ is specified as follows on each condition.
  # If the facility is used even in rough weather condition; $\mathbf{d_f}$ **is 10%** of the fender height
  # If the facility is not used in rough weather condition;
    Wave condition is hostile;
    $\mathbf{d_f}$ **is 10%** of the fender height
    Wave condition is mild;
    $\mathbf{d_f}$ **is 10%** of the fender height
* Safety factor for holding power of anchors and sinkers
  $\mathbf{F_s}$ **is 1.2**
* On the design of pile type dolphin, examination on the lateral and vertical bearing capacity shall be made.
* Design of bollards and bits shall be made in conformity with the "Draft of Design Standard of Bollards and Bitts", No.102 of the Technical Note of the Port and Harbour Research Institute. The standard of the safety factor $\mathbf{F_s}$ is specified as

1.2. As for bollards and bits of which bases are constructed on aprons, examination on sliding, overturning and bearing capacity shall be made.

g. Maintenance of floating facilities

As facilities are floating and composites of floating bodies and mooring facilities, the use and the safety is concerned in the performance of each part which may so abrasive and corrosive, therefore, special attention shall be paid on maintenance than ordinary port and harbour structures. Major items of maintenance are specified as follows.

1) Strength of mooring ropes: in special deterioration much attention shall be paid
2) Corrosion and abrasion of chains
3) Change of characteristics for repetition of loading, deterioration and creep of rubber fenders
4) Corrosion of bodies of floating facilities and cracks of concrete and so on

4. DESIGN OF THE MOORING FACILITIES OF ORIANA

(1) Outline

Oriana was built at the Vicars Ship Building Yard of Great Britain in 1957, of 41,920 gross tonnage, which used to be a deluxe passenger ship placed on British-American and British-Australian Lines, and moored in the basin south of the 1st pier of the Port of Beppu, Oita Prefecture, and started business in July, 1987. Length over all is 245.06m, moulded breadth is 29.57m, height from the keel to the top of chimney is 51.21m. Mooring facilities consist dolphins and fenders.

(2) Design Conditions of Mooring Facilities

a. Condition of wind

As the life time of the facility is 20 years, the return period is determined 50 years with consideration of the function and the importance of the facilities. The probability wind speed is estimated to 26.2m/s through the analysis of the data obtained at the Oita weather bureau for 45 years, and through the correction to the ocean wind, the design ten minute mean wind speed becomes 33.9m/s. All the direction of wind shall be taken into consideration.

b. Wave conditions

Design wave conditions are determined as listed in **Table-6** based on the materials for port and harbour planning and the results of the wave hindcasting.

c. Other conditions

1) Tide

* Highest high water level(HHWL)	+3.4m
* Mean monthly-highest water level(HWL)	+2.1m
* Mean tide level(MTL)	+1.3m
* Mean monthly-lowest water level(LWL)	0.0m
* Lowest low water level(LLWL)	-0.3m

Table-6 Design Wave Conditions of Oriana

	NNE	N E	ENE	E	ESE	S E
$T_{1/3}$	6.0s	7.0s	7.0s	7.0s	6.2s	4.7s
$H_{1/3}$	2.1m	2.5m	3.3m	3.3m	2.9m	1.9m

2) Design horizontal seismic coefficient $k_h=0.1$
3) Soil conditions
Fine sand of 10 of N value to 3.0m below the surface, and sand gravel layer of 50 of N value below 3.0m.

(3) Design of mooring facilities

a. Properties of the ship

* Lpp 225.56m
* B 29.60m
* d 9.00m
* DT 35,775tf

b. Fenders

Fenders are selected with consideration of wind force, wave drift force and ship motions due to wave force, where variation of the characteristics of fenders are taken account. Fender type is so called buckling type and the size of the biggest ones is 3.0m and two of them are installed in series.

c. Design of dolphins

Design load for dolphins is maximum fender reaction force times 1.1. Stability for sliding, over turning, revolution and bearing capacity are examined.

d. Numerical simulation

Numerical simulations are made for wave conditions above mentioned with consideration of wind force, irregularity of loads and the non-linear characteristics of fenders. Results of the numerical simulations are analysed statistically, and the maximum expected value of motions, deflections and reaction forces of fenders are estimated. Then, fender deflections are examined with comparison of allowable deflection.

5. CONCLUSION

As above mentioned, construction of floating facilities are increasing in accordance of recent active development of coastal zone. Such as event facilities, convention halls, marine restaurants, floating berths and floating piers for pleasure boats are going to be constructed more in future. The Design Manual for Floating Facilities are compiled by the Coastal Development Institute for Technology through prudent discussion of the committee consists of Professor Goda as chairman, members from the Nippon Kaiji Kyokai, the Bureau for Ports and Harbours, the Bureau for Marine Technology Safety, the Ship Research Institute and the Port and Harbour Research Institute.

FIELD EXPERIMENT ON WAVE ENERGY UTILIZATION SYSTEM WITH WAVE POWER EXTRACTING CAISSON BREAKWATER

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1. Introduction

Ocean wave energy is clean and inexhaustible. Repeated oil crises and the urgent need to ensure environmental preservation on a global scale have made utilization of ocean wave energy increasingly important.

The Japanese Ministry of Transport has been developing a wave power extracting caisson breakwater to absorb wave energy and convert it into electric power. The use of the breakwater as a wave power converter will effectively cut the power generation cost. This breakwater also aims at improvement of the wave resisting stability and performance as a breakwater by absorbing the wave energy.

The research and development work on the wave power converter is being carried out through collaboration by the First District Port Construction Bureau, the Port and Harbour Research Institute and the Coastal Development Institute of Technology under the guidance of the home office of the Ministry of Transport. The Port and Harbour Research Institute had conducted basic research for five years since 1982. The 1st District Port Construction Bureau, Ministry of Transport, began a field verification experiment for the breakwater in 1987 in the form of a joint study with the Coastal Development Institute of Technology and twenty private companies. A test breakwater was constructed in the summer of 1989 at Sakata Port, Yamagata Prefecture. The breakwater began the power generation in the winter of 1989. Photo 1 shows the wave action on the completed caisson and Photo 2 shows the on-land observation house and a tower illuminated by the converted energy.

The field experiments are planned for the five years from fiscal 1987 through fiscal 1991 aiming at the following items:

1) to verify the methods of designing the caisson including the air chamber as a breakwater,
2) to verify the design method of the air chamber, turbine and generator as a wave energy converter,
3) to study methods of constructing the breakwater
4) and also to demonstrate utilization of the power output for various uses.

This paper introduces the system with a wave power extracting caisson in the field experiment and the interim results of the field experiment.

2. Wave Power Extracting Caisson Breakwater in the Experiment

The wave power extracting caisson consists of a hollow box called "the

air chamber", which is supported by an ordinary caisson as shown in Fig. 1. The front wall makes a curtain wall with openings to allow water to enter the air chamber. The air chamber is the primary converter of the oscillating water column (OWC) type to use the vertical movement of water to compress and expand air, and produces air flow at the turbine nozzle. It is 7 m long from the front wall to the rear, and 20 m long in the direction of the breakwater alignment line. The height is +12.5 m above the static water level. The area is 115 m2, not including the thickness of the walls.

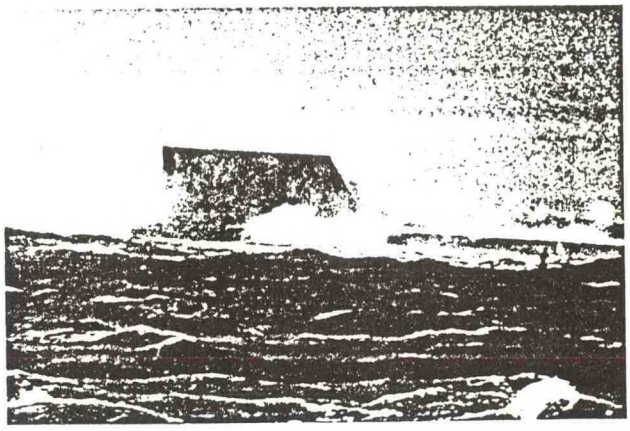

Photo 1 Wave Action on Wave Power Extracting Caisson

Figure 2 gives a concept of the machine room. The air flow converts its energy into the kinetic energy by rotating the turbines and subsequently the generator in Fig. 3, which are installed at the center of the machine room in the upper portion of the caisson. Two Wells turbines 1,337 m in diameter are used to get a one-way rotation from the reciprocal movement of the air and are placed sandwiched between and aligned with the generator to make a tandem type arrangement canceling the forces that work in the axial direction of the turbines. The generator is a 200 V synchronous generator with a rated output of 60 kW and a maximum revolution of 3,000 rpm.

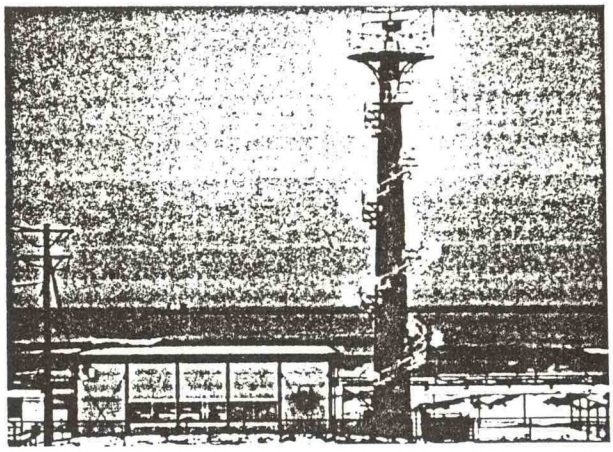

Photo 2 On-land Observation House and Illuminated Tower

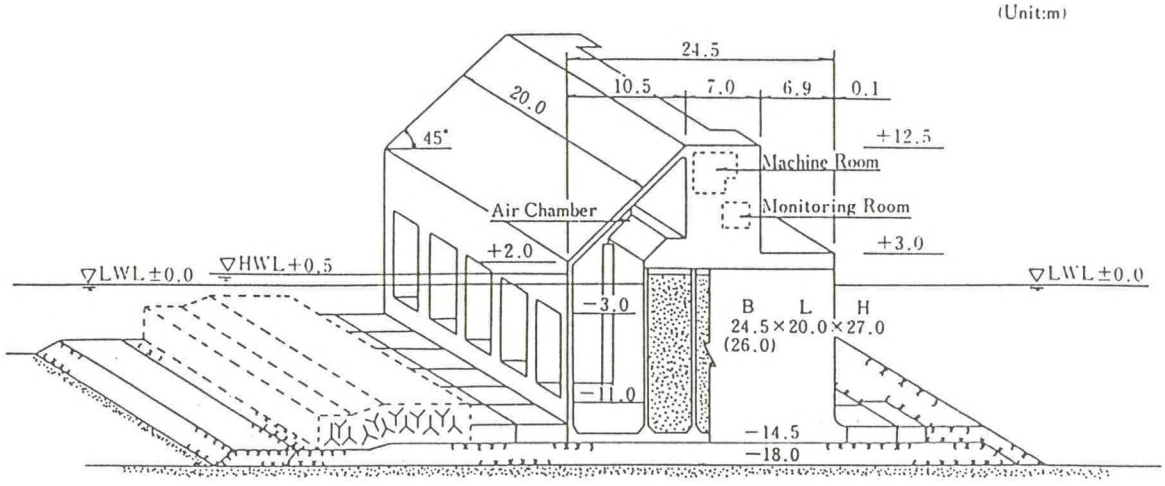

Figure 1 Shape of the Caisson Breakwater

The protection devices that control the air flow from the air chamber to the turbine consist of three types of valves: the air flow regulating valve (bypass valve), the pressure release valve and the emergency cutoff valve.

The power generated is sent to the on-land observation station via underwater cables, where it is consumed by electric resistors. Experiments are also being made to utilize the electric power for various appliances to prepare for the application of the system for actual use.

A caisson of the Second North breakwater of Sakata Port is used for verification experiments, as shown in Fig. 4. The breakwater is now under construction as a composite breakwater, with a planned length of 1,900 m. The depth of the water is 18 m at the construction site. The foundation is mostly sand with viscous soil in some places. A sink of about 1 m is predicted.

3. Design of the Experimental Breakwater

3.1 Design of the Conversion System

In designing a wave energy converting system, it is necessary to

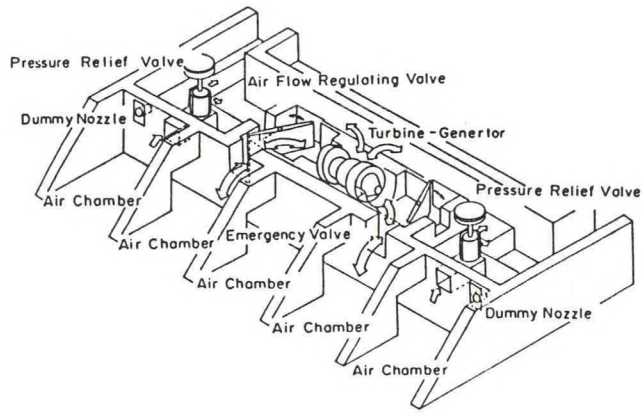

Figure 2 Conceptual View of the Machine Room

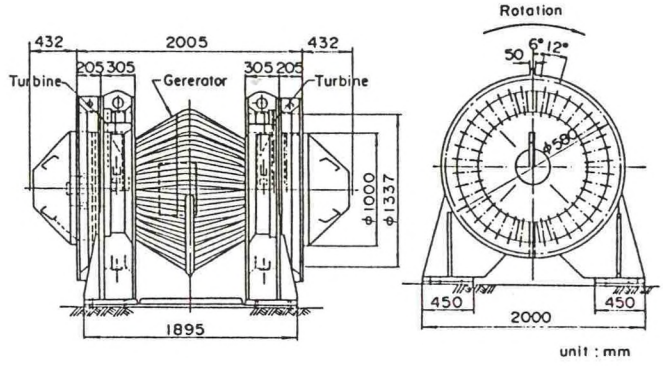

Figure 3 Turbine and Generator

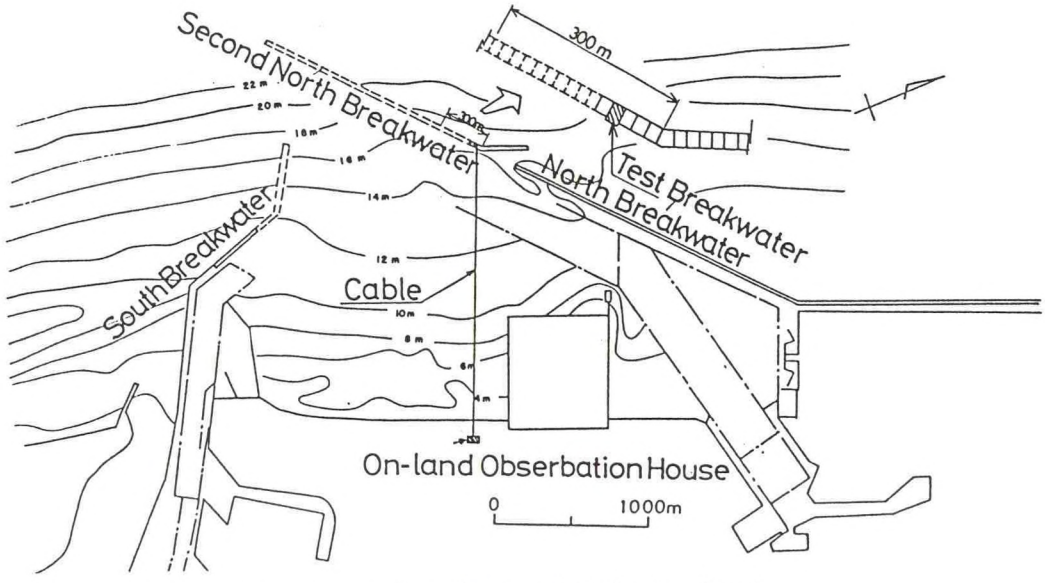

Figure 4 Location Map of Sakata Port

assess the wave conditions and to determine the use of the converted energy. Then the frame plan of the system can be established. The fundamental dimensions of the components of the system such as the diameter of the turbine are determined based on the frame plan. Finally, the components are designed in detail.

Wave data at Sakata Port for about twenty years were analyzed to find the wave conditions there. Numerical calculations based on the thermodynamics and wave-kinematics theory were conducted to determine the fundamental dimensions of the components of the system.

It should be noted that the diameter of the turbine is much smaller than that of the optimum turbine matching with the air power from the air chamber. This is because of the limitation of research funds. Two dummy nozzles are installed to consume the extra air energy, which is almost half of the total air power. The electric generator is also small so that the air power to the turbine is limited by the air flow regulating valves and pressure relief valves so as not to exceed the limitation of rotation speed of the turbine and generator. Power generation is stopped when waves are extremely large (when the significant wave height is above 5 m) by fully opening the air flow regulating valve and simultaneously closing the air flow to the turbine.

In fiscal 1989, the system was operated rather discreetly under Setting I, while in fiscal 1990, experiments were conducted under Setting III using the optimized control method to make the generator output larger.

3.2 Design of Breakwater

Through model experiments prior to the field experiment, the function and the stability of the wave power extracting caisson breakwater were revealed. The design of the experimental caisson was made based on the results. For example, the Goda formula is used as the standard method to calculate the wave pressure on a composite breakwater caisson. The formula was extended for the wave power extracting caisson. The wave pressure distribution on the air chamber walls was also proposed according to the model experiments.

4. Measurement

A number of sensors are incorporated in the caisson and the power generating system to make measurements in the following four categories.

(1) Wave conditions (directional spectrum, heights, periods and directions of waves)
(2) Stability of the breakwater (wave pressure and air pressure)
(3) Stability of the wall members (stress of the reinforcement)
(4) Air output and power output (water level and pressure in the air chamber, turbine speed, power output)

Data are amplified and converted into optical signals before they are sent by an opto-electric power combination cable to the observation station on land, where they are analyzed and processed using four personal computers. In addition to the above procedure, detailed data are sampled and stored in a digital recorder, for 20 minutes at one operation, for further analysis of the breakwater stability .

5. Results of the Field Experiment

5.1 Wave Observation

Figure 5 shows the wave data from December 1989 to March 1990. The significant wave height and period, mean wave direction and wave power are shown in the figure. For example the average significant wave height was 2.05 m and the average wave power was

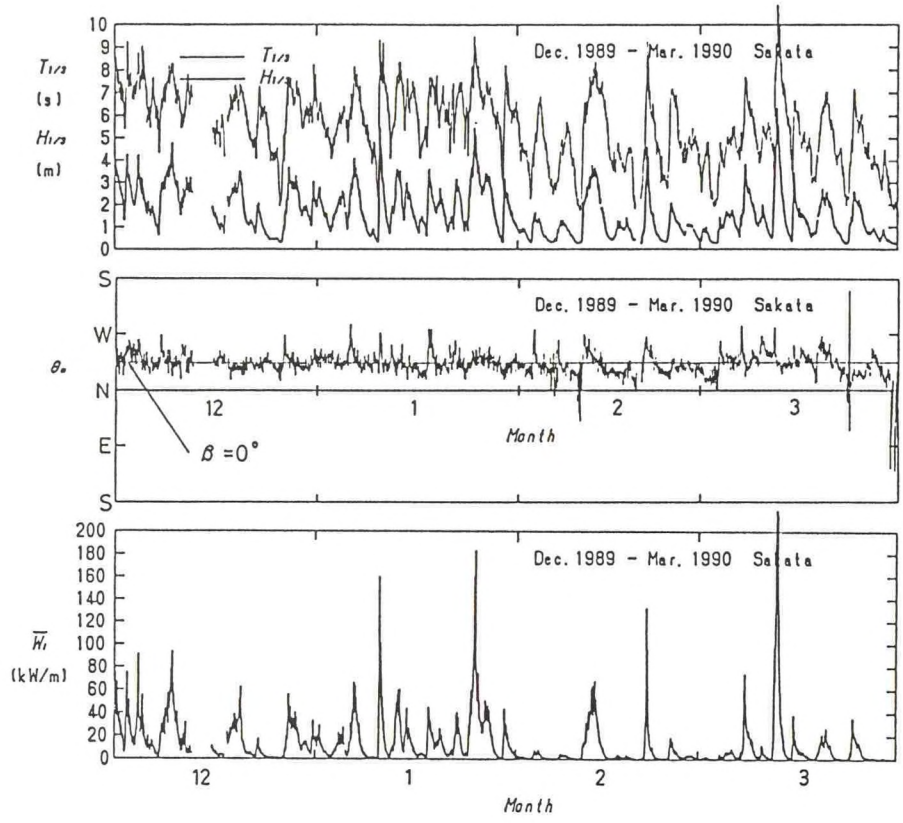

Figure 5 Variation of Significant Wave and Wave Power

18.5 kW/m in January 1990. The wave height varies very widely and the largest value of the significant wave height and the wave power were 5.45 m and 101 kW/m in this month. The significant wave height exceeded 5 m several times and the largest value of the significant wave height was 7.5 m at 7 p.m. on November 19, 1989. The mean wave direction was usually northwest, which is almost perpendicular to the breakwater alignment line.

5.2 Wave Power Conversion

Figure 6 gives an example of the records of power generation, i.e., water level and pressure in the air chamber, opening of the air flow regulating valve, pressure difference in the turbine and turbine speed, and power output for 20 minutes, that were recorded at 11:00, January 7, 1990, when the significant wave height and period were 3.2 m and 7.5 s, respectively, and the incident wave power was 40 kW/m. The turbine rotation varies from 1300rpm to 2000 rpm and the electric power varies from 20 kW to 50 kW. As the turbine speed exceeds 1800 rpm the air flow regulating valve opens to reduce the air flow to the turbine as shown in the figure. The average electric power is 31 kW, and the conversion efficiencies from wave power to air power, from air power to turbine power and turbine power to electric power are 0.5, 0.39 and 0.92, respectively. However, a large amount of air power is released by the dummy nozzles and valves. Therefore, the utilization rate of air power is very low (0.23). If all the power is used, the electric power is about 120 kW.

Fig. 7 gives the values of electric power. For example, the electric power is from 20 to 40 kW when the significant wave height is 3 m. The electric power becomes larger when the wave direction is near 0 degrees. The electric power by the control ST III in the winter of 1990-1991 is larger than that by the control ST I in the winter of 1989-1990. The control I is a safety

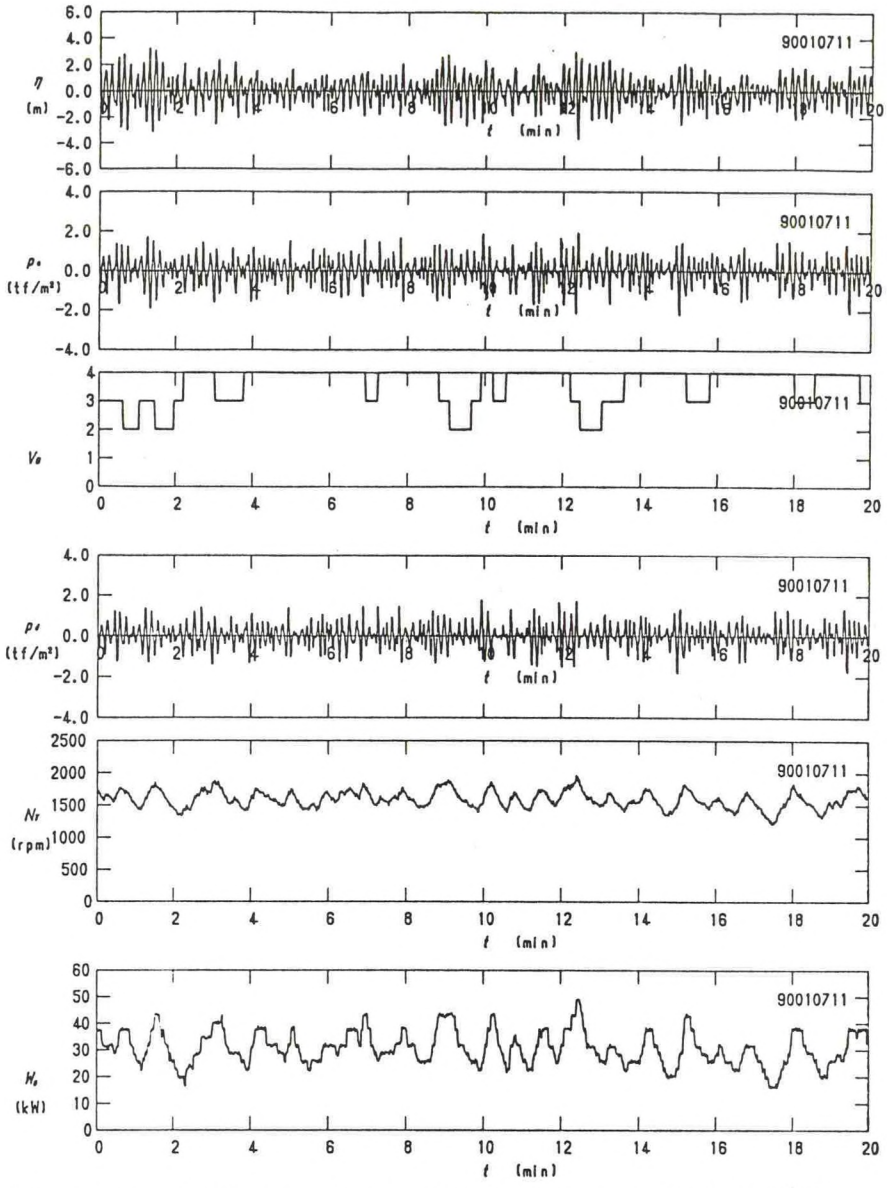

Figure 6 Analogue Data of Wave Power Conversion

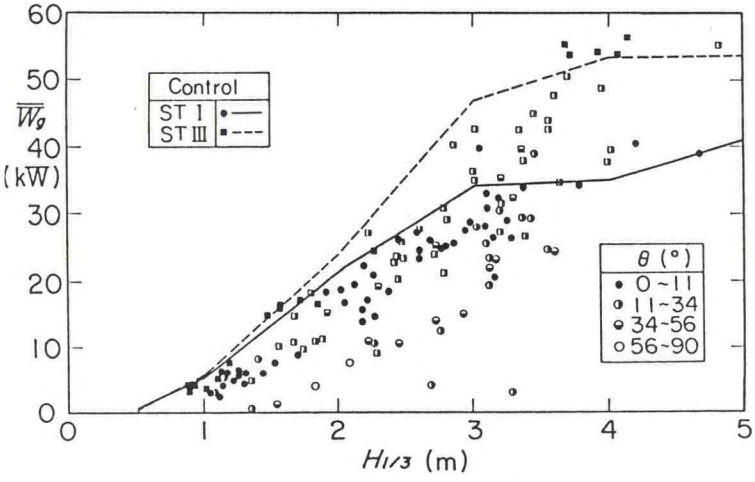

Figure 7 Electric Power

side control. The calculated values shown by the solid and dotted lines roughly make the upper limits of the measured values.

5.3 Stability of the Caisson

Extraordinarily high wave conditions, such as with significant wave height of 7.5 m and Hmax=12.1 m (estimated) were experienced several times from November 1989 through March 1990. Although the maximum wave heights experienced were close to the design wave height of 15.3 m, the caisson remains intact. During the storms the measuring instruments coped sufficiently and collected data of pressures on caisson and the stress of the reinforcement of the caisson walls.

Figure 8 gives the records of wave pressure. The pressure due to the air compression appears at the upper portion of the air chamber with a peak value of 5 tf/m^2. The pressure caused by direct wave action is seen on the sloping wall outside the air chamber. The direct pressure is superimposed on the air pressure on the inner side of the sloping wall.

The values of the pressures and stresses obtained in the field experiment are a little smaller than the calculated values, except for the pressures on the compartment walls in the air chamber. However, the stresses in the compartment walls are much smaller than the calculated values. The design method of the caisson is confirmed in the field experiment.

6. Utilization of the Electric Power

The utilization of energy converted from wave power is an important subject of be discussion. If large and cheap energy storage apparatuses are developed, the converted energy could be used for a variety of purposes as commercial electricity. However, the converted energy could be used directly for

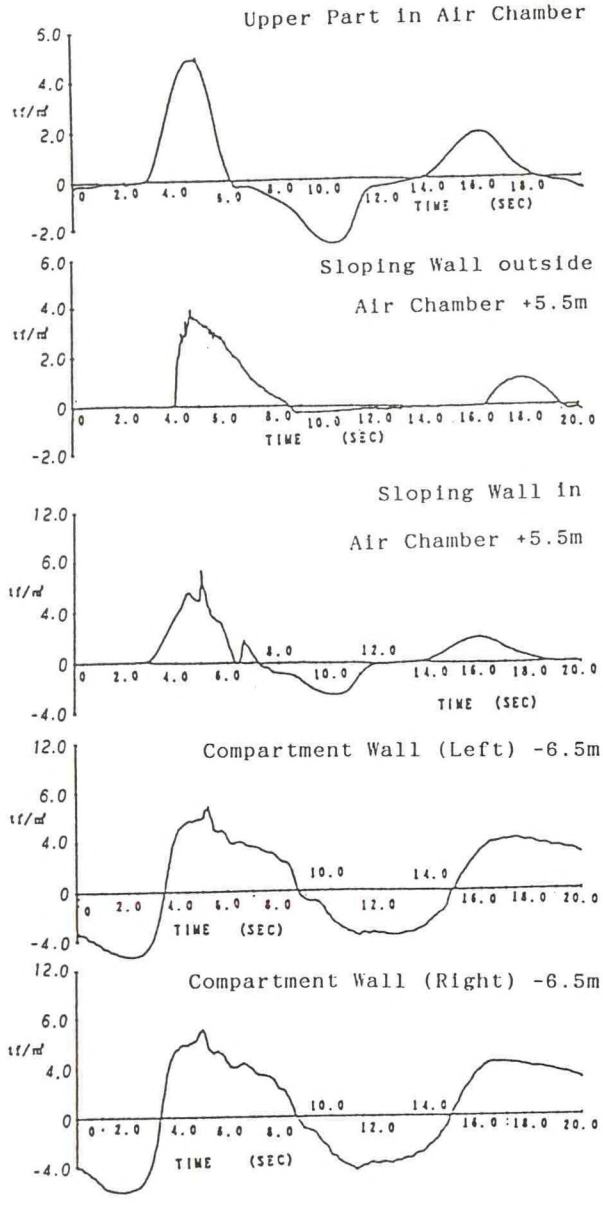

Figure 8 Example of Recorded Pressures

selected uses. Various equipments are tested to utilize the power output in the field experiment.

Figure 9 shows a water pumping system, which pumps water from the beach in front of the observation house into the house. The water is smoothly pumped even though the frequency of the electricity varies. The water quality in a closed harbour can be improved by this system. The system is also applicable to the sub-sand filter method to prevent beach erosion.

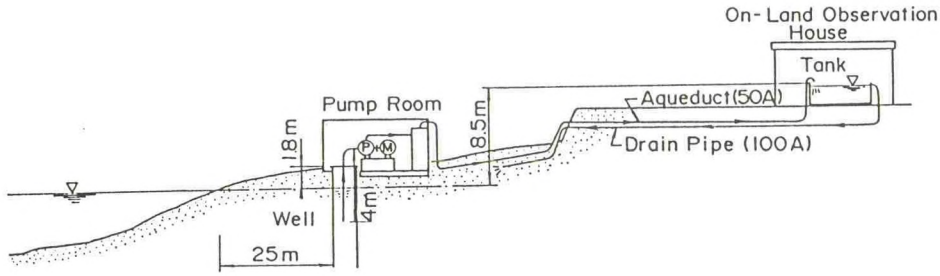

Figure 9 Water Pumping System

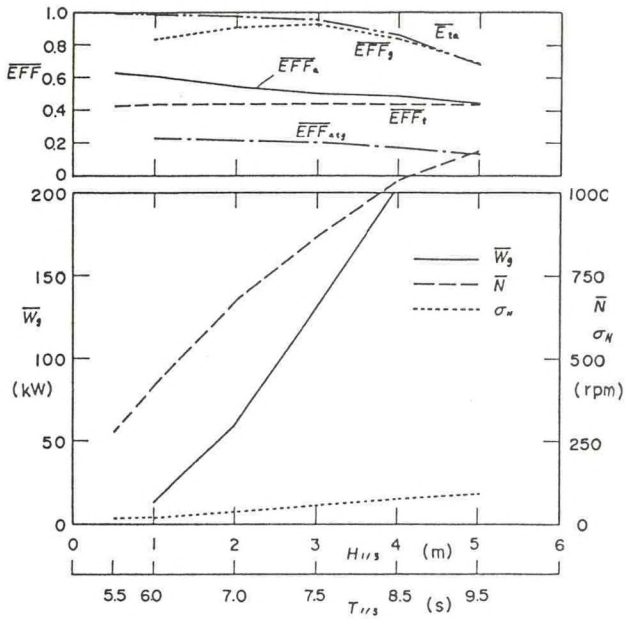

Figure 10 Wave Power Conversion by a Full Size System

7. Wave Power Conversion by a Full Size System

Figure 10 shows the calculated result of the wave power conversion by a full size system with optimal turbine and generator. The diameter of the turbine is 2.4 m, which is almost twice that in the experiment. The rated power of the generator is 200 kW. The turbine speed is expected to be 700 rpm and the electric power is 75 kW when the significant wave height is 2.2 m. The electric power becomes 200 kW when the significant wave height is 4 m.

8. Concluding Remarks

The design method of the breakwater including the power conversion system is verified by the results in the field experiments. The field experiment is continuing and the data will be analyzed in detail. The results will be reported as soon as possible.

The field experiment is being carried out by the collaboration with many people. Thanks to their efforts, valuable results are now being obtained. The authors wish to express their sincere gratitude to all these people.

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TAKING MEASURES AGAINST EARTHQUAKE INDUCED SOIL LIQUEFACTION

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Introduction

Liquefaction of loosely deposited sand often causes serious damage to the structures in ports and harbours. Recent tragic events such as Roma Prieta Earthquake of 1989 in U.S. and Luzon Earthquake of 1990 in the Philippines are a few of the examples.

In Japan, port and harbour structures are designed in accordance with the Technical Standard of Port and Harbour Facilities and its Commentary (Japan Port and Harbour Association,1989). The procedure for earthquake resistant design was compiled as early as in 1950, revised, supplemented or legislated in 1959, 1967, 1971, 1975, 1979 and 1989. The most recent revision in 1989 aims at assuring, in practice, the greater safety against soil liquefaction; i.e. the lesson learned from the case history in 1983 Nihonkai Chubu Earthquake of magnitude 7.7.

According to the Technical Standard, the steps to be taken for earthquake resistant design are as follows;

(1) take into account the effects of seismic inertia force upon the safety and stability of structures or the effects of seismic displacement upon lifeline facilities and
(2) assess the liquefaction potential of soil due to earthquakes and, if necessary, take measures against liquefaction.

In this paper, the current procedures taken for designing against liquefaction will be briefly reviewed.

ASSESSMENT OF LIQUEFACTION

Soil liquefaction, if occurs, considerably affects the stability of structures. Liquefaction potential, in the current practice, is assessed by the following procedure (Iai et al, 1989).

(1) Classify the soils by comparing the grain size accumulation curves with the ranges shown in Fig. 1;

Soils within the range (A): Very easily liquefiable soil.
Soils within the range (B_f) or (B_c) : Easily liquefiable soil but less liquefiable than the soils within the range (A).

Consider that no liquefaction will take place for the soils which do not belong to either the ranges (A), (B_f) or (B_c).

(2) Obtain the equivalent N-values from SPT N-values with corrections for effective confining pressures to 0.66 kgf/cm^2 and with corrections for

fines content. Conduct the earthquake response analysis of ground by equivalent linear method and obtain the equivalent acceleration from the maximum shear stress ratio (the ratio of maximum shear stress over vertical effective stress) by multiplying the factor of 0.7g as a conversion factor.

(3) Use the design charts shown in Fig. 2 in accordance with the ranges for grain size accumulation curves. Assess the liquefaction potential in accordance with the regions to which the the equivalent N-value and the equivalent acceleration belongs;

Region I : Consider that liquefaction will take place.
Region II : Conduct a further study such as laboratory test of soils if desirable. Otherwise, consider that liquefaction will take place.
Region III : Conduct a further study such as laboratory tests of soils if high reliability is required in the stability of the soil deposit. Otherwise, consider that liquefaction will not take

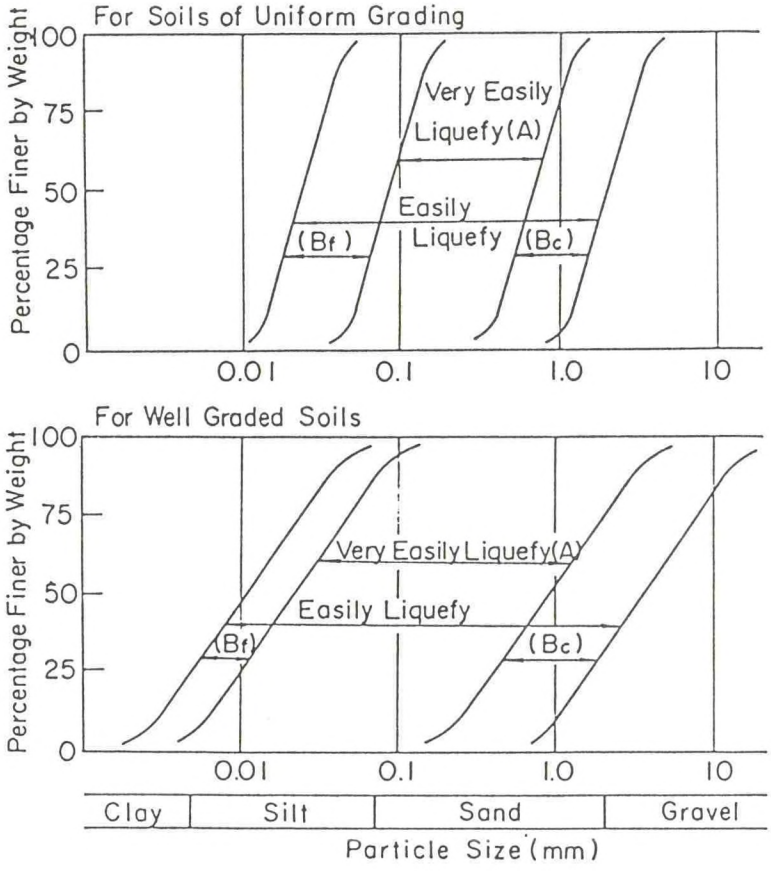
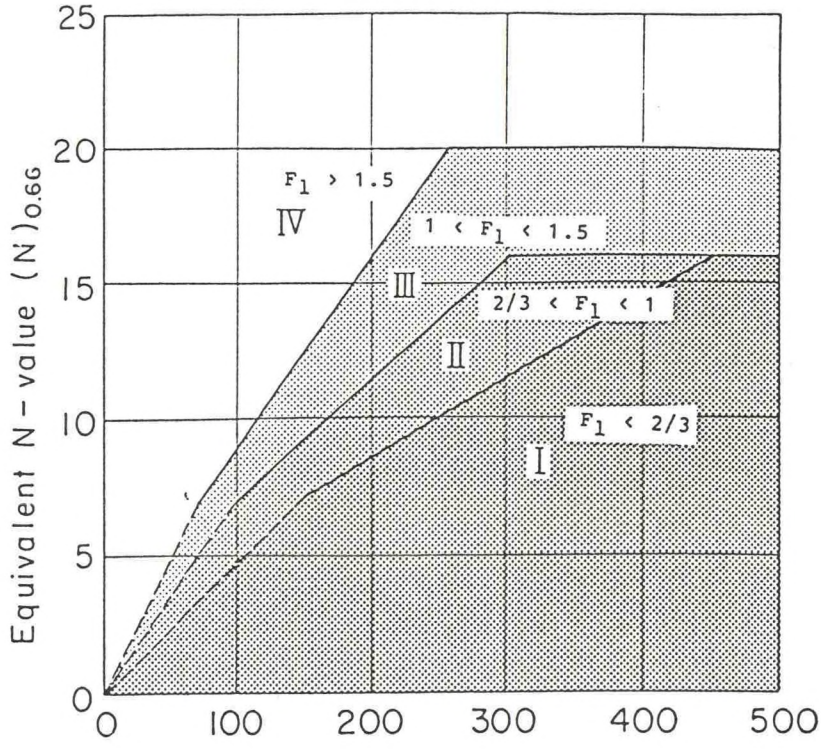
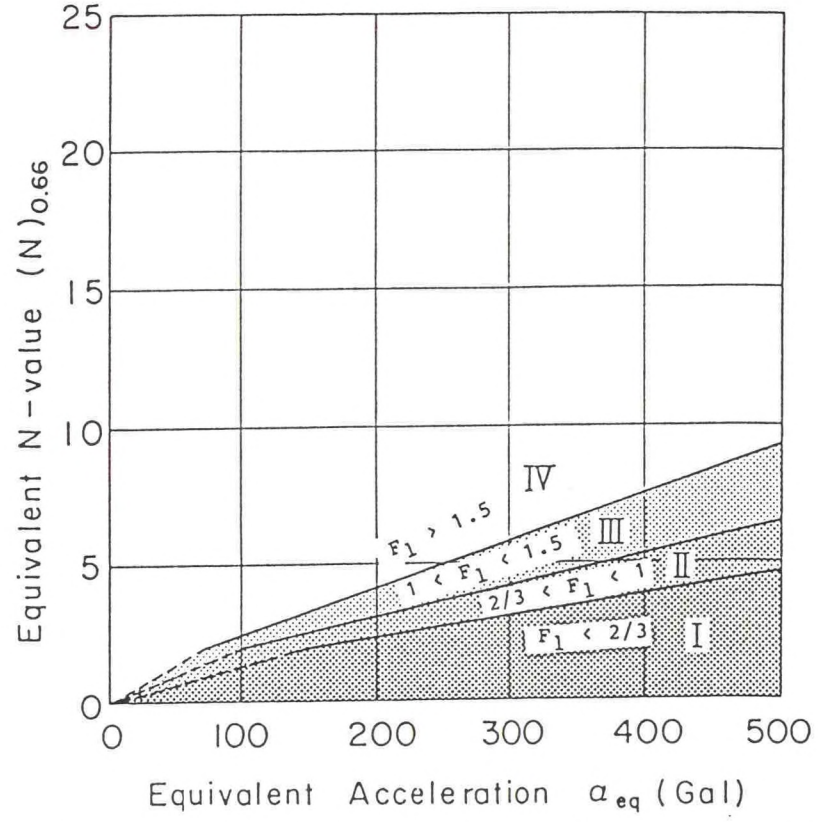


Fig. 1 Ranges of Grain Size Accumulation Curves of Liquefiable Soils (after Iai et al, 1989)



(a) For Soils in the Range (A)



(b) For Soils in the Ranges (B_f) or (B_c)

Fig. 2 Design Chart for Assessing Liquefaction Potential (after Iai et al., 1989)

place.

Region IV : Consider that liquefaction will not take place.

The present criterion has evolved from the studies since 1964 Niigata Earthquake (Tsuchida and Hayashi, 1971). Though the evolution process is quite independent from the studies by Tokimatsu and Yoshimi (1983) and Seed et al.(1985), all of these criteria show remarkably good agreement as shown in Fig. 3 (Iai et al, 1989).

In assessing liquefaction potential by the present procedure, maximum accelerations should be specified for the input motions to be given at the base rock for earthquake response analysis. Based on the recent study on seismic zoning (Kitazawa et al, 1984), maximum accelerations as an rock outcrop motions (i.e. double amplitudes of incident waves) are specified for five regions as 300, 250, 200, 150 and 100 Gals.

Based on the assessment of liquefaction potential, adequate measures will, if necessary, be taken against liquefaction. Relevant studies can be referred to on designing the area of ground compaction (Iai et al, 1987) and on designing spacing of gravel drains (Iai et al, 1988).

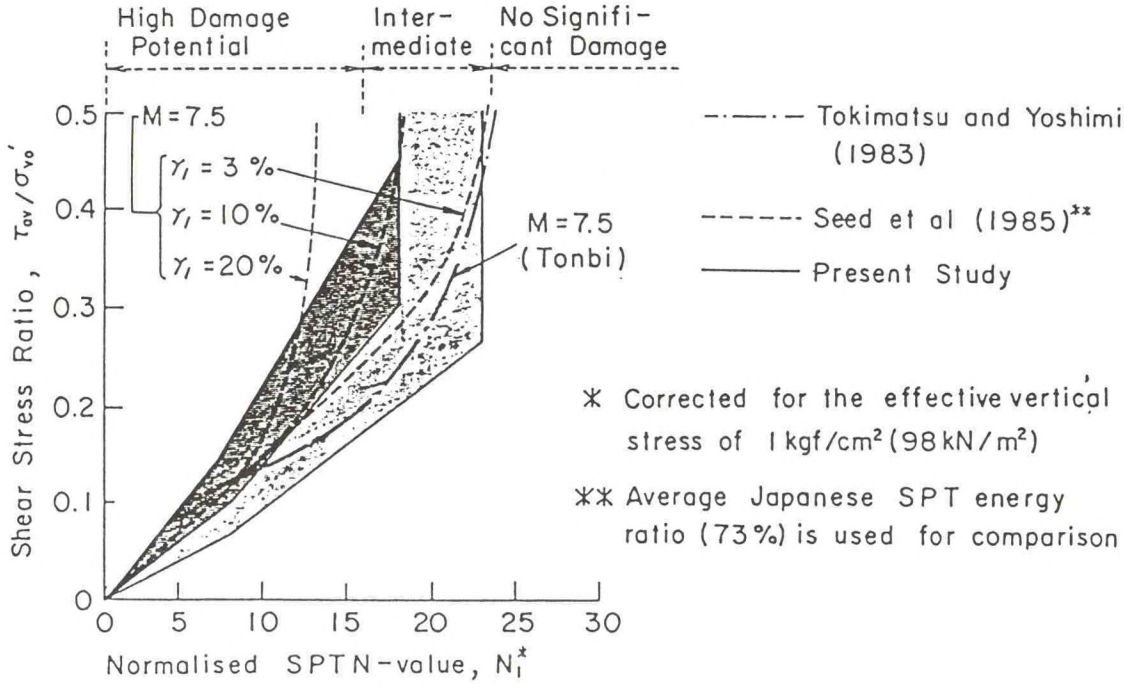


Fig. 3 Comparison with Other Criteria (after Iai et al, 1989)

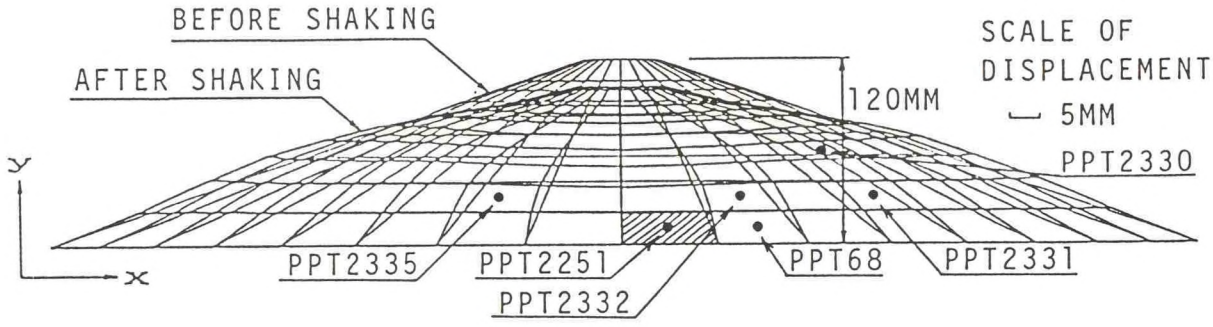


Fig. 4 Residual Deformation in Model Embankment due to Liquefaction (after Iai, 1989)

Two dimensional analysis of liquefaction and cyclic mobility has been known to encounter serious difficulty in the numerical solution as soon as the effective stress path becomes very close to the failure condition. In order to overcome the difficulty, a numerically robust approach is developed and coded into a finite element computer code FLIP (Iai et al,1989). The approach, when applied to a saturated model embankment shaken in the centrifuge at Cambridge University, simulates the gradual deformation of embankment with the residual deformation shown in Fig. 4 and with the excess pore pressures shown in Fig. 5. (Iai, 1989).

The present approach, when applied to an anchored steel sheet pile quaywall during an earthquake motion of 200 Gals, simulates the gradual

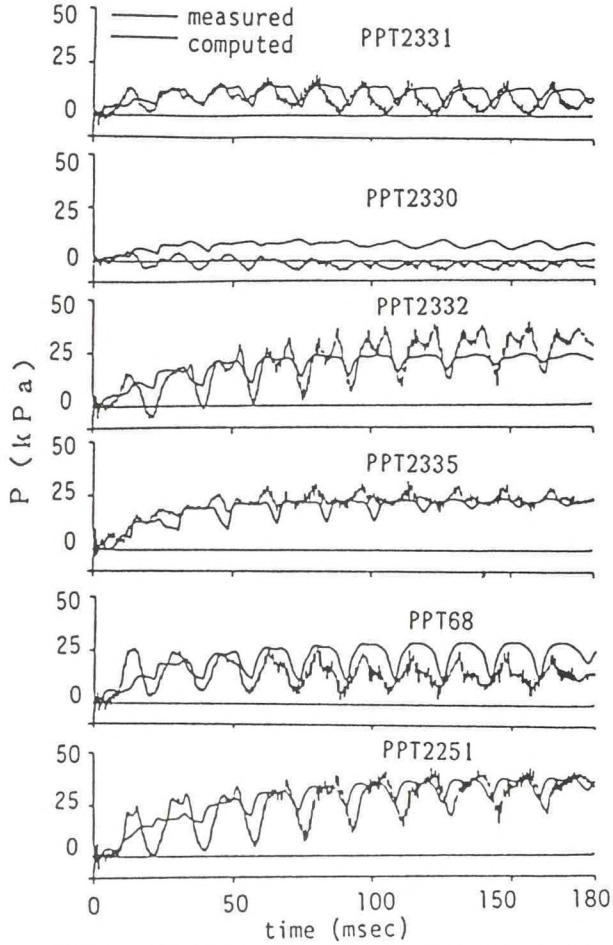


Fig. 5 Excess Pore Pressures

deformation of quaywall with the residual deformation shown in Fig. 6, in which settlement in the soil retained by the sheet pile, swell at the sea bed before the sheet pile and horizontal displacement of the sheet pile toward sea are all recognized. Soil wedges in front of and behind the sheet pile are also recognized. Earth pressures due to liquefying soil-structure interaction is computed as shown in Fig. 7, the corresponding bending moment acting on the steel sheet pile in Fig. 8. (Iai et al, 1989)

The present approach, when applied to such an underground structure as subaqueous tunnel during an earthquake motion of 225 Gals, simulates the gradual uplift as shown in Fig. 9 due to liquefaction of soil layers above the depth of 25.3 m level.

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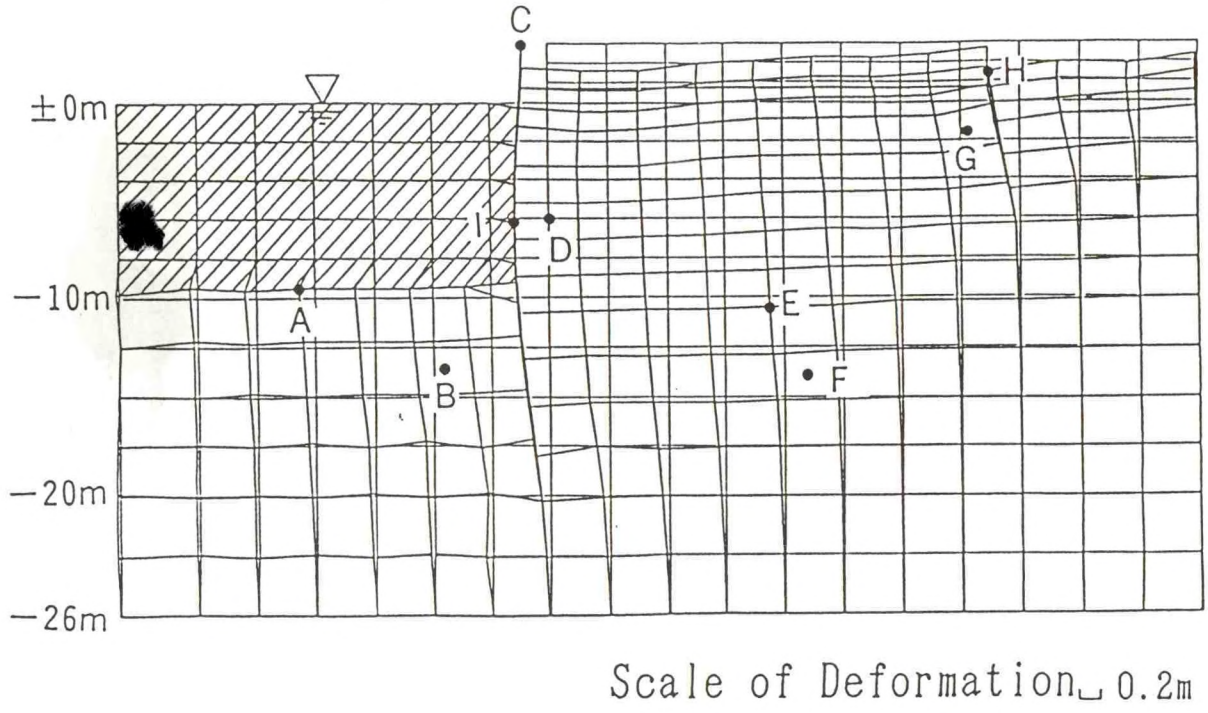

Fig. 6 Residual Deformation of Anchored Steel Sheet Pile Quaywall due to Seismic Loading and Liquefaction (after Iai et al, 1989)

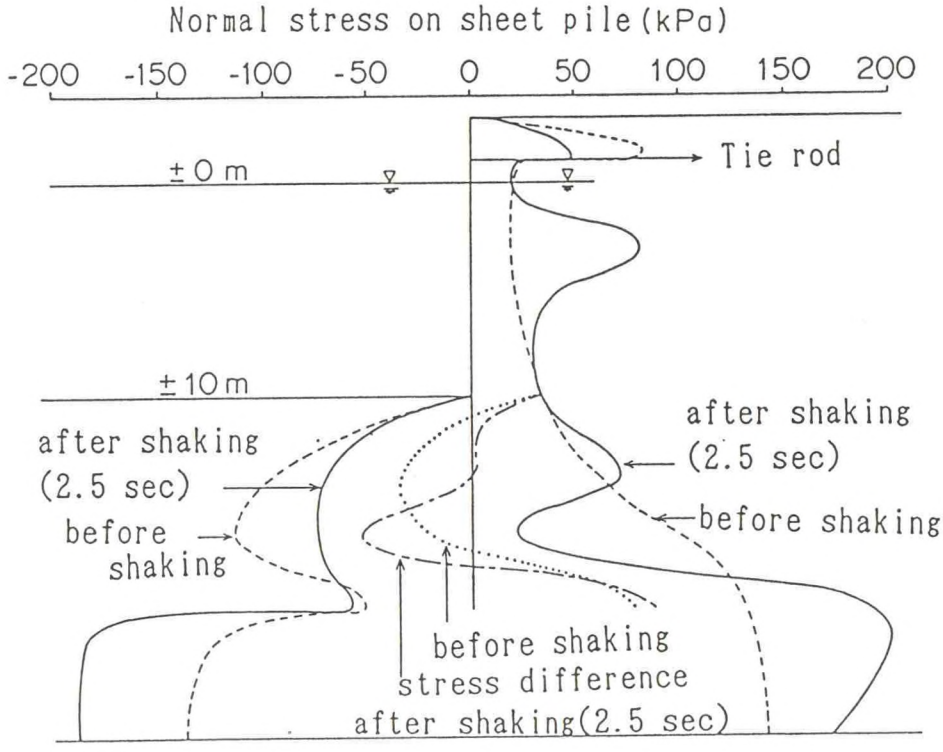

Fig. 7 Normal Total Stresses Acting on Sheet Pile due to Soil-Structure Interaction with Liquefaction (after Iai et al, 1989)

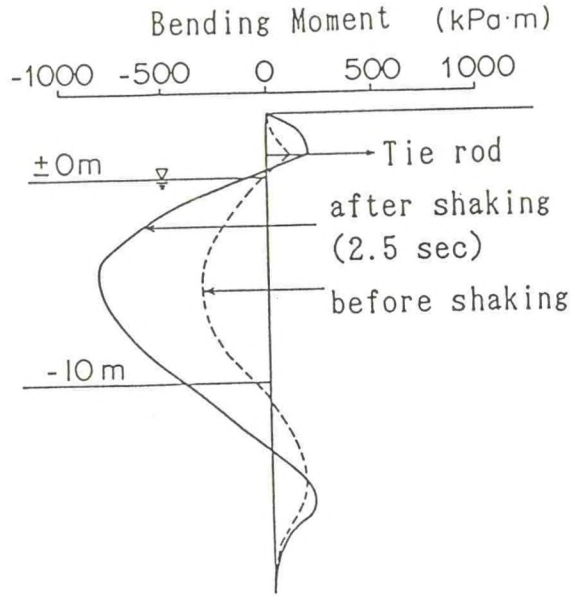

Fig. 8 Bending Moment due to Seismic Loading and Liquefaction (after Iai et al, 1989)

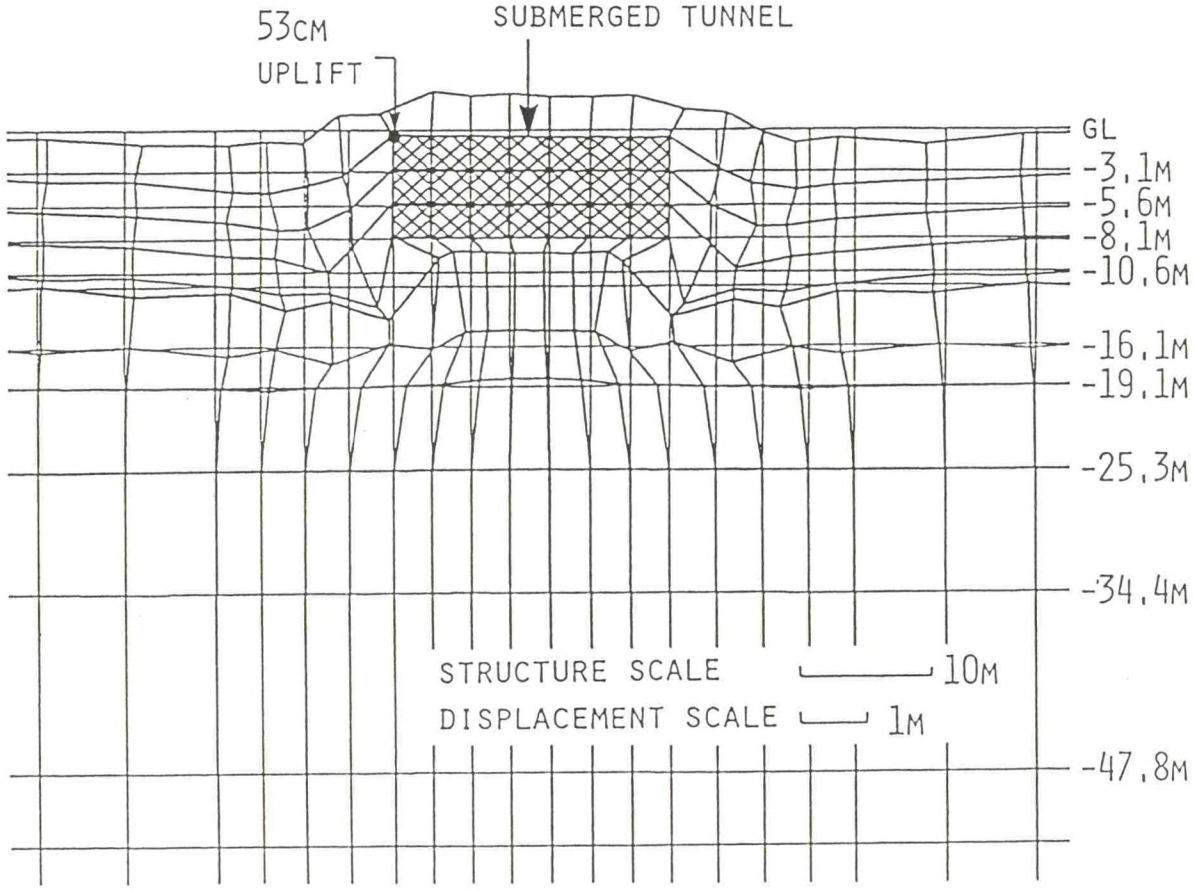

Fig. 9 Uplift of Subaqueous Tunnel due to Liquefaction

CONSTRUCTION OF THE KANSAI INTERNATIONAL AIRPORT

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Kansai International Airport Company, L.T.D.

1. Introduction

In Japan, because it is an island country bounded by oceans, it has become an important issue to not only use the land effectively but also to develop the coastal sea area.
The idea of making man-made offshore islands has become part of the solution for the development of the coastal sea area. The construction of the Kansai International Airport (KIA) is the first notable project.

2. Location of the Kansai International Airport

The KIA is now under construction approximately 5 km offshore of Senshu along Osaka Bay : a sea area, 16.5~19 m deep, will be reclaimed to accommodate airport facilities, which will be connected to the mainland by highways and railways over an access bridge.

The site is situated 34 km from downtown Osaka, 30 km from Kobe, 80 km from Kyoto, 60 km from Nara (Fig.1).

3. Need for a new international airport in the Kansai region and the principles of the airport

The international and domestic air transport volume in Japan is growing rapidly (Fig.2).
A lot of improvement or expansion projects for airports have been energetically carried forward, however these efforts haven't adequately supplied the increasing demand.

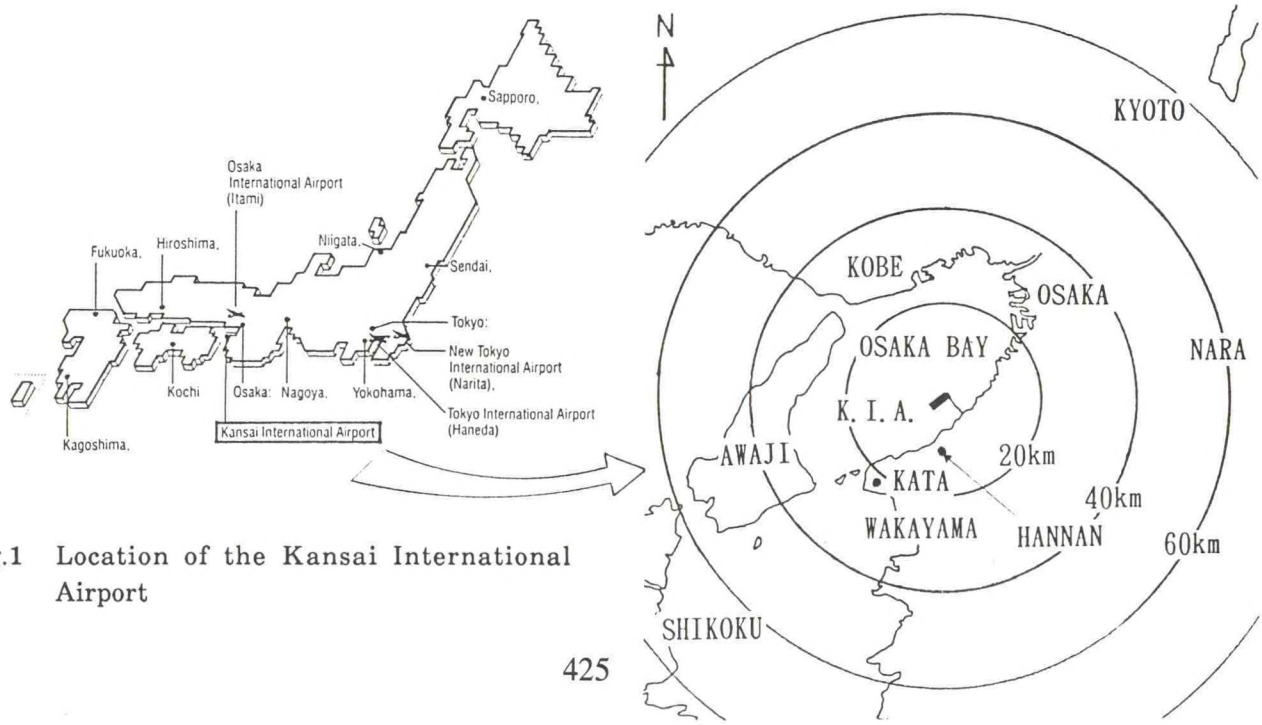


Fig.1 Location of the Kansai International Airport

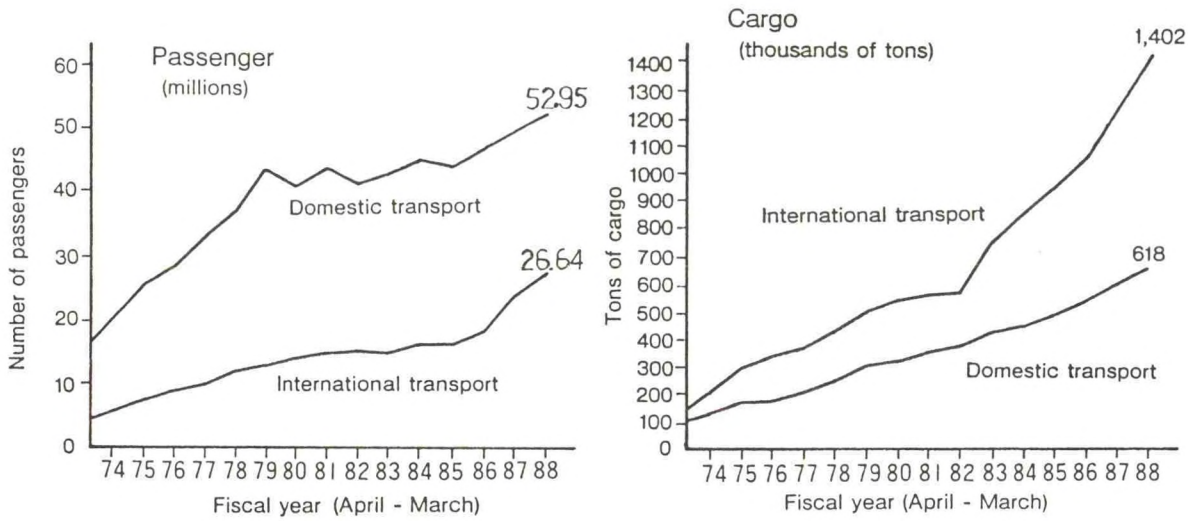


Fig.2 Increasing Demand of Air Transport Volume

The Kansai region (population : approx. 20 million), is similar to the Tokyo metropolitan region (population : approx. 35 million), as a center of political and economical activities in Japan. There is Osaka International Airport (Itami Airport), but this airport has only one main runway (3,000 m long) and aircraft operation on it is limited (from 7 am to 9 pm) because of environmental problems such as aircraft noise to the residential area.

Further expansion work of this airport is difficult because it is situated in densely inhabited districts, so it is extremely difficult both now and in the future to accept requests for new additional flights by both domestic and foreign carriers.

Under these circumstances, construction of the Kansai International Airport was decided upon as a means of easing the environmental problems imposed by the existing Osaka International Airport and of meeting the increasing demand for air transport in the Kansai region.

In the construction of the Kansai International Airport, four basic guiding principles are employed.

1) The airport should contribute to a growth in international air transport capabilities, as the first airport in Japan to operate on an unrestricted 24-hour schedule.
2) The airport should facilitate flight connections by efficiently accommodating both international and domestic lines.
3) The airport should be connected to other important points in the Kansai area by a fast and efficient transport network, including railways, highways and sea routes.
4) The airport should pay due and full regard to pollution control and environmental protection in Osaka Bay and its surrounding area (Fig.3).

4. Outline of the Kansai International Airport Plan

1) Phase I Plan

The airport is being built on a nearly rectangular man-made island 4,370 m long, 1,250 m wide, with an area of 511 ha. It will have one runway 3,500 m long, which can handle 160,000 takeoffs and landings a year.

A variety of facilities on the island will be constructed, including passenger terminal building, railway station, sea access area, cargo terminals, fuel supply area and navigation aids, etc. (Fig.4).

The airport access bridge that will connect the airport island with "Rinku Town" will be 3.75 km long, one of the longest continuous steel truss bridges in Japan.

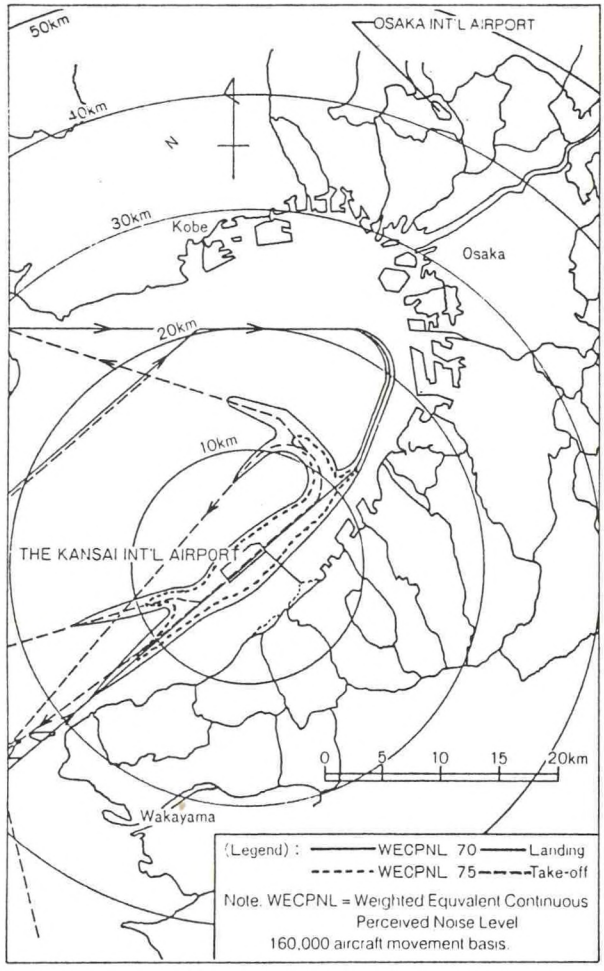


Fig.3 Predicted Pattern of Aircraft Noise Distribution

2) Phase II Plan (Master Plan)

The airport will be expanded in the future to a ground area of about 1,200 hectares. When expanded, there will be two main 4,000 m runways, as well as a 3,400 m auxiliary runway. This will increase airport capacity to 260,000 takeoffs and landings a year (Fig.5).

3) Construction of the airport island

Construction work on the airport is taking place in the following order ; foundation improvement, seawall construction, reclamation, and airport facility construction. Construction work on the airport access bridge and the access railroad are progressing concurrently.

The seabed soil in the construction area consists of a 20 m thick layer of soft alluvial clay on top of a 400 m thick layer of diluvial clay. For this reason, the entire foundation of the Airport Island was improved using the sand drain method. In this method, a sand pile is driven into the alluvial clay layer and the water in the clay is discharged due to the weight applied from above, thereby consolidating the foundation. A total of one million sand piles were driven into the seabed during this step.

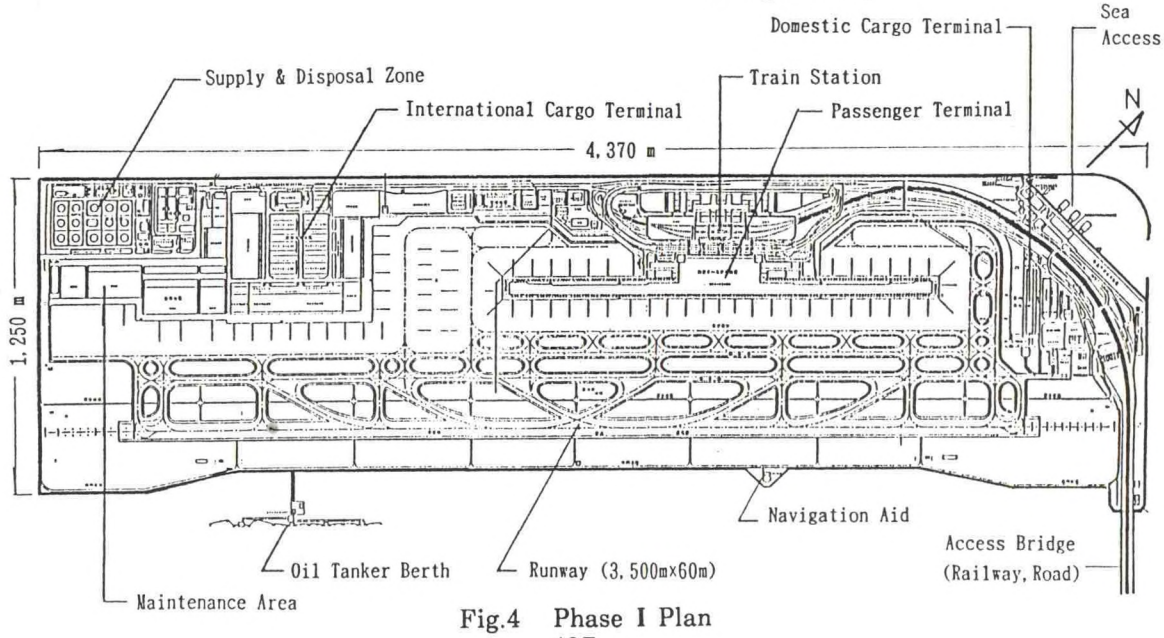


Fig.4 Phase I Plan

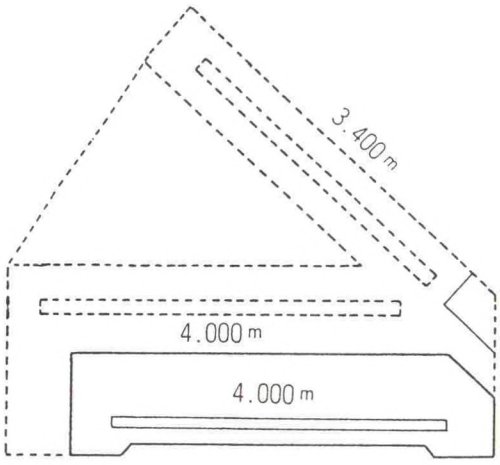


Fig.5 Phase II Plan (Master Plan)

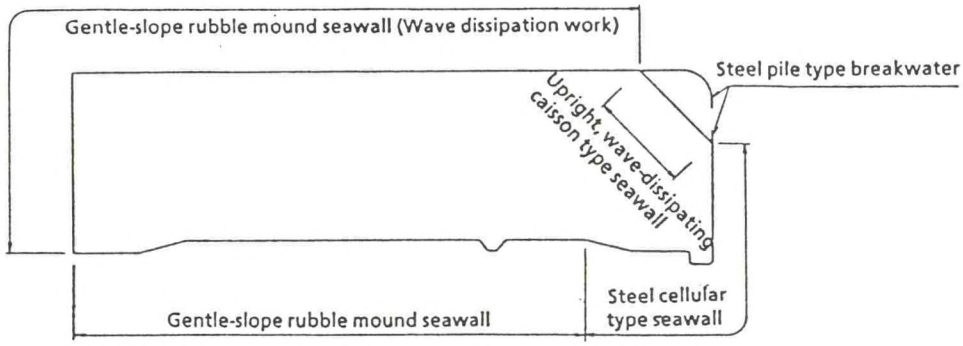
The next step was the construction of 11 km of seawalls to form the perimeter of Airport Island. Most of the seawall was constructed by piling sand and stones onto the improved submarine foundation. Depending on the location, however, some sections are steel cellular-type seawall, made by arranging steel cylinders side-by-side, and other sections are wave-dissipating caisson-type seawall, ideal for approach and departure by ship (Fig.6).

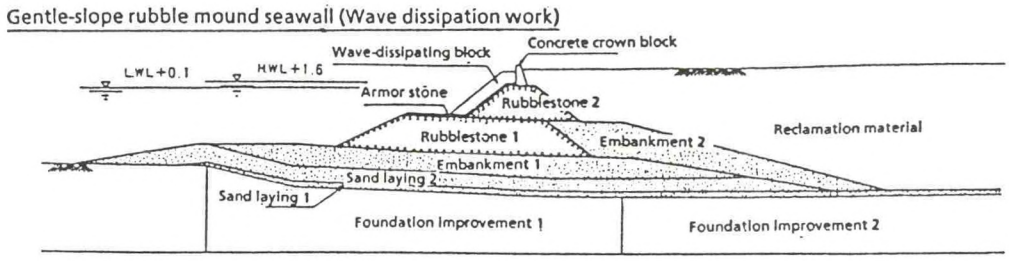
Next, a total of approximately 164 million m^3 of soil will be dumped into the main island area created by the seawall. The earth and sand used for reclamation is being transported from excavation sites in Hannan-cho, Osaka Prefecture, the Kata area of Wakayama Prefecture and Awaji Island in Hyogo Prefecture.(ref.Fig.1) The total settlement after 50 years from the airport opening under the consolidation of alluvial and diluvial layers is approximately 11.5 m, which includes a compression of fill material 0.5 m. Therefore, reclamation soil height becomes approximately 33 m, which is equal to a 8~9 story building (Fig.7).

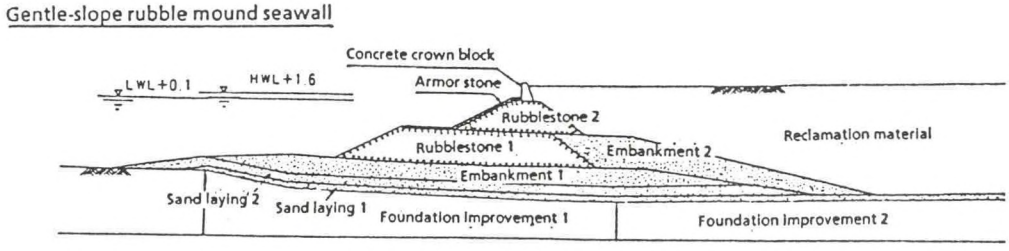
4) Construction of the access bridge

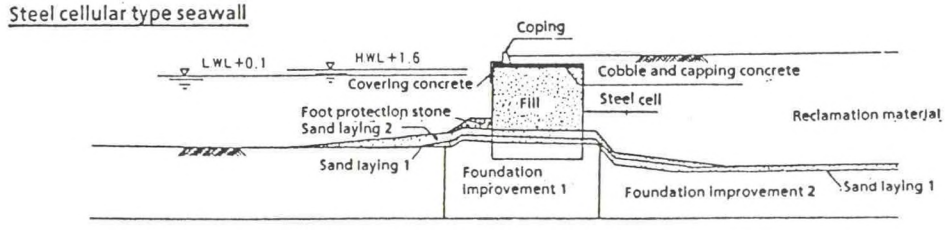
The structure of the bridge has three main sections, the portion over open water, the two ends at the airport island and the mainland Osaka area. The central portion over open water is to be of steel truss configuration, with an upper vehicular expressway and lower rail route. The configuration of the access bridge was designed to meet the requirements of three interrelated considerations : (1) height specifications for international air traffic, (2) the Southern Osaka Coastal Area Development Project, and (3) shipping clearance specifications for ocean-going vessels. These specifications will place a maximum height restriction of approximately 49 m and will necessitate a minimum sea lane clearance under the bridge of 130 m wide by 25 m in height (Fig.8).

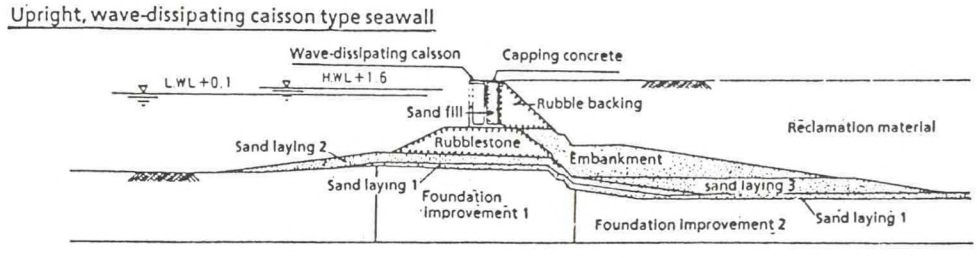
Bridge construction commences with the construction of bridge piers to support the bridge girders. However, the weak foundation problems are caused by settlements of soft clay strata . These are solved by driving 1-1.5 m diameter 50-70 m length steel-pipe piles into the foundation to support the weight of the bridge. Once the bridge piers are finished, the girders are set in place upon them. The bridge piers and girders are produced at factories throughout Japan, and they are then transported to the construction site and set in position by large pontoon cranes.











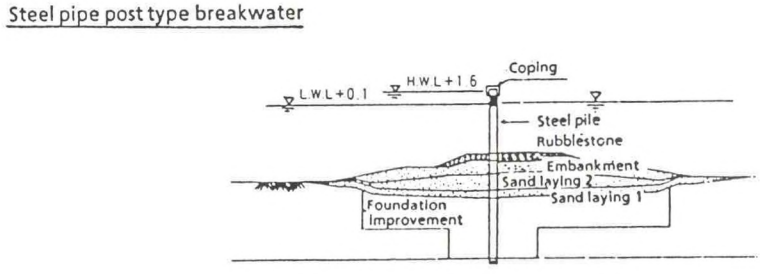


Fig.6 Seawall Structure and Location

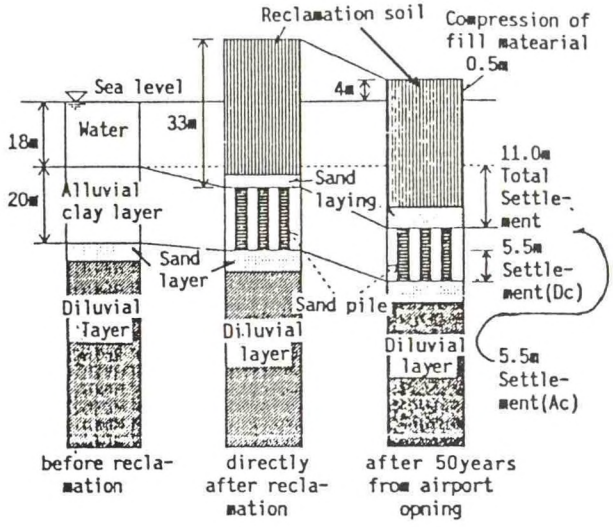


Fig.7 Settlement of Seabed due to Reclamation

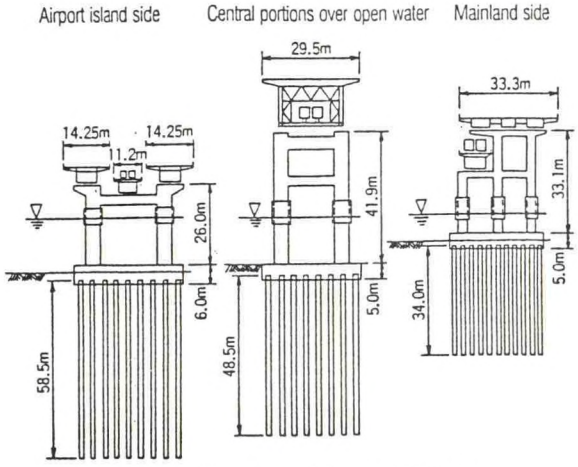


Fig.8 Cross Section of Access Bridge

5) Airport facilities

The airport island will not only serve as an airport, but will also function as a fully integrated airport city with high-level communication systems and numerous other urban facilities. The biggest one on the island is the Passenger Terminal Building, which has one main terminal building (300 m long) and both wings (700 m long × 2). The basic concept of the Passenger Terminal Building was drafted based on a plan submitted by the Aeroports De Paris. An international architectural design competition was then held to give that concept form, and Italian Architect Renzo Piano's design was selected as the winning entry. A special feature of the design is its emphasis on ecology ; a symbiotic relationship between Nature and Architecture, which results in an intimate blending of light, air, and greenery with structure and function. Aerodynamic themes are beautifully incorporated into the structure through a recurrent use of large, curved beams and boomerang-shaped frames (Photo 1). A special functional feature of the building is its three-story construction to facilitate flight connections, with the groud floor for international arrivals, the second for domestic arrivals and departures, and the third floor for international departures. Passengers need only go up and down levels for connecting flights. Domestic flight passengers will board from the gates in the main terminal, while international passengers will quickly and easily reach their gates in the wings on the airport's fast and efficient AGT (Automated Guideway Transit) system.

The air freight processing zones on Airport Island will consist of a 26.4 ha international and a 4.5 ha domestic cargo terminal. Both will have all the necessary functions for air cargo processing. The main priority in planning is clear-cut zoning for the efficient use of space and smooth movement.The facilities themselves will adopt a simple design to ensure maximum frontage, with due attention being paid to the working environment as well.

In addition to the Passenger Terminal, an annex building is planned to serve an urban space possessing a comprehensive array of service and convenience facilities. It will consist of hotel and rest facilities, restaurants, shopping zones, offices and many other facilities for the convenience and enjoyment of passengers, wellwishers, and visitors.

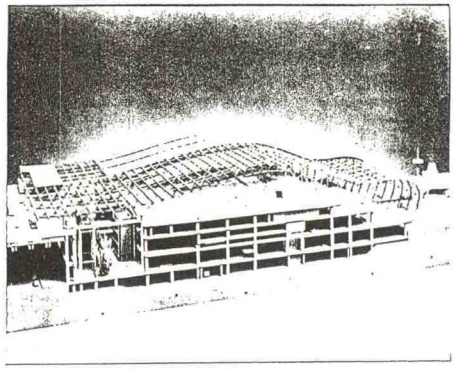


Photo.1 Passenger Terminal Building (Main Building) Sectional Model

6) Efforts to protect the environment

In order to protect the environment both during construction and after commencement of airport operations, we have conducted measurements of noise, air quality, water quality, seabed sand and mud properties, oceanographic phenomena and marine life. The results have been analyzed and evaluated, and suitable protective measures are being taken. These results and other data are collected at the KIA Environmental Research Center. Reports are periodically made to local governing bodies, and information is regularly made public to area residents.

7) Construction schedule

The airport island will be constructed in the seven years (with approximately two years devoted to seawall construction and approximately another three years to 164 million m^3 of reclamation). At the same time as the island is being reclaimed, airport facilities construction will begin and the entire airport will be completed approximately seven years after the start of construction. The access bridge will be constructed concurrently within the six-year project construction period (Fig 9).

8) Establishment as a semi-public corporation

Japan's airports have traditionally been administered either directly by the government or by public corporations. The Kansai International Airport is the first example of ownership and administration by a private corporation bringing together the resources of the National Government, local public entities and the private sector. This arrangement is being widely hailed for its advantages in maintaining links with the local communities, and in utilizing the energy of the private sector.

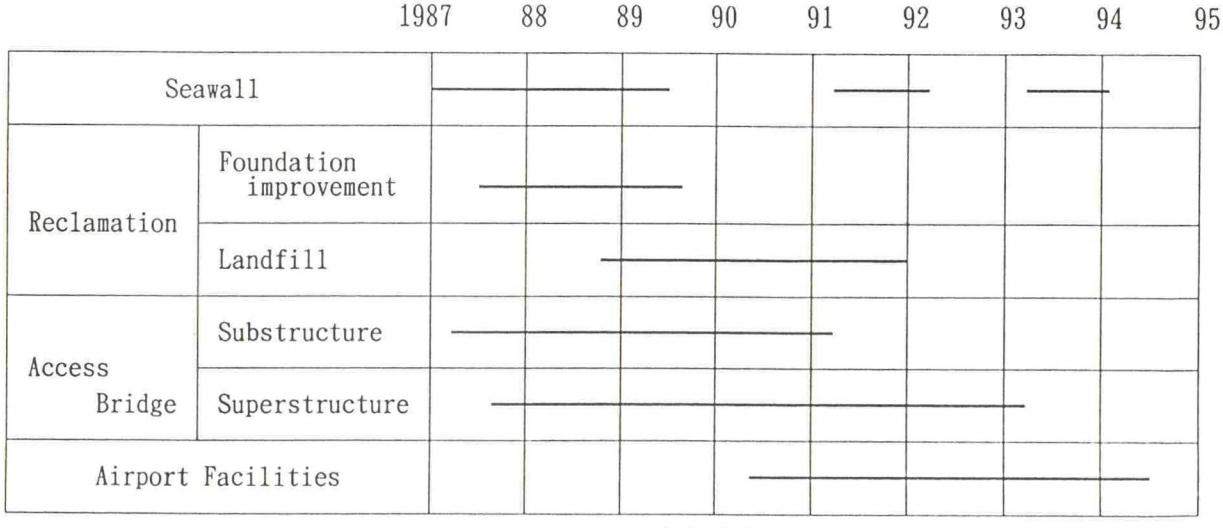


Fig.9 Construction Schedule

9) Project cost and financing plan

Phase I construction cost is approximately 1,430 billion yen. This cost is the result of the latest re-estimation in Dec. 1990.

5. The State of the Construction Work as of Spring 1991

When the UJNR meeting is held, the reclaimed land above sea will be 340 ha (67 % of total area), soil volume dumped will be 139 million m^3 (85 % of total volume) and the airport island will be completed by the end of 1991 as scheduled. As for the access bridge, all piers in the sea have been installed completely, and all girders for the full length of the bridge, will be finished and set in place by the end of May. Construction of the Passenger Terminal Building has been started on February, 1991, and all the facilities are being prepared for full-scale work.
Photo.2 shows the state of the construction work as of, January 1991

6. Conclusions

The construction works on the airport island are noted for a number of technical problems induced by various constraints for example ; the particular soil conditions of the site and the compressed construction schedule. But all those concerned with this project are doing their best to overcome any obstacles that may arise by utilizing the latest technical developments and the past survey results. We hope that our construction methods, technology and construction management system will be useful for future use and development of coastal sea areas.

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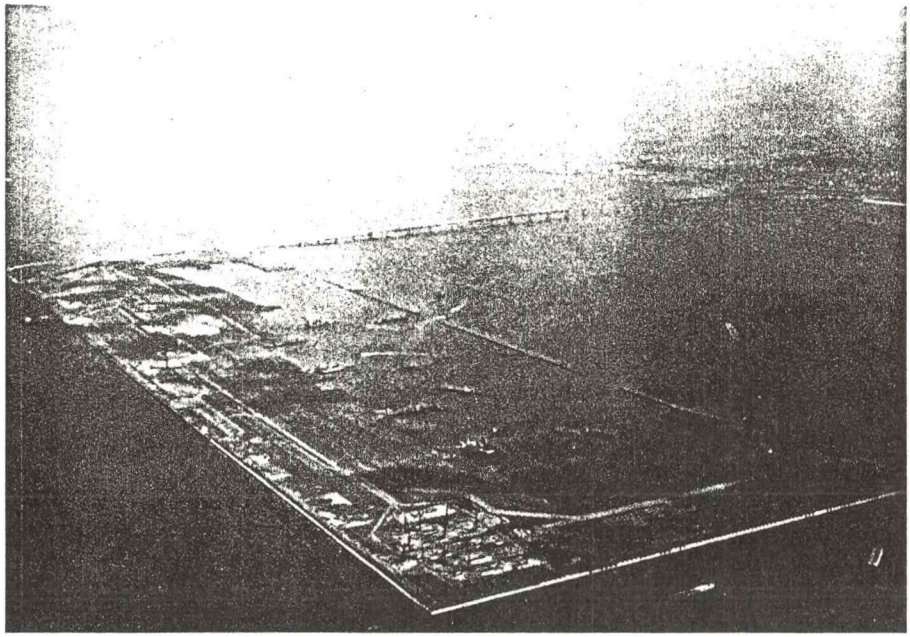

Photo 2 The State of the Construction Work as of, January 1991

TOWARD AN ENRICHED WATERFRONT
—FOLLOW-UP TO "THE PORTS AND HARBORS FOR THE 21ST CENTURY" —

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I. Introduction to "Toward an Enriched Waterfront"

1. Ports and Harbors for the 21st Century

(1) Changing functions of ports and harbors

Since ancient times, ports and harbors have developed mainly as the nucleuses of maritime and land transportation and as places of trade, commerce and other socio-economic activities, with their functions changing with the times.

During the period of rapid economic growth which started in the 1960s, ports and harbors, responding to the rapid industrial modernization, handled the expanding volume of physical distribution and created vast industrial centers to meet socioeconomic needs.

Toward the 21st century, Japan is becoming increasingly internationalized, information-oriented, and urbanized, thus evolving into a mature society. In such a society, its needs focus on higher quality and diversification.

(2) Ports and harbors for the 21st century

With the 21st century approaching and the start of a new era, the Ports and Harbors Breau of the Ministry of Transport compiled a long-term Port and Harbor development policy in "The Ports and Harbors for the 21st Century" in April, 1985, recognizing the future direction of socioeconomic changes and the role of ports and harbors as mentioned above.

One of the objectives of the policy is to place emphasis on the people-oriented functions of ports and harbors, which was often overlooked during the period of rapid economic growth, when the distribution and industrial functions were heavily emphasized. This is to achieve harmony and good coordination among these three kinds of functions, which will allow these functions, sophisticated as a whole,to be fully put to use, thus completing "the creation of a comprehensive port and harbor space."

Another objective is "the promotion of networking among ports nad harbors" which will allow ports and harbors to strengthen mutual links and operate jointly via not only maritime transportation but also imformation and air and land transportation. Important measures to acheve such objectives are also sugggested in "The Ports and Harbors for the 21st Century."

2. Implementation of the policy

Following "The Ports and Harbors for the 21st Centry," the Ports and Harbors Bureau of the Ministry of Transport drew up the 7th Five-Year Port Implementation Plan and the 4th Five-Year Plan for Coastal Protection Works with 1986 as the first year of the plans.

Furthermore, the Ports and Harbors Bureau revised the "Basic Policy for the Development, Utilization and Preservation of Ports and Harbors and for the Development of Waterways to be Developed and Preserved " and a model regulation regarding restriction for construction of buildings for sections in a port-designated district

, which would serve as guidelines for, respectively, port and harbor planning and the use of ports and port-designated districts, in accordance with the ideas of the policy.
The Ports and Harbors Bureau also established new projects such as the "Port Renaissance 21 Project," which aims at the redevelopment of ports and harbors whose functions no longer meet the demands of the time, and the "Coastal Resort Project, "which aims at regional resort development .Moreover, to promote reserch and studies for these projects, the Waterfront Revitalization Research Center was founded, and the Japan Marina Association was expanded and reorganized as the Japan Marina and Beach Association.
As well, projects relevant to the creation of a comprehensive port and harbor area, carried out by private enterprises and public-private joint enterprises, are supported through a special port and harbor development area system, tax incentives, and financial aids which were established in accordance with the "Provisional Measures Law for Promotion of the Construction of Specific Facility through the Participation of Private Enterprises" and relevant regulations. As for technological development, the "Technical Standards for Port and Harbor Facilities" were revised, and the "Evaluation System for Port and Harbor Technologies of Private Enterprises" and so on were introduced.

3. Socioeconomic Trends Surrouding Ports and Harbors

(1) Socioeconomic Changes

Viewing recent changes in the international socioeconomic environment surrouding ports and harbors, one notices Japan's economic expansion, trade imbalance, and the rapid and sustained appreciation of the value of the yen since September, 1985 , thus requiring Japan to contribute to the international community commensurately with its economic power and to change its economic structure into a more domestic market-oriented one. As well, exchange with thriving, newly industrialized economies in East Asia and Southeast Asian counries is growing vigorously.
Domestically, as social maturation continues, quality is becoming the focus in various aspects in society. People's interests in waterfront areas, marine recrea tion, cruising on a passenger vessel are growing. Economic and social activities are expanding beyond the conventional boundaries of their fields, and even beyond the national boundaries.
In terms of regional development, the overconcentration of various functions in Tokyo is continuing, and land prices are skyrocketing in major urban areas. On the other hand, rural areas are having difficulty in achieving economic progress, further expanding the gap between urban and rural areas. Such changes have been taking place at a rate far greater than estimated at the time of the compilation of "The Ports and Harbors for the 21st Century."

(2) National Plans

In line with these changes in the social and economic enviroments, the national land and economic plans were revised one after another. In the "4th National Comprehensive Development Plan" announced in 1987, "the formation of a multicentered nation through the promotion of interregional exchange" was proposed as the basic goal. In the "ECONOMIC MANAGEMENT WITHIN AGLOBAL CONTEXT" in 1988,"the realization of diverse life styles which enable people to feel true affluence, the correction of trade imbalance, and the contribution to the international community" were selected as themes.

4. Examination of "The Ports and Harbors for the 21st Century"

Amid such socioeconomic changes, continued examination and flexible implementation of measures are indispensable in order for "The Ports and Harbors for the 21st Century" to remain significant as a long-term policy.

At present, five years since it was first drawn up, measures proposed have already begun to take shape. The social and economic changes surrounding ports and harbors have taken place beyond previous expectation, and preparations are being made for new five-year plans which will start in 1991 now that the ongoing five-year plans for port and harbor development and coastal projects have entered their final year. Accordingly, measures proposed in "The Ports and Harbors for the 21st Century" were reexamined while referring to the present situations, making considerations for necessary additions and further emphasis.

5. Toward an Enriched Waterfront

As a result, it was decided that it was appropriate to maintain the basic points of "The Ports and Harbors for the 21st Century" as a long-term policy for port and harbor development. Considering the social and economic changes which have taken place since its compilation, however, additonal emphasis is necessary on the following points.

(Contents are shown on Fig.1.)

(1) Qualititative Enhancement of a Comprehensive Port and Harbor Space

Since the drawing up of "The ports and Harbors for the 21st Century," the importance of improving distribution, industrial, and people-oriented functions of ports and harbors, by implementing various measures intended for the creation of a comprehensive port and harbor space, has been recognised anew.

It was also recognized that the quality of port and harbor space as easy-to-use and beautiful space, besides having improved functions, was important in trying to respond to people's demand for higher quality with the background of social development.

Therefore, it was decided that future endeavors would focus on the improvement of both the functions and the quality of a port and harbor space, thus aiming for an easy-to-use, beautiful port.

(2) Contribution to Balanced National Development

Networking among ports and harbors has been actively promoted for balanced national development.

Meanwhile, passenger maritime transportation has been reevaluated with the backdrop of the growing popularity of cruisers sailing around the county and the world as well as the successive commencement of new operations of high-speed passenger vessels. The volume of import of finished goods has increased rapidly. At the same time, regional problems in urban and rural areas have been becoming serious. These are some of the changes which were not predicted in specific terms when "The Ports and Harbors for the 21st Centry " was drawn up.

Therefore, it is necessary to further promote the formation of physical distribution and information networks as well as to establish a passenger transport network.

As well, in order to solve regional problems, infrastructures should be improved to establish integrated local settlement in coastal areas. In rural areas, indigenous and new industries, including the resort industry, will be fostered to realize a life style having more choices. In urban areas, on the other hand, necessary space

will be appropriately prepared to respond to the housing demand,and infrastructures will be improved to solve traffic problems and to improve the living environment to deal with urban problems successfully.

(3) Measures to realize an enriched waterfront

To achieve such objectives smoothly, systems responding to the new demand for qualitative enhancement of ports and harbors will be established, and closer cooperation with other fields will be promoted. As well, multiple measures will be set up to meet a variety of requirements. Port management bodies and local municipalities where ports and harbors are located will be strengthened to respond to the emergence of diverse project implementation bodies. At the same time, funds will be prepared by expansion of financial sources. Furthermore, long-term perspective for technological development of ports and harbors and marine utilization will be drawn up, on which future technological development and marine utilization will be based.

Ⅱ. Major Topics

1. The Formation of an Easy-to-Use, Beautiful Port and Harbor Space

(1) The formation of an easy-to-use port and harbor space

An easy-to-use port and harbor space will have a fremework of definite structure covering the entire place which will make the port and harbor safe, easy-to-use, and friendly for its users, vessels sailing or moored, automobiles passing through, and even first-time visitors.

Such a framework will be formed by systematically arranged coastal roades, railway passenger transportation systems, navigational routes and canals, and green space and belts with an unobstructed view. Landmark structures, such as a tower with a commanding view of the port, will be established at major points of the framework.

In a port and harbor space thus created, consideration will be given to the correlation of functions. For example, functions whose attractiveness or performance can be enhanced by linking, such as the central business area and the comprehensive distribution terminal, and the marine recreation center and attractive indusrial space, will be located closely, and boundaries between such functions will be in complete harmony.

On the other hand, functions which may adversely affect each other if located adjacently will be separated as much as possible. Where it is not possible, appropriate buffer zones will be set up.

For advanced use of a port and harbor area , elevated decks and the use of underground space will be also considered.

In addition to the development of facilities, to make a port an interesting and pleasant place, it is vital to promote events and festivals related to such theme as the sea, ships, and ports, thereby promoting pleasant and lively images of the port. The organization of citizen-participatory and community-wide campaigns will be pursued to secure people's cooperation for such events as well as for seaside and beach clean-up.

(2) The formation of a beautiful port and harbor space

A beautiful and pleasant port and harbor space where people can enjoy the sea and port will be formed by taking advantage of resources unique to a port, such as dynamic views of ships and cranes, romantic, historical or exotic atmospheres, public access to water's edge, boating, and expansive sea view on waterside.

For this, the port space should not appear unfamiliar to people working at and visiting the port. For example, consideration will be given to the "human scale," and facilities with curved lines will be introduced, and greenery space will also be appropriately arranged. Special consideration will be also given to the location ,scale, and color of the buildings to achieve a scenery in harmony with the sea, the surrounding landscape, and the city area behind the port. Some structures may be lit up at night to produce an atmosphere unique to the port.
The purification of water and beaches will be promoted to allow people to enjoy the closeness to water, and an effective arrangement of a marine, beach and hill overlooking the port will be achieved.
The waterside area, where people can enjoy the closeness to water, will be expanded by estabrishing high-amenity break waters, floating structures, and piers beyond the shoreline into the sea, excavating waterways to the land area.
Moreover, characteristic natural environmental factors such as an island or cape and attractive port facilities such as brick warehouses and canals will be preserved and put to use to create attractive port and harbor scenery.

2. The formation of an advanced distribution space
The importation of finished goods is rapidly increasing in Japan because of the Japanese economy's shift toward a more domestic market-oriented structure due to the strong yen, the development of horizontal international specialization, and worsening labor shortage.
The importation by containers, in particular, is expected to expand almost twofold by the beginning of the 21st century,from 48 million tons as of 1988.In major navigational routes of North America and Europe, container vessels are becoming increasingly larger in size, and a vessel with a loading capacity of over 4,300 TEU is expected to appear in the near future. Meanwhile, more container vessels sailing navigational routes in East and Southeast Asia have recently been calling directly at regional ports in Japan.
As well, containers themselves are becoming larger in height and length.
At present, the development of a new super high-speed cargo vessel is under way, appropriate measures will be necessary depending on its outcome.
Following three themes are especially important for the formation of an advanced distribution space.
1) The development of foreign trade containner treminal
2) The development of the super high-speed cargo vessel terminal
3) The development of the comprehensive physical distribution terminal
4) The development of "port freeway" (high-standard dockroad)

3. The formation of a comfortable space for marine passenger transportation
Recently a sea voyage, which offers sea-viewing in a relaxed atmosphere and comfortable cabin stay, is attracting a lot of attention, leading to the growing popularity of cruising. The pleasure of cruising comes from the time spent aboard as well as that at the port where beautiful scenery, shopping at passenger terminals, and various events can be enjoyed.
Super high-speed vessels are now being introduced one after another for domestic routes connecting regions and islands and for short-distance international routes.
As well, since car ferries which were built in the mid-1960s are now in the substitution period, and increasing number of new ferries with higher speed and quality

of passenger service facilities are being put into operation.
Moreover, the operations of "seaborne buses" (marine passenger shuttle services) connecting cities, or major points in a city, is being planned as a measure to solve traffic congestion in urban areas. Marine passenger transportation is also expected to develop as a means for access to an airport on waterfront area.
To meet such growing demand for marine passenger transportation, passenger terminals will be developed which are enjoyable both to passengers and the general public. Such passenger terminals will be spacious, easy-to-use, and equipped with restaurants , a shopping mall, an observatory, and other such service and convenience facilities, with beautiful greenery and event squares arranged around them.
Furthermore, the development of such terminals will be carried out as part of an integrated system with land transportation terminals. Where necessary, coastal roads or a railway passenger transportation system will also be developed as access from the terminals to the center of the city.

4. The Infrastructure Development for Integrated local Settlement in Coastal Areas

(1) The infrastructure development for promotion of regional economy
As the gap between urban and provincial areas widens today, ports in provisional area are required to respond to various regional problems in an appropriate manner .
(Ports and Harbors in Nucleus Cities in Provincial Areas)
Ports and harbors located in nucleus cities in provincial areas are required to have the integration of advanced functions , and at the same time, to prepare a high-amenity environment. In connection with this, efficient distribution terminals, international information bases, and port related business areas will be developed as regional centers for internationalization and promotion as well as greeenery and recreational facilities commensurate with such nucleus cities in provincial areas.
(Other Ports in Provincial Areas)
In other ports in provincial areas, infrastructures necessary for promoting indigenous industries and new kinds of industry, such as the resort industry, will be developed, along with public areas and facilities for community events and recreational activities.
In regions having disadvantages in transportation conditions such as isolated islands, breakwaters to keep the port area calm and a necessary alternative port will be built or improved since such regions depend almost solely on ports for public transportation means, industrial infrastracture, and the supply of daily necessities. As mentioned above, transportation conditions will be improved.

(2) The infrastructure development to counter urban problems
In large urban areas, the demands for expansion of business functions and the development of new, information-oriented infrastructures are growing with the backdrop of internationalizing trends and the emergence of a sophisticated industrial structure. Port related and international business areas will be created to meet such demands.
Meanwhile, shortage of housing and recreationl facility caused by the rise of land prices, traffic congestion, and other such negative conditions unique to large urban areas are becoming serious social problems.
To solve such problems, it is necessary to devise some measures in promoting the for-

mation of an enriched waterfront space in an urban area.
To meet the housing demands appropriately in large cities, necessary space for housing will be prepared in underused or unused land in coastal areas while seeking coordination with land use in the surrounding areas, promoting sophisticated and well-planned land use, and developing greenery, roads, and other relevant infrastructures.
To cope with the problem of traffic congestion, the development of a marine passenger transportation system using "seaborne buses" (marine passenger shuttle services)" which have been drawing attention in recet years, and port-area transportation facilities intended to reduce traffic flow into city streets will be promoted. Moreover, ports will be developed outside the major bay areas to handle a substantial amount of cargo accumulated in the major bay areas, such as the Tokyo Bay area.
Greenery and recreational facilities will also be developed in coastal areas to create a favorable living environment.

Note. This paper is a part of "Toward an Enriched Waterfront". This is a tentative english translation of "Yutakana Waterfront wo mezashite" which is written in Japanese.

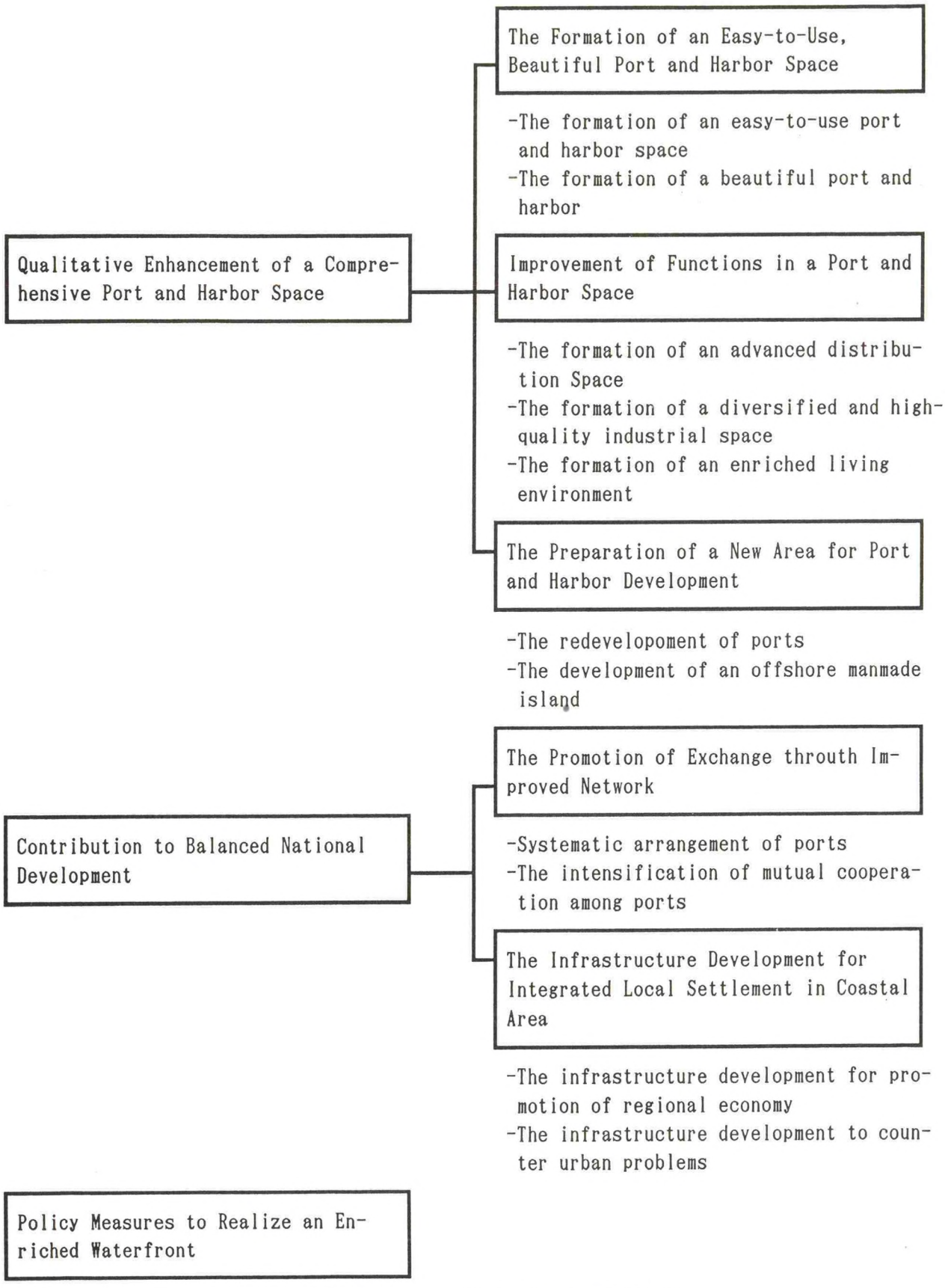

Fig.1 CONTENTS OF "AN ENRICHED WATERFRONT"

Ocean Measurement, Assessment and Environmental Protection

SUPERCRITICAL WATER OXIDATION OF WASTEWATERS

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Introduction

The long-term pollution prevention goals must be to minimize waste production and reduce risk. In the case of toxic wastewaters and sludges, the objective might be to achieve two further goals: (a) total destruction of toxic substances; and (b) perform this task in a totally enclosed system.

Magnitude of the Problem

Hazardous wastes in the USA continue to grow (Gloyna 1987). Industrial contributions amount to about 280 MMT. Chemicals and allied products account for 30% of this total. There are about 70,000 and 125,000, respectively, large and small hazardous waste generators.

The amount of industrial and municipal sludge production is about 36 million metric tons per year, equally divided between the two sources. By year 2000, the municipal contribution may double.

Regulations

Society has reacted to the hazardous waste problem by passing increasingly complex legislation and creating massive regulatory requirements. Figure 1 illustrates the rapid increase in major Federal Laws.

Wastewater Treatment and Disposal Options

Wastewaters require some form of treatment. The alternatives for treatment and disposal of residual wastewaters are shown in Table 1.

Supercritical Fluids

Much has been written about supercritical fluids (SCF), supercritical extraction, and supercritical water oxidation (SWO). Special SCFs are too attenuated to be true liquids and too dense to be true gases. SCFs occur when both temperatures and pressures within the fluid exceed the critical point (Tc and Pc). Under these conditions the density, dielectric constant, hydrogen bonding, and some other physical properties are altered such that the water behaves as a moderately polar organic liquid under ambient conditions. For example, benzene under supercritical water conditions becomes miscible in all proportions, and similarly, some types of wood completely dissolve. However, under the same conditions the solubility of NaCl and CaCl, respectively, might be as low as 100 mg/L and 10 mg/L. The changes in the characteristics of water as it is subjected to supercritical conditions are shown in Fig. 2.

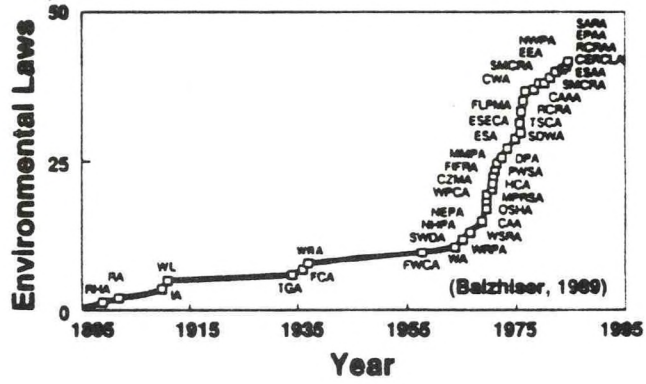


Figure 1. Growth of U.S. Environmental Laws

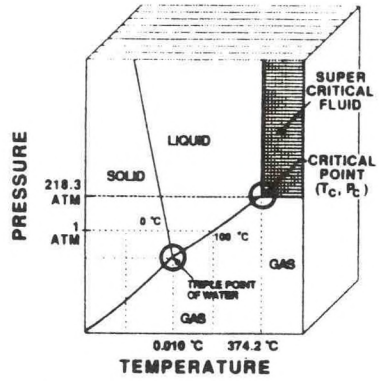


Figure 2. Phases of Water at Moderate Pressures (Josephson 1982)

At elevated temperature and pressure, a fluid has much greater ability to act as a solvent because the internal energy of the SCF is sufficient to overcome the internal bonding of the fluid molecules (hydrogen bonding disappears in the case of water). The great solvent properties of SCF at low density provides high diffusivity and rapid mass transfer (Johnston, 1982).

Table 1. Alternatives for Treatment and Disposal of Wastewaters

Technology	Acceptability/Potential Problems
1. Dilution	Not a substitute for treatment
2. Biol./Phys./Chem	Economical and efficient for removal of dilute organic wastes
3. Deep-Well Injection	Technically feasible, costly, but increasingly unacceptable
4. Solar Evaporation	Technically feasible, but alledged air pollution and groundwater problems.
5. Land Disposal	Potential groundwater pollution and crop contamination
6. Oxidation-Regener.	For waste concentrations below 1%, relatively expensive
7. Incineration	For concentrated organic wastes (>20%); temperatures of 900°C to 1,100°C and residence time of 2 sec.
8. Ozonation	Limited by rate of mass transfer and produces refractory residual low-molecular weight compounds
9. Wet Air Oxidation	Off gases and effluent may require additional treatment
10. Subcritical, (WAO)	Applicable for biological sludges and organic liquid wastes
11. Supercritical Water	Potentially totally enclosed and system applicable to wide range of organic compounds and waste characteristics

Supercritical Water Oxidation

The SCWO process embraces the oxidation of organics, in the presence of high concentrations of water under temperatures and pressures above the critical point (C.P.) values of water, 374°C (705.5°F) and 22,120 KN/M^2 (3206 psia or 218 atm). The C.P. lies on the vapor-liquid saturation dome, 374°C and density of 0.1 to 0.5 g/cm^3, a dielectric constant of 3 to 10, and nearly 100% solubility of organics. The surface tension of water under these conditions becomes zero. The thermal energy contained in the water molecules reduces hydrogen bonding, and therefore SCW becomes an excellent solvent for non-polar organic substances.

The conversion of organic materials in a waste to CO_2, H_2O, and acids or oxyacids of heteroatoms and metals under SCWO conditions is a function of the reaction temperature and residence time. The products of organic nitrogen and ammonia, below 650°C, are primarily N_2 and N_2O. The latter decomposes to N_2 and O_2. SCWO at about 400°C (750°F) does not destroy ammonia. Heteroatoms (chlorine, sulfur, and phosphorus) are oxidized to the respective acid forms or corresponding salts if sufficient cations are present.

The SCWO process provides a very strong oxidizing environment. It is expected that 80% of the metals in a waste stream are likely to be incorporated in the ash. Calcium sulfate is expected to form. Calcium passing the reactor may be divided equally between ash and liquid. Sulfates may be split between ash and liquid. In supercritical water (SCW) conditions (374°C to 450°C) salts may remain dissolved or condense as a concentrated brine solution or as a solid particulate (>450°C). The heavy metals may form carbonates or oxides and depending on their volatility may precipitate. The organics are converted to CO_2 and H_2O during the oxidation stage. Char will most likely oxidize slowly.

Physicochemical Properties of SCWO

One of the key characteristcs illustrating the structure of water in the supercritical region is the static dielectric constant. This constant is a measure of the extent of hydrogen bonding and polarity of water. The static dielectric constant of water under normal conditions is about 80

(Uematsu, et al., 1980). The unusually high dielectric constant value is due to the strong hydrogen bonding between water molecules. In the critical region, as the density of water decreases, the extent of hydrogen bonding decreases since hydrogen bonding is a short range force.

Another important solvation characteristic of supercritical water is that many gases that are only sparingly soluble in normal liquid water are completely miscible with supercritical water. Phase behaviors of H_2O-O_2 and H_2O-Air (Japas, et al., 1985a) and H_2O-N_2 (Japas, et al., 1985b) systems at supercritical conditions show that both gases are completely miscible with supercritical water. Carbon dioxide and argon are also completely miscible with supercritical water.

Supercritical water is a very poor solvent for inorganic salts. The solubilities of salts gradually increase over the temperature range of 200 °C to 450 °C with a few exceptions (potassium sulfate, sodium sulfate, sodium phosphate, sodium carbonate, and lithium sulfate) (Marshall, 1975). At temperatures above 450 °C and densities less than 0.3 g/cm^3, however, supercritical water exhibits dielectric constant values less than 2. The low density substantially reduces the solubilities of inorganic salts in supercritical water.

Experimental Apparatus

The SCWO facility, located at the Balcones Research Center at The University of Texas at Austin, contains a number of reactor systems. These are used to conduct basic kinetic studies, materials performance, heat transfer, corrosion, erosion, encrustation material balances, liquid-solid separations, mixing, and treatability tests. The equipment list includes the following units:

a. Mark I Batch Reactor System (liquid or sludges)
b. Mark II Batch Reactor System (liquid or sludges)
c. Mini-Tubular, Plug-Flow Reactor System
d. Vertical, Concentric-Tube Reactor System (hydrogen peroxide and liquid)
e. Vertical Concentric Tube Reactor System (H_2O_2 or O_2, liquid or sludges)
f. Pilot-Scale Reactor System (Complete SCWO Reactor Facility)

The Mark I reactor system, Figure 3, consists of a frame in which the various components are housed. The frame occupies a space roughly 9.2 m x 1.2 m x 1.5 m. Major components include a reactor vessel assembly, a fluidized sand bath, a water bath, a wrist action shaker, and a reactor vessel assembly transfer system. The fluidized sand bath (Techne, Model SBL-2, 2.9 kW) is capable of rapidly increasing the reactor temperature. The wrist action shaker enhances mixing and heat transfer.

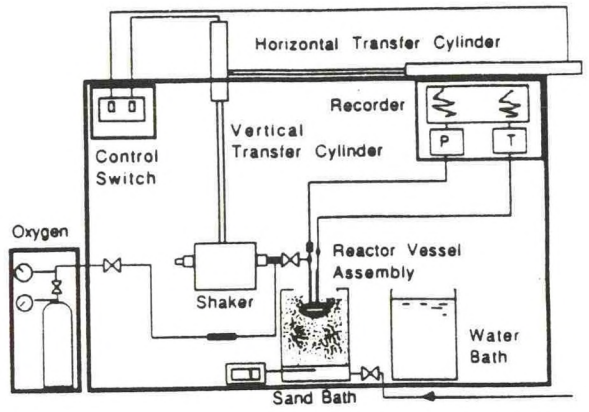


Figure 3. Batch Reactor System (Mark I)

A typical reactor vessel assembly consists of a coiled tube reactor vessel, a high-pressure tee (Swagelok), a type-J thermocouple (sheathed with inconel 600) with adapter, a pressure transducer (Viatran Model 345BH3DHA20), and an oxygen connector. The coiled tube reactor vessel is made from Stainless Steel 316, 0.36 cm I.D. (0.64 cm O.D.) tubing, and accommodates relatively large volumes of sample (25 mL). Either pure oxygen gas or hydrogen peroxide may be used. Temperatures up to 550 °C and pressures up to 410 atm may be imposed.

A second generation microreactor system, Figure 4, is capable of simulating temperature-depth profiles of a deep-well, subcritical and SCWO operation. The reactor is made of SS 316 tube, the outside diameter (O.D.) of the tube is 9.5 mm, the inside diameter (I.D.) is 6.5 mm and the length is 1.22 m. The volume of this tubular reactor was 40 mL. The reactor accommodates either manual or computerized control.

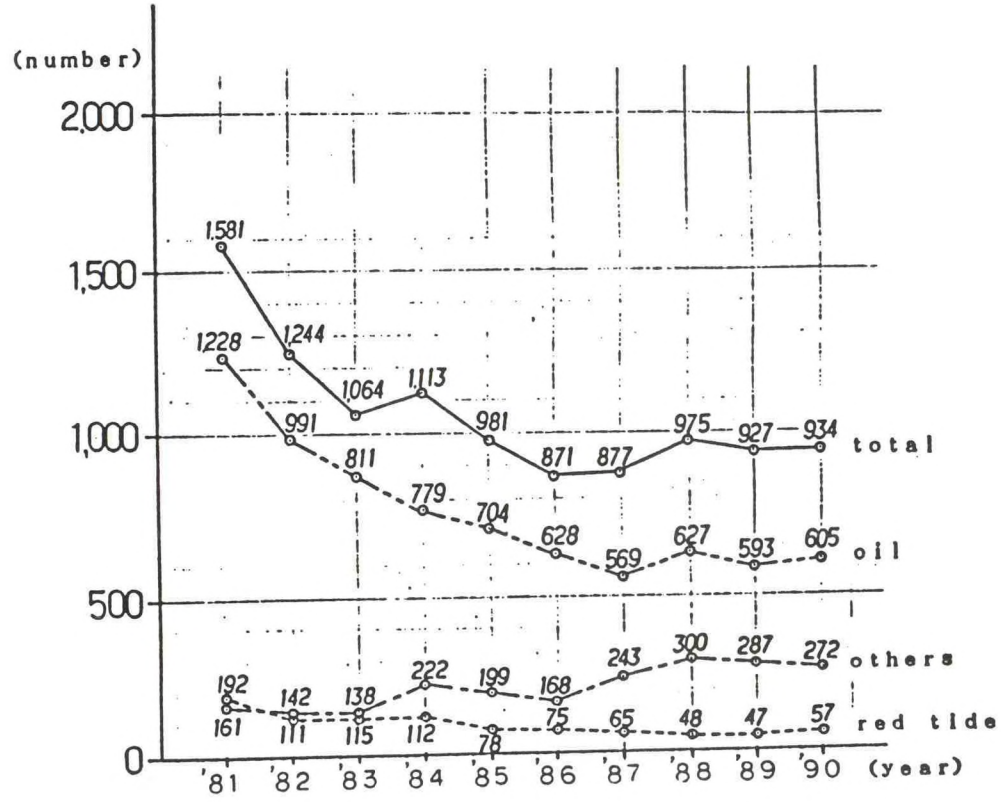
A miniature, tubular, plug-flow reactor system is used to evaluate oxidation kinetics. This continuous-flow reactor system achieves reasonable turbulent plug-flow and isothermal conditions.

speed of 2 kt and using cyclone type oil skimmers which are designed to fulfill their function under the rough sea conditions. A helicopter guided Seiryu Maru to find the place where water-in-oil emulsion floated over the sea. As spilled oil concentrated here and there, helicopter services provided by 8th R.M.S.H. was quite effective for Seiryu Maru's work.

On 14th no oil was found on the sea and the next day in the evening, the 8th R.M.S.H. notified Seiryu Maru that the vessel was relieved from the task. Seiryu Maru left Maizuru Port for Nagoya Port on 16th. On the way the vessel unloaded oily water of 910 ton at the waste oil disposal facility in Sennen Port in Hiroshima Prefecture, reserved by Marine Accident Prevention Center under the supervision of Maritime Safety Agency. On 19th Seiryu Maru returned to Nagoya Port and benthed for the tank cleaning. The Seiryu Maru's work costed 70 million yen, including personnel expenses, fuel expenses, expenses for cleaning the hull etc., and excluding the waste oil disposal charges.

diag.1

Confirmed number of occurrence of marine pollution issued by The Maritime Safety Agency.

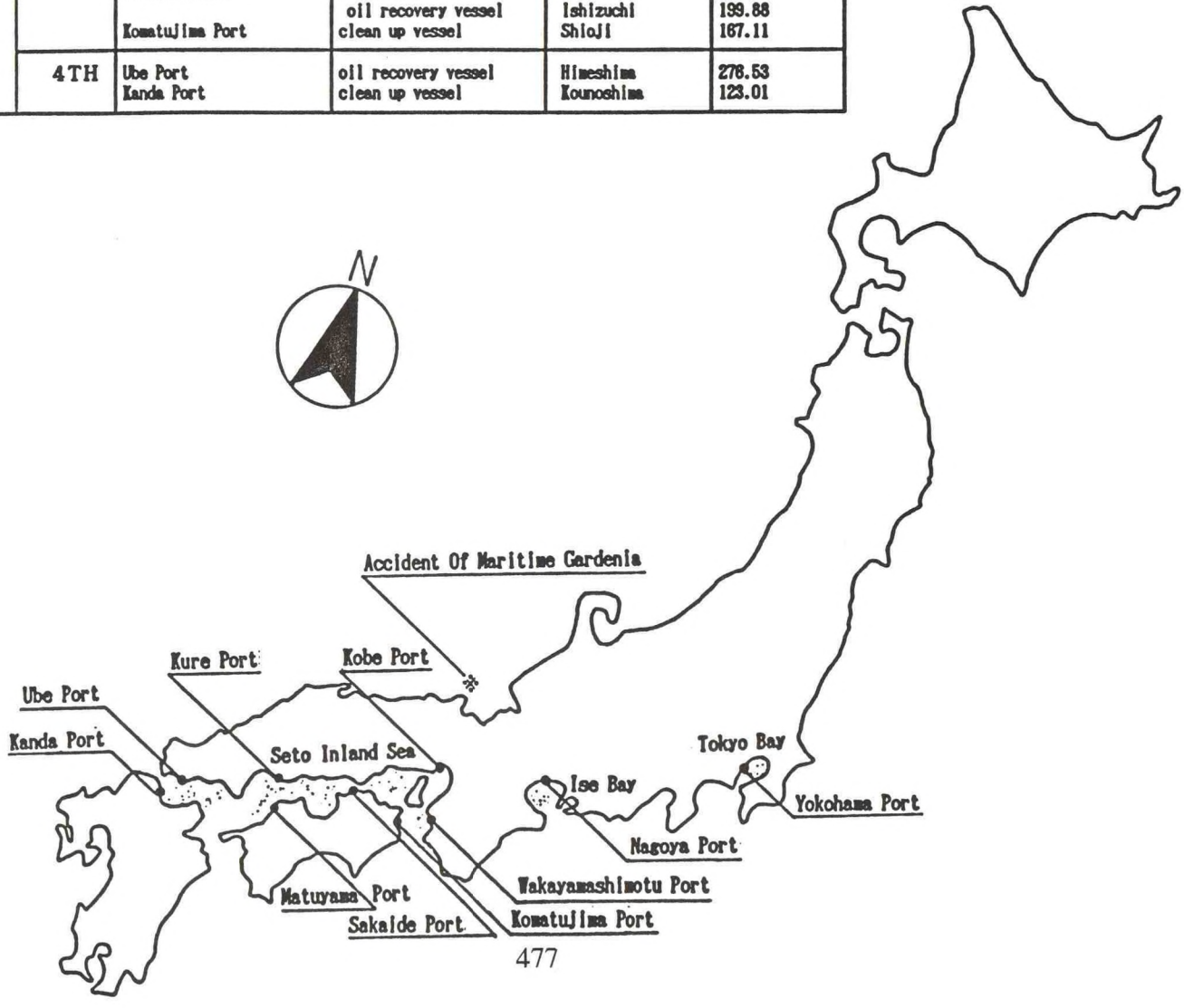


(Note)
Others are pollution caused by any pollutants other than oil and red tide.

diag.2

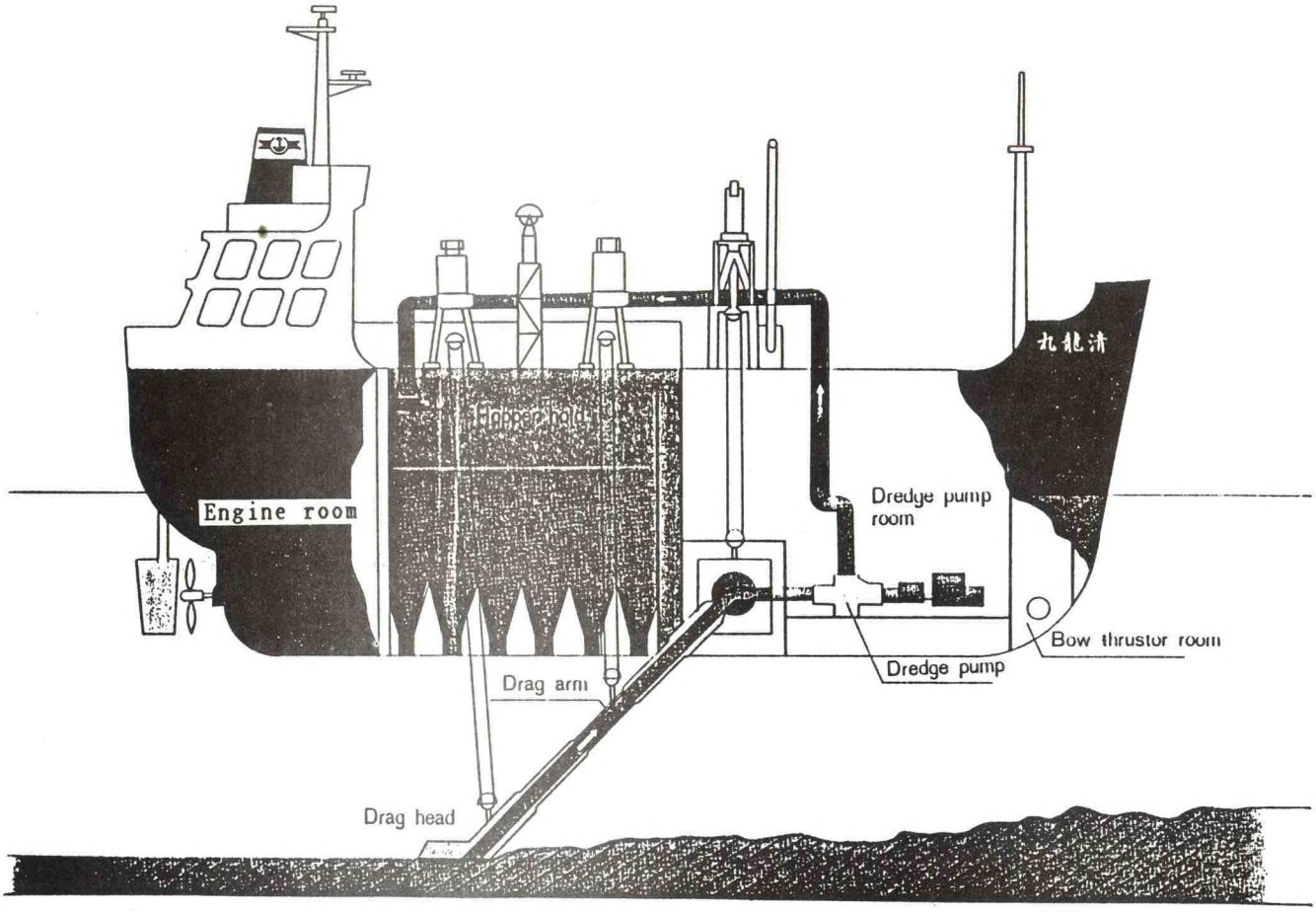
Environmental protection vessels belonging to the District Port Construction Bureaw.

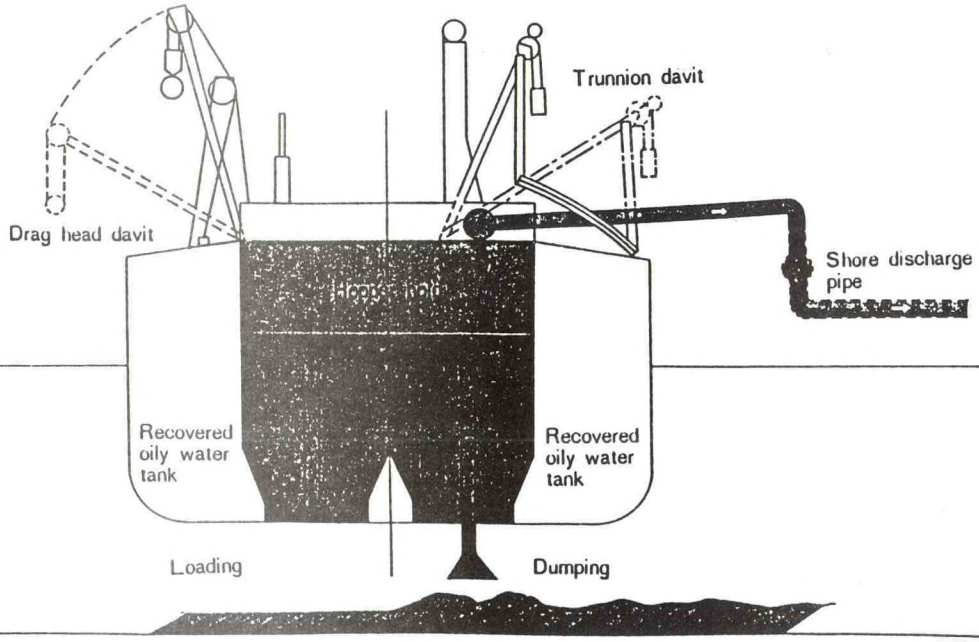
Area / District Port Construction Bureau		Base Port	Grouping	Vessxel's name	G.T
Tokyo Bay	2ND	Yokohama Port	clean up vessel	Seikai	167.95
				The second Seikai	203.32
			oil recovery vessel	Soukai	328.03
				The second Seikai	378(new law)
Ise Bay	5TH	Nagoya Port	clean up vessel	Hakuryu	198.17
			dredging / oil recovery vessel	Seiryumaru	3,528.17
Seto Inland Sea	3RD	Kobe Port	clean up vessel	Ikoma	162.94
			clean up / oil recovery vessel	Harima	199.37
			oil recovery vessel	Sumamaru	127(new law)
		Wakayamashimotu Port	clean up / oil recovery vessel	Kitanmaru	428.29
		Kure Port	clean up vessel	Ondo	168.11
		Sakaide Port	clean up / oil recovery vessel	Wasyu	194.77
		Matuyama Port	clean up / oil recovery vessel	Ishizuchi	199.88
		Komatujima Port	clean up vessel	Shioji	167.11
	4TH	Ube Port	oil recovery vessel	Himeshima	278.53
		Kanda Port	clean up vessel	Kounoshima	123.01



diag. 3

Dredging function of Seiryu Maru





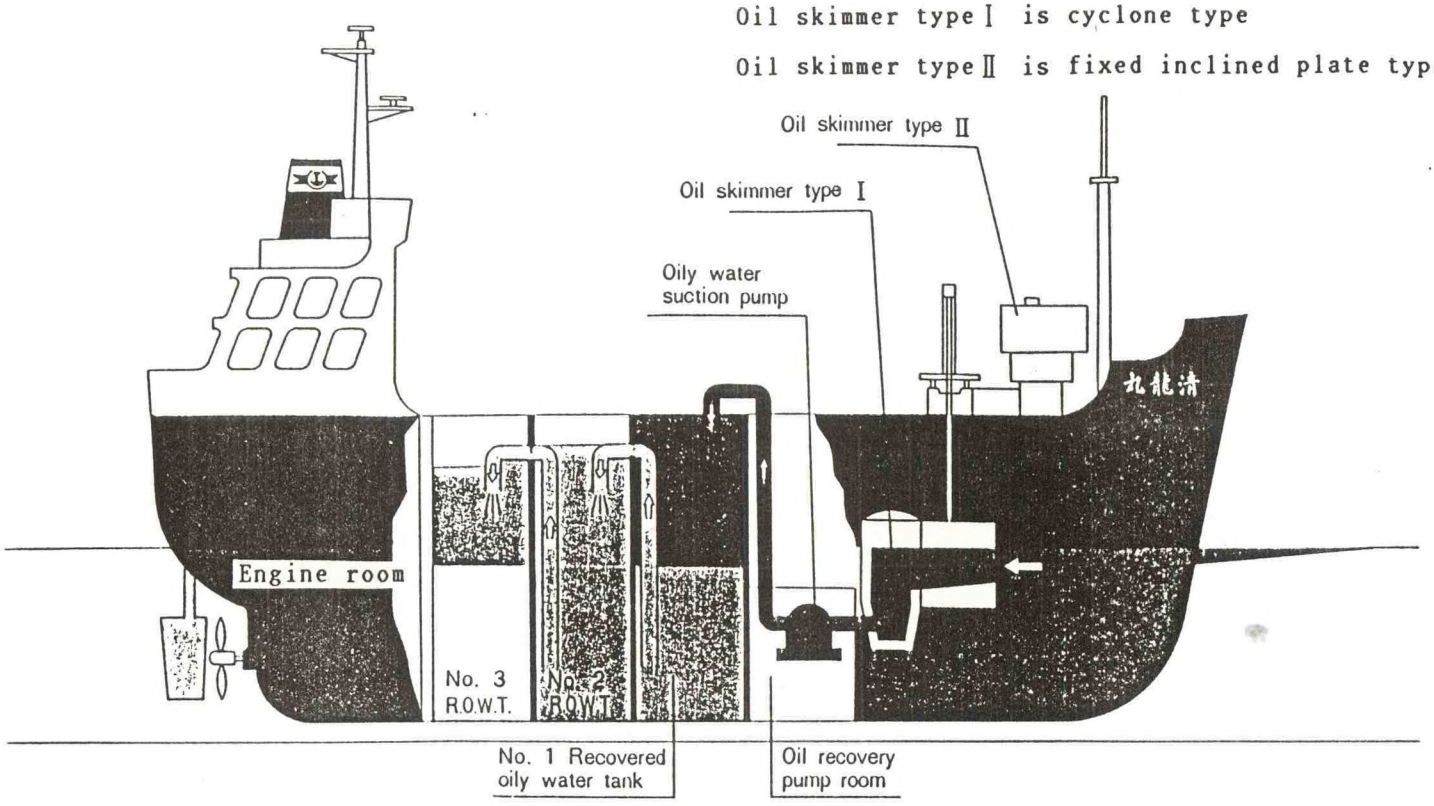
diag. 4

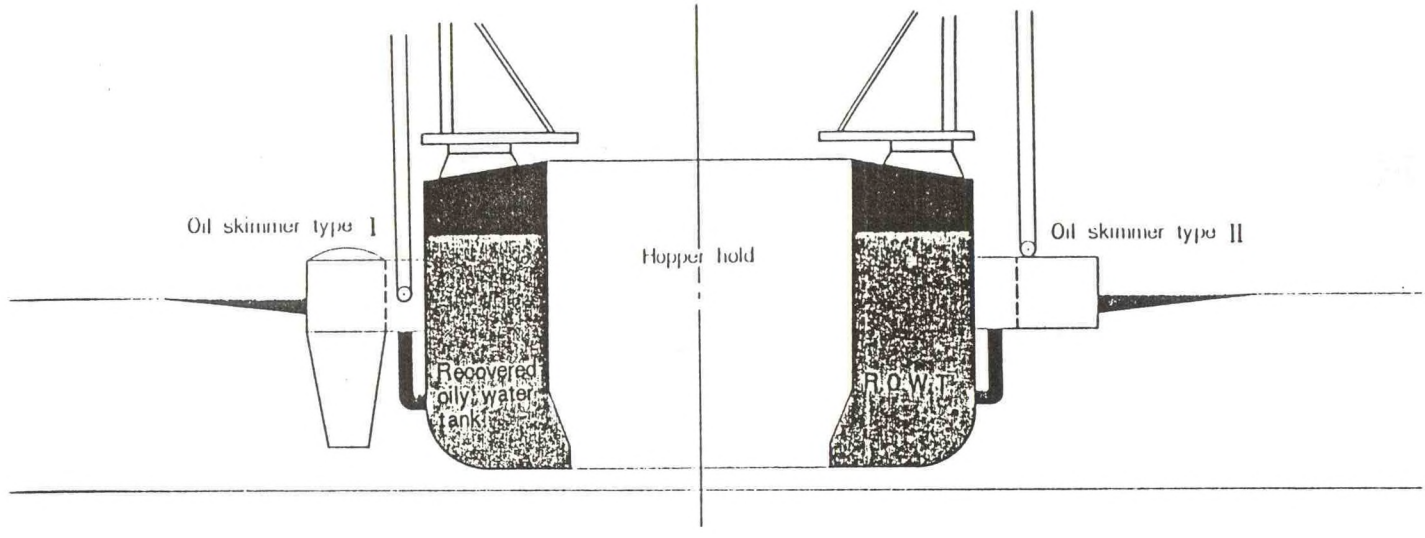
Oil recovery function of Seiryu Maru

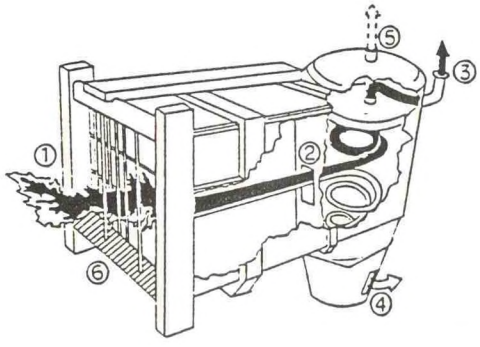
(Note)

Oil skimmer type Ⅰ is cyclone type

Oil skimmer type Ⅱ is fixed inclined plate type

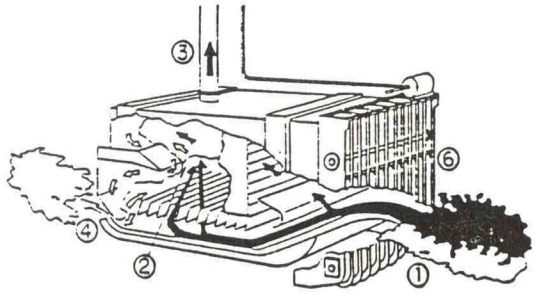






Oil skimmer type Ⅰ

1. Oily water inlet
2. Oily water suction mouth
3. Oil suction pipe
4. Water outlet
5. Air suction pipe
6. Floating waste defense slit



Oil Skimmer type Ⅱ

TANKER DESIGN FOR PREVENTION AND MITIGATION OF OIL SPILLS

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1. Introduction

After coming into effect of MARPOL 73/78 which requires Segregated Ballast Tanks, Crude Oil Washing etc. mandatory to oil tankers, the marine pollution caused by oil has been decreasing. However, by the recent serious disaster caused by grounding of a VLCC, it was recognized that an oil spill accident by a big tanker caused serious disaster to the marine environment, and that further measures are needed to reduce the pollution.

International Maritime Organization was asked to put forward proposals for further action for prevention of oil pollutions of the oceans in the Economic declaration of the Arch Summit held in July 1989. The Assembly of the Organization, in its sixteenth session held in October of that year, adopted Resolution A.675(16).

To meet with this, double hull structure, vacuum system, and double sided structure with mid-height deck have been studied.

Quantitative consideration only on groundings was studied, as the advantages and disadvantages of each method in the case of collisions are fairly easy to understand.

2. Double Hull Structure

Studies have been made on the effectiveness of the double hull structure for preventing oil spills, safety features and the economy. The results of the studies can be summarized as below:

1) Assessments were made on the cases of grounding accidents of ships in the last decade recorded in the decisions of the Marine Accidents Inquiry Agency. The results of the assessment show:

a) For 86% of considerably serious grounding accidents, damage to cargo can be prevented by the provision of a double bottom structure.

b) Even in the case of a high energy grounding, there is no particular sign suggesting the ineffectiveness of the double bottom structure.

c) Although there is a tendency for bottom damage to occur often in the fore part of ship, the damage is scattered throughout the length of ship.

Furthermore, the overwhelming majority of grounding accidents are collision-type, which are often associated with a massive oil spill accident.

2) The crack length and amount of oil spill in the case of a collision-type grounding were obtained by an

←analytical approximation with seven type ships of a trial design using the height of damage as a parameter (Fig.1). The lengths of cracks generated in the bottom shell plating of a ship are longer in the double bottom structure than in the single bottom structure when the height of the damage is less than the height of the inner bottom plating, whereas it is greater in the single bottom structure when the height of damage is larger than that of the inner bottom plating of the double bottom structure. When the height of damage is smaller than the height of the inner bottom plating, no oil is spilled in the double bottom structure, but a relatively large amount of oil is spilled in the single bottom structure. When the height of damage is greater than the height of the inner bottom plating, the number of damaged tanks decreases in a relative sense with a consequent decrease in the amount of oil spilled in the single bottom structure, but in the case of the double bottom structure, it is even less than that. It must be noted, however, in the case of the single-row tank arrangement in the double bottom structure, that the difference between them is not so great.

3) If the double hull structure is to be employed, effective measures to counter difficulties associated with inspection and maintenance, risk of explosion following an oil spill, added difficulty of the refloating operation due to loss of buoyancy etc. are necessary to be considered. However, these problems have been experienced in dealing with conventional O/B/O carriers, and therefore are considered to be technically possible to solve.

4) Compared with a single hull tanker, 20 percent rise in ship price of a double hull tanker is expected. This will push up the operating cost by 12 to 15 percent.

3. Vacuum System

When a rupture occurs in the bottom of an airtight tank, negative pressure is created in the ullage space of the tank as the liquid level goes down due to the oil spillage through the rupture. This negative pressure prevents further oil spills. The vacuum system utilizes this vacuuming effect to prevent massive oil spills.

To enhance the effect of the vacuum system, system settings such as the following are necessary:

a) isolating each tank before or immediately upon ruptures,

b) changing the set pressure of the vacuum valve of each tank to the lower pressure level.

We have studied the effectiveness, safety, and problems of the vacuum system proposed for the minimization of oil spill from a grounded tanker.

The following is a summary obtained.

1) The vacuum system was studied with respect to both hardware and software aspects, and the feasibility study of the following three systems were carried out.

a) A system in which the vacuum system is set ready for operation prior to entry into dangerous waters.

b) A system in which the vacuum system is automatically put into action only in case

of a grounding accident.

c) A system in which the vacuum system is set ready all the time when the tanker is at sea.

2) The effect of the vacuum system on the reduction of oil spill was computed based on the hydrostatic pressure balance between oil in tank and the external seawater, and the following was found:

a) The vacuum system is effective for small to medium tankers where the level difference between the cargo oil in the tank and the surface at sea water is small.

b) In the case of fully loaded tanks oil spill from a damaged tank of 80,000 DWT tanker, 150,000 DWT tanker and VLCC can be reduced to 0.6%, 1.0% and 1.4% of the quantity of oil stowed in the tank if the tank pressure is set to a negative value of about 0.25 kg/cm^2, 0.35 kg/cm^2 and 0.45 kg/cm^2 in gauge pressure. This degree of oil spill corresponds to 6% to 9% of the oil spill from the conventional tankers without the vacuum system. In the case of a half-loaded tanker, however, the spill reduction effect of the vacuum system is extremely deteriorated(Fig.2).

3) Oil spill experiments including a case where the rupture in the hull bottom is not parallel to the water surface have verified the justifiability of the computation methods as per 2) above, etc. Tidal currents and waves have been found to have little effect on the oil spill, though further study is required for details.

4) The tank inner pressure vs. hull strength relationship has been studied by computational model,when the vacuum system is applied to large vessels of the conventional design.

In emergency condition where the hull receives a half of the deck load due to the waves and the negative pressure as per 2)-b) above, it is found that the maximum stresses of 80,000 DWT tanker, 150,000 DWT tanker and VLCC are smaller than the allowable values.

The deflections of the deck and bulkhead are found to be as small as the thicknesses of the plates used, and will not affect the pipelines and other installations.

5) The safety of the vacuum system-equipped vessels against fire and explosion is expected to be on a level with the conventional vessels. It should be noted, however, that explosion hazards due to static electricity of fluid handling machines, tanks and pipelines, etc. associated with post-grounding tank pressure preservation and oil transferring operations need further study.

6) The findings 2),3) and 4) have proved that the vacuum system can be used successfully for the vessels, and that it has a substantial effect on the reduction of marine pollution due to oil spill.

In addition to 5), load conditions at the time of grounding accident, preservation of tank airtightness, and accuracy and reliability of pressure control valves need further study.

7) Economics of the vacuum system, technique for operations at the time of system setting-up, and emergency oil transfer system need further study, also.

We have investigated the proposed vacuum system as to its conceptual design, effectiveness, safety, and reli-

ability as a means of preventing and controlling marine pollution due to oil spill from tankers.
The vacuum system is considered more viable from the economic viewpoint than the double-hull structure and double-sided structure with mid-height deck, though the following problems have been identified for further study.
We should be aware of the possibilities that the existing tankers of the conventional design may be retrofitted with the vacuum system successfully.

The vacuum system is effective for reduction of oil spill against groundings, but it is impossible to perfectly prevent from oil spill except those of small tankers when even small penetration occurred through the bottom hull. And the protection of the vacuum system-equipped vessel against collision remains no better than the conventional tankers.

Problems associated with the hull strength of overage vessel, and maintenance required for the purpose of maintaining a negative pressure in such vessels.

4. Double sided Tanker with Mid-height Deck

As mentioned in Section 2, the double hulls tanker needs some measures to prevent oil spill in a high energy grounding and explosion risk due to oil leakage into the double bottom space. The double sided tanker with a mid-height deck (named mid-deck tanker hereinafter) has been developed to solve these problems.
The principle of preventing oil spill is illustrated in Fig.3. If the cargo oil pressure is less than the sea water pressure on ship's bottom, no oil outflow occurs at a grounding.
The basic concept of the mid-deck tanker is based on this principle.
The mid-deck tanker features the following basic structures.
(i) Cargo oil tank spaces are provided with the double sided hull on both ship's sides.
(ii) Cargo oil tank spaces are divided into the upper and lower tanks by the oil-tight mid-height deck to keep the cargo oil pressure less than the sea water pressure on ship's bottom.
(iii) The position of the mid-height deck is decided to be lower than the maximum allowable height "Ho" from the ship's bottom, at which the pressure of the cargo oil loaded in the lower tank up to the mid-height deck becomes equal to the sea water pressure acting on the ship's bottom at the minimum draught of the ship when the cargo oil with the maximum specific gravity predicted is loaded.
The spaces in the double sided hull are used for segregated ballast tanks or void spaces.
The mid-deck tanker offers the following oil spill preventing functions at a collision or grounding:
(i) Compared with the double hulls tanker, the breadth of the double sided hull could be approximately double. Therefore, the probability that the side damage at a collision reaches to the cargo oil tank will decrease and the cargo oil tanks are better protected.
(ii) Even if lower cargo oil tanks sustain bottom damage at a grounding, the cargo oil in the damaged tanks does not

spill out due to the sea water pressure acting on the ship's bottom.
If the cargo loading rate in the lower cargo oil tanks is 98% full or less, as in ordinary oil tanker, sea water enters the damaged cargo oil tanks, because the sea water pressure exceeds the cargo oil pressure at the ship's bottom. Due to the greater specific gravity of sea water than cargo oil, the sea water that has entered the cargo oil tanks forms a layer on the tank bottom, and the sea water layer acts effectively to prevent oil spill.
The effectiveness of a mid-deck tanker against an oil spill at a grounding has been confirmed by model tests.

A mid-deck tanker has a double sided hull structure over the entire length of the cargo tank space, which is divided into the upper and lower cargo oil tanks by a mid-height deck. The effectiveness, safety and economic features of the mid-deck tanker are summarized below:
(1) Oil spill prevention effects at collision
With the provision of about double breadth of the double sided structure compared with the case of the double hulls tanker, the probability of the stem of another ship penetrating the inner hull in a collision decreases to a considerable extent, giving increased protection to the cargo oil tanks.
(2) Oil spill prevention effects at grounding
By controlling the loading level in the lower cargo oil tank to 98% or less, sea water enters the damaged cargo oil tank and forms a layer of sea water on the tank bottom. As a result, an oil spill can be prevented irrespective of the ship's speed at the time of grounding and the depth of damage.
(3) Effects of waves, currents and tidal levels on oil spill
If the sea water layer formed on the bottom of the damaged lower cargo oil tank is thin, there may be some possibility of an oil spill from the cargo oil tank by the ship's motion at the rough sea, the extreme current velocity and ship's inclination and/or the ebbing tide in case of ship's staying on the sealed or the rock. In order to prevent this, an emergency cargo oil transfer system will be effective, which is capable of shifting the cargo oil from the damaged lower cargo oil tank to an empty tank by an emergency transfer piping installed below the mid-height deck.
(4) Safety features
With the provision of about double breadth of the double sided structure compared with the case of the double hulls tanker, narrow spaces can be avoided, thus enhancing ease of inspection and maintenance. Furthermore, in the absence of a double bottom, the mid-deck tanker is free from difficulties in inspection, risk of explosion due to oil leakage in the double bottom, and difficulties in refloating due to loss of buoyancy in grounding accidents.
Gas freeing can be carried out using the access trunks and tank cleaning holes, but thorough studies may be required for gas freeing work of the lower cargo oil tanks
(5) Construction cost
The preliminary study on the VLCC shows that the construction cost of a mid-deck tanker is at the same level or

slightly lower than that of a double hulls tanker

(6) Operating cost

In a mid-deck tanker, the increased number of cargo oil tank will increase the cargo handling work and the maintenance work for the tank fittings.

On the other hand, the inspection and maintenance work for WBT coating can be reduced compared with the case of the double hulls tanker due to the smaller coating area.

5. Conclusion

This report covered the effectiveness of prevention of oil spill and of safety with three systems, the double hull structure, the underpressure system and the double sided structure with mid-height deck, where grounding incidents are concerned. The advantages and disadvantages of each method were evaluated.

5.1 Double hull structure

1) This system is effective for groundings, especially with low kinetic energy. Most of the grounding casualties which have occurred around Japan could have avoided oil spills by using this method.

Even in groundings with high keinetic energy which would damage the inner bottom, the amount of oil spill is smaller compared with single hull tankers.

2) One of the advantages is that there would be no possibility of accidental oil spill since no operation of valves or pumps is needed in order to prevent oil spill.

3) No oil spillage may happen in collision with low kinetic energy without damage to the inner hull.

4) The structure has the following disadvantages.

Oil spill should happen in grounding with high kinetic energy.

The building and operational cost will increase compared with the conventional tanker.

5) Although the following are to be considered, it is believed that both of them can be solved.

The inspection and maintenance of the double sided and double bottom spaces are difficult to perform.

Consideration is needed to prevent oil leakage from the oil tanks into the spaces between the hulls.

5.2 Vacuum System

1) The system becomes more effective as the vessels become smaller, the amount of oil spill from the damaged tanks is as much as 6 to 9 %, compared with conventional tankers in fully loaded condition even for large vessels.

It should be noted that the capability of mitigating the oil spill reduced drastically in half load condition.

2) From the calculation of hull structure point of view, conventional tanker can withstand the operational pressure of the system.

3) The vessels are as safe as conventional ones from fire and explosion points of view.

4) As a rough estimate, the operational cost seems to be lower than the other proposed systems.

5) The disadvantages of the system are as follows;

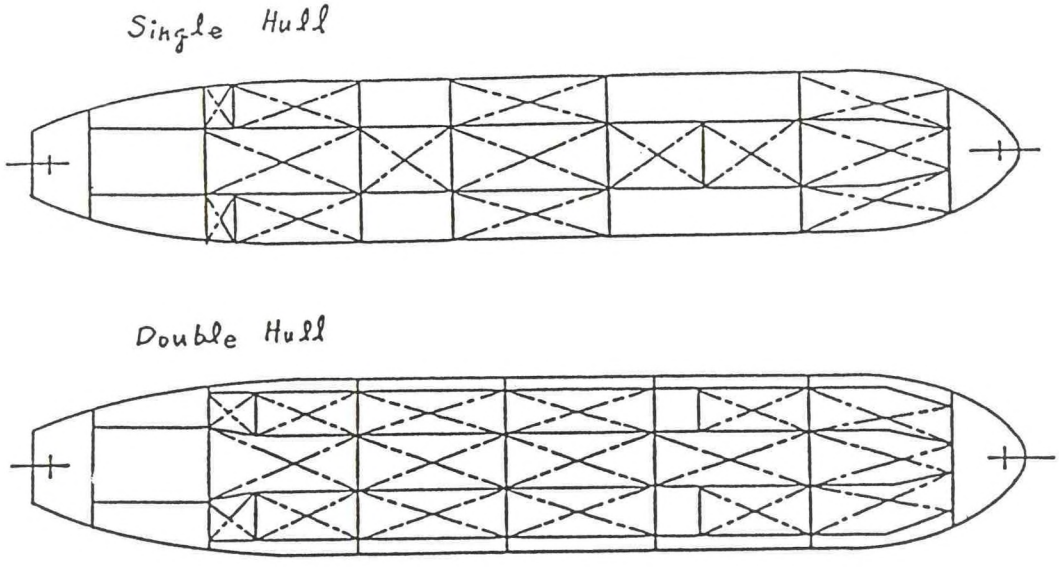
The oil spill cannot be prevented completely; and

the vessels have same protection characteristics as conventional ones in the case of

collision.
6) The Following should be solved in employing the system;
a) the loading condition in design calculation
b) the accuracy and reliability of the pressure adjusting valve
c) maintenance to make the older vessels able to keep on air tight condition in operation.
d) the change of pressure in the damaged tanks, and maintenance of the inerted condition to prevent the risk of explosion by static electric during the emergency transfer of cargo oil.
e) prevention of mistakes by (seafarers) in operating the system.

5.3 Double sided structure with mid-height deck
1) Oil spill can be prevented with the system, even if groundings occur with deep penetration according to mathematical simulations.
2) Since the breadth between the inner and outer hull becomes twice that of the double hull, oil spill can be avoided in the case of collision with high kinetic energy.
3) Double sided spaces are inspected and maintained without difficulty.
4) No concern for the difficulty of inspection of the double bottom space is needed. There is no risk of the explosion caused by leakage into the space.
As there is no reduction of double bottom space buoyancy in the case of groundings, there is little difficulty in ungroundings.
5) The disadvantage of the system is that the building cost will increase.
6) The following items are to be studied, but it is believed that they can be solved.
1) establish an emergency transfer system from damaged cargo tanks to other tanks in the accident.
2) make gas free easily in the lower part of cargo tanks, or clean the tanks safely and easily.

5.4 Common problems
One common problem is the amount of oil spilled from the cargo tanks by currents and waves, when the damaged vessel keeps a rather stable condition and there is little change of the tide.
In any method, establishing an emergency transfer system from damaged cargo tanks to other tanks is necessary for prevention and mitigation of oil spills, when the vessel changes its trim and/or heel because of movement of the hull, of currents, of grounding on huge rocks, or of the change of the tide.



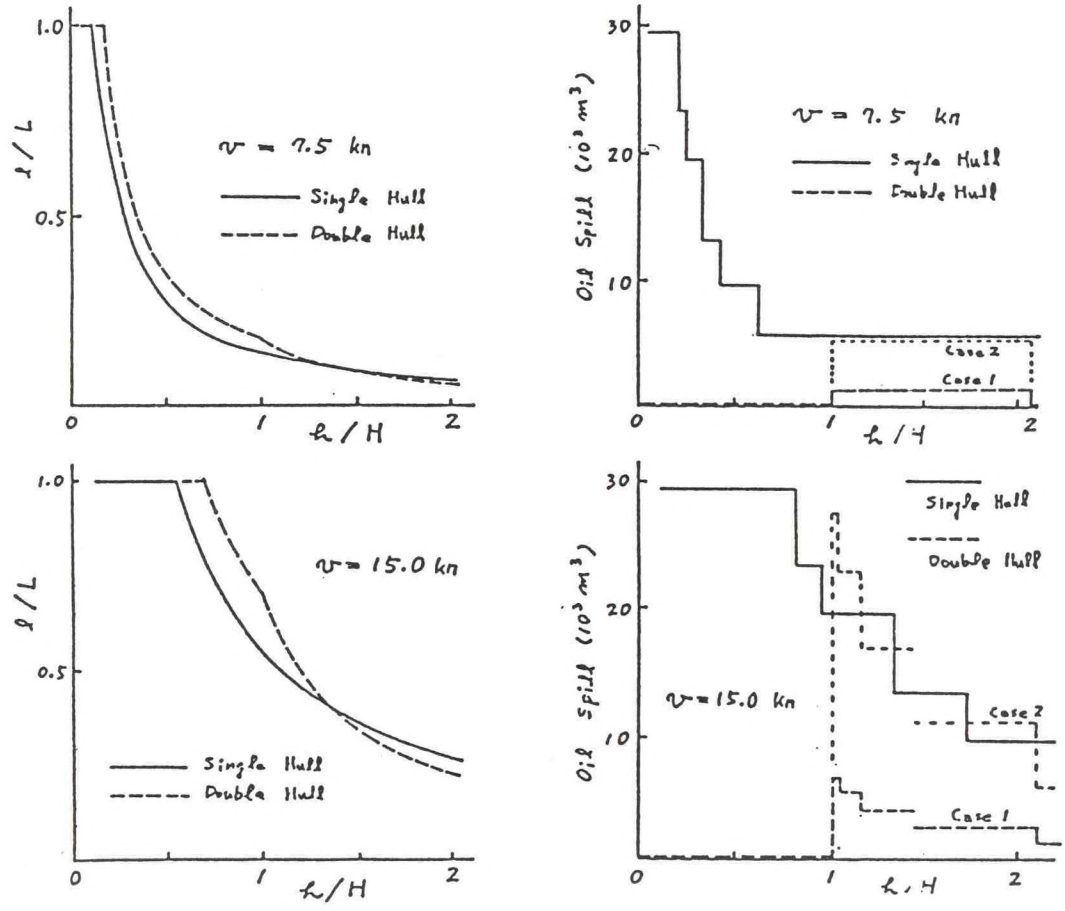
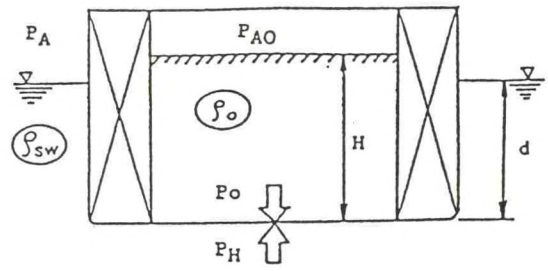


Fig 1 Crack Length and Amount of Oil Spill on VLCC
(For Collision-type Grounding)

Table-1 Calculation Result of Oil Outflow on VLCC
(For grounding)

	Present System (Non-Vacuum System)		Vacuum System					
Set Pressure of Vacuum Relief Valve : (Gauge pressure ; mAq)	−0.7		<-4.2	−2.5	−5.0	−2.5	−5.0	−5.0
Loaded Condition	Full	Partial (75%Draft)	Full	Full	Partial (75%Draft)	Partial (75%Draft)	Full	Full
P_{v_1} : Initial Tank Pressure (Gauge pressure ; mAq)	0.0						0.7	0.0
ρ_o : Density of Oil	0.85							0.9
D : Tank Depth (m)	30.0							
d : Draft (m)	20.0	15.0	20.0		15.0		20.0	
Calculation Result								
(1) Oil Outflow : $h_1 - h_2$ (m)	4.46	10.49	0.40	2.34	5.43	8.37	0.46	1.07
(2) Oil Outflow from One Tank : (m^3) (Max. One Tank : abt. 38,000 m^3)	5,648 (A)	13,285 (B)	510 (C)	2,965 (C)	6,877 (D)	10,603 (D)	585 (C)	1,351 (C)
(3) Oil Spill Rate to Stowage : q $(h_1 - h_2)/h_1 \times 100$ (%)	15.2	35.7	1.4	8.0	18.5	28.5	1.6	3.6
(4) P_{v_2} : Tank Pressure after Oil Outflow (Gauge Pressure ; mAq)	−0.7	−0.7	−4.2	−2.5	−5.0	−2.5	−4.1	−5.0
(5) Oil Outflow Ratio to Present System	Base (100%)	235% (B)/(A)	9% (C)/(A)	53% (C)/(A)	----	----	10% (C)/(A)	24% (C)/(A)
	----	Base (100%)	----	----	52% (D)/(B)	80% (D)/(B)	----	----

Fig. 2 PRINCIPLE OF PREVENTING OIL SPILL
(For Grounding)



Cargo oil pressure on ship's bottom (Po)

$Po = H \times \rho o + P_{AO}$

(ρo ; Specific gravity of oil)

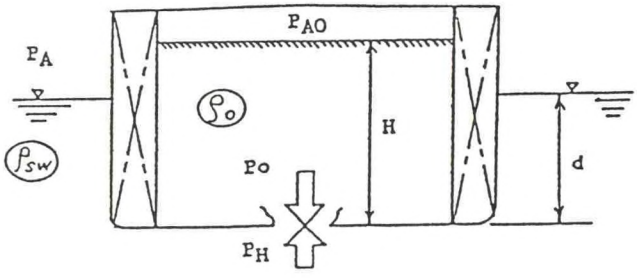
(P_{AO} ; Gas presssure in cargo oil tank)

Sea water pressure on ship's bottom (P_H)

$P_H = d \times \rho sw + P_A$

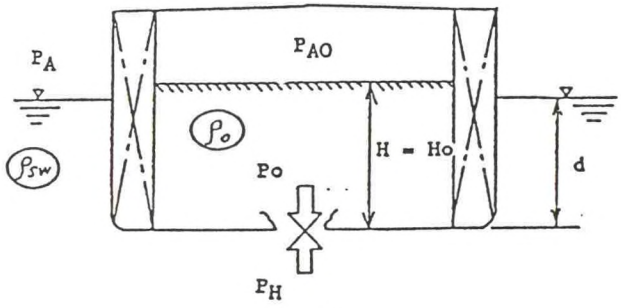
(ρsw ; Specific gravity of sea water)

(P_A ; Atmospheric pressure)



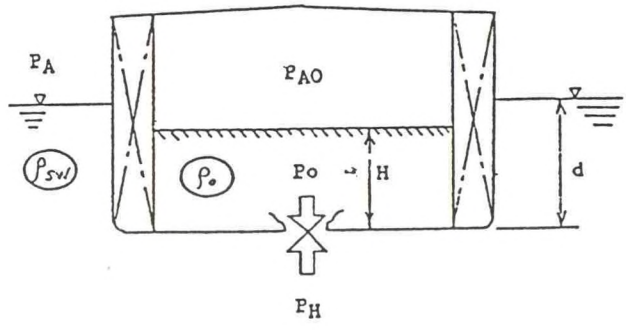
$Po > P_H$ (H > Ho)

Oil outflow occurs



$Po = P_H$ (H = Ho)

No oil outflow &
no sea water inflow
occurs



$Po < P_H$ (H < Ho)

Sea water inflow occurs

Monitoring and Prediction System of Wind-driven Currents and Drifts in Semi-enclosed Seas.

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1. Introduction

Monitoring of sea conditions has become important for safty navigation and preservation of the environment in the semi-enclosed seas such as Tokyo Bay or Osaka Bay where some big ocean development projects are under way. Maritime Safety Agency has already operated the Maritime Information System, in which tidal current prediction at any place and any time is supplied using the installed mesh data. Combining the wind data getting from ADESS line of the Japan Meteorological Agency, the pathes of drifting articles are also predicted in the system. However the wind-driven current is not included in the system, which is predominant for the inner region of semi-enclosed sea. For the sake of the improvement of prediction of current and drifting path, it is necessary to consider the effects of wind more precisely. Therefore we made a plan of the advanced prediction system which consists of following 3 functions; (1) Current and sea condition monitoring system , (2) Analysis and Prediction system, (3) Information supply system. Now we are engaged in the development of

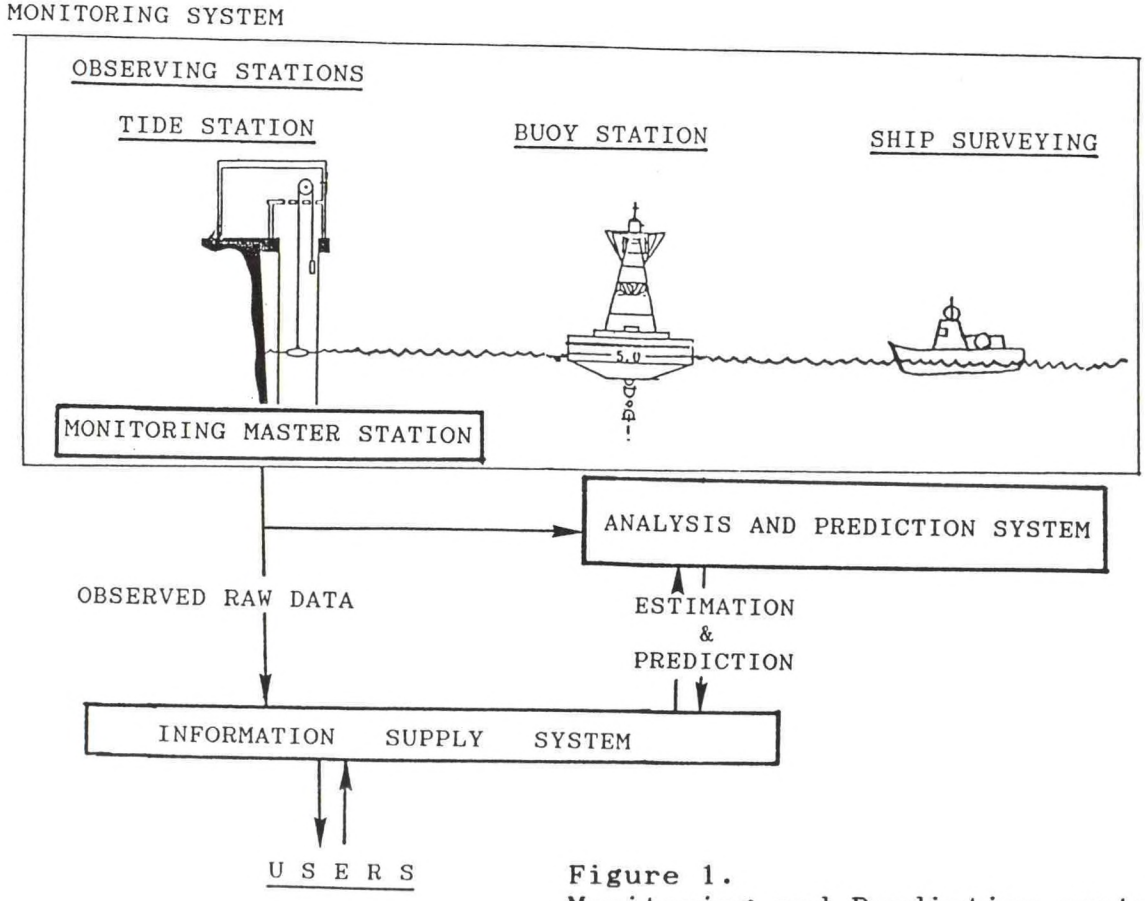


Figure 1.
Monitoring and Prediction system in Semi-enclosed Seas.

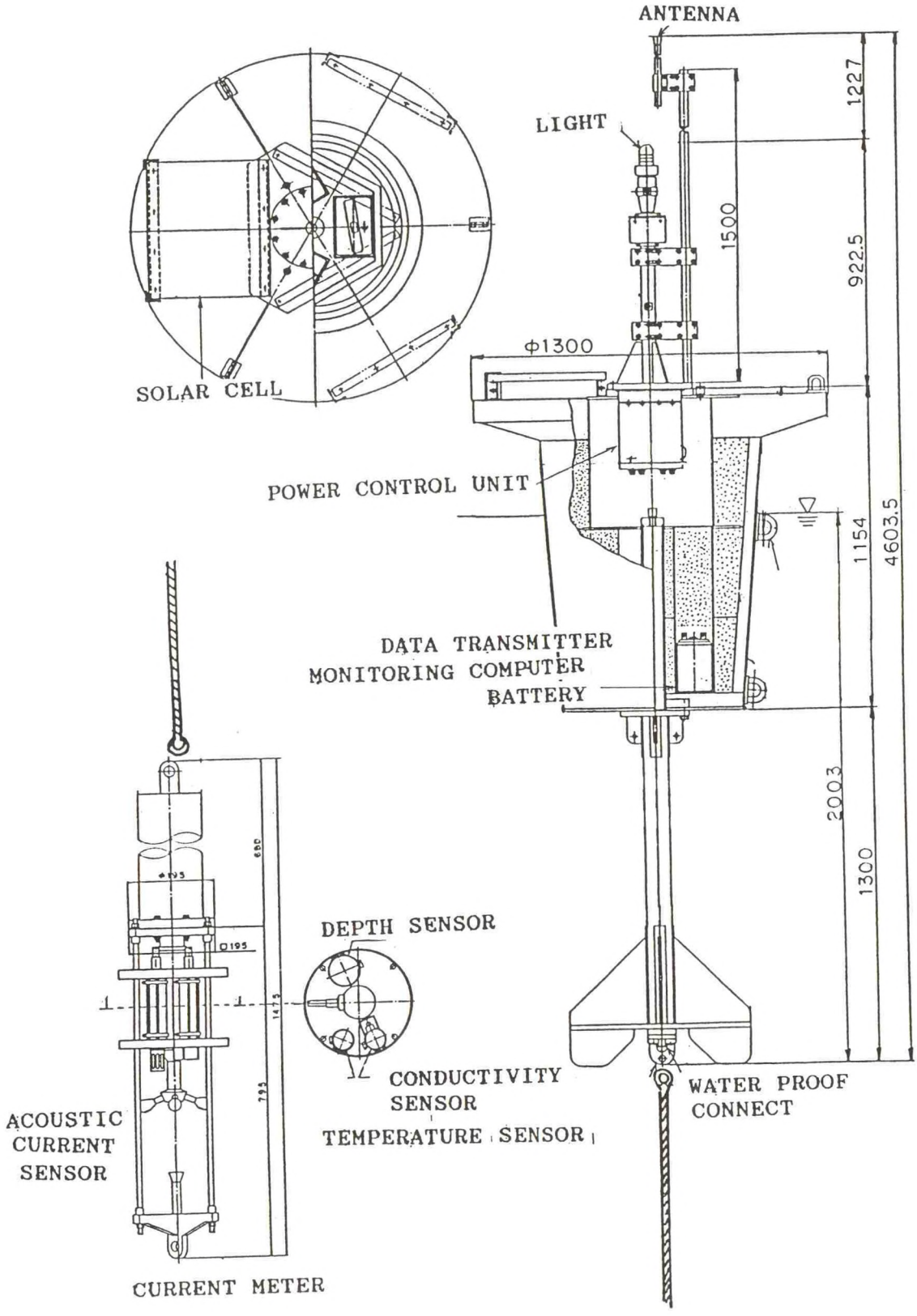


Figure 2.
Monitoring buoy system for coastal current and sea condition.

(1) and (2), but the Information supply system is remained on the future plan.
In this paper, we introduce the present status and preliminary results of the development of monitoring and predicting system of current and sea condition.

2. Development of monitoring buoy system

Development of the current and sea condition monitoring buoy system was carried out from 1987 to 1989 by the Hydrographic Association under the lead of M.S.A. and supported by Sasakawa Foundation. The buoy was made by AKASAKA DIESEL LIMITED. Its specification is shown in table 1 and figure 2. The observing unit is consists of the acoustic current meter (Steedman CM-2), which is optionally installed temperature and conductivity sensors. The acoustic current meter is selected because of less trouble than rotor or propeller type current meter. The observed data is transmitted to the monitoring station using a ship telephone, which is easy to connect a computer system and to access from any place through the modem. The electric power unit is consist of the combination of solar cells and batterys, and enough to supply electric power to transmitting unit and the light in the ordinary condition. The field experiment was made for 17 days in October of 1989, off Yokosuka port in the south of Tokyo Bay. Resultingly, the system was recognized to be of practical use.

3. Study on Analysis and Prediction System of wind-driven current

Tokyo bay has a narrow entrance (fig.3) and its average depth is about 20m, length 50km and width 20km. The western part of the bay is a little shallower than the eastern part. Analysis and Prediction system for Tokyo bay was initially constructed in 1984. Field test of the system was held in 1985 and showed rather good results in the prediction of the drifting path in surface layer, but a few unsatisfactable points were remained. For example, the predicting layer is limited in the surface layer, and vertical structures of current and its seasonal changes are unknown, because the method is almost empirical based on the accumulated data. More sophisticated system is desired for more precise current prediction and for the preservation of environment. So that we started the study, "Prediction of Wind-driven Currents and Mass Transport in an Enclosed Sea" supported by the Environment Agency of Japan. As little data is available for analysis, we have started this study at the coastal current observation for a sufficiently long period (40 days) and in the sufficiently dense layers (6 layers) to consider the effects of the wind blowing on the sea surface.

First field observation was made in winter of 1989 at 4 stations in Tokyo Bay (fig.3). As shown in fig.4, the mean currents of all observation period differ from layer to layer and from place to

Table 1

Specification of Monitoring Buoy

Total Length		4604 mm
	in air	2601 mm
	in water	2003 mm
Buoy diameter	upper	1300 mm
	lower	650 mm
Buoyancy		569 kg
Total weight in air		286 kg
	buoy	213 kg
	loading	73 kg

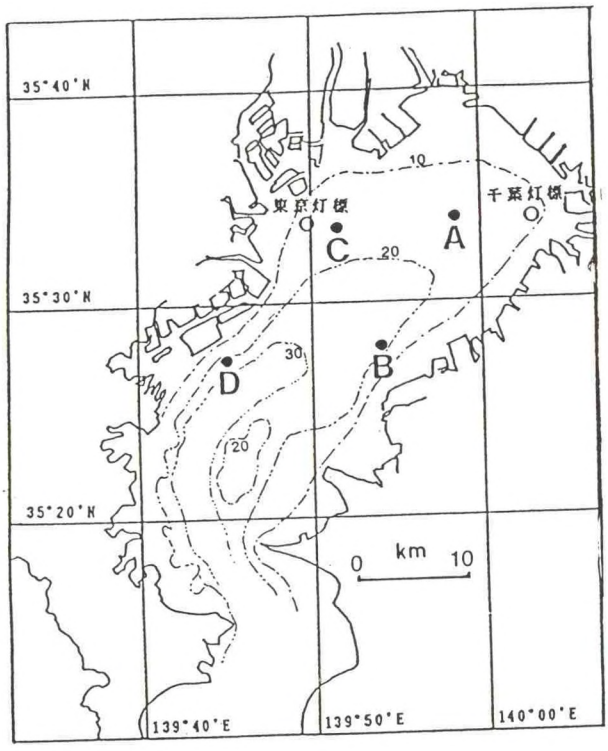


Figure 3.
Locations of observation sites in Tokyo Bay.

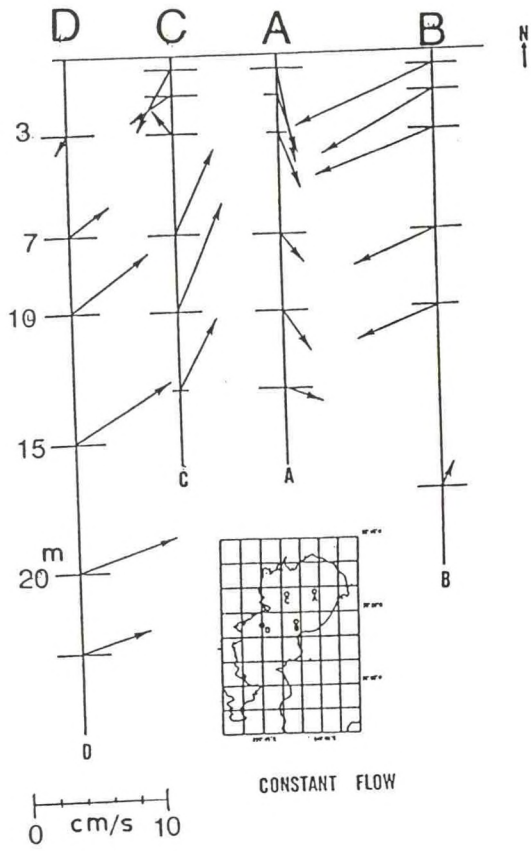


Figure 4.
Mean currents in winter.
Wind blew from north.

place. North wind was blowing during the observation period. At stn.D near Yokohama, at surface weak current flew to south-west which followed the wind, but the currents at mid layers directed to north-east which is opposite to the wind. Current speed reached maximum at 15m deep below the sea surface and its vertical profile seemed parabolic. At stn.C, the suface current flew to SSW but the mid layers currents flew to NNE. At stn.A, current directions were SSE or SE, which were almost same at all layers. At stn.B, the currents were directed to WSW and decreasing almost linearly according to the layer depth. Resultingly, a clockwise circulation caused by the north wind was recognized in the innner-most area of the bay. Remarkably, in the west side of the bay, the currents flowing to the opposite direction of the wind appeared in the mid layer.

Second field observation was made in autumn of 1989 at the same stations as the first observation. Although the season was autumn, seasonal thermocline was remained. Fig.5 shows the observed mean currents. The wind during the observation period was weak and mainly blowing from N. Mean currents in autumn were significantly stronger than those in winter. Particularly, at stn.D, the current going to the opposite direction of the wind became stronger and limited in the thin layer from 5m to 10m below sea surface. Furthermore, at stn.B, surface currents flowing to the same direction with the wind were very strong and limited in the thin layer above 5m. Therefore, it is concluded that the stratification of sea water develops the wind-driven currents

and makes their vertical difference severe. Additionally, it was noted that internal oscillation of thermocline was observed at every station, which was also generated by the wind.

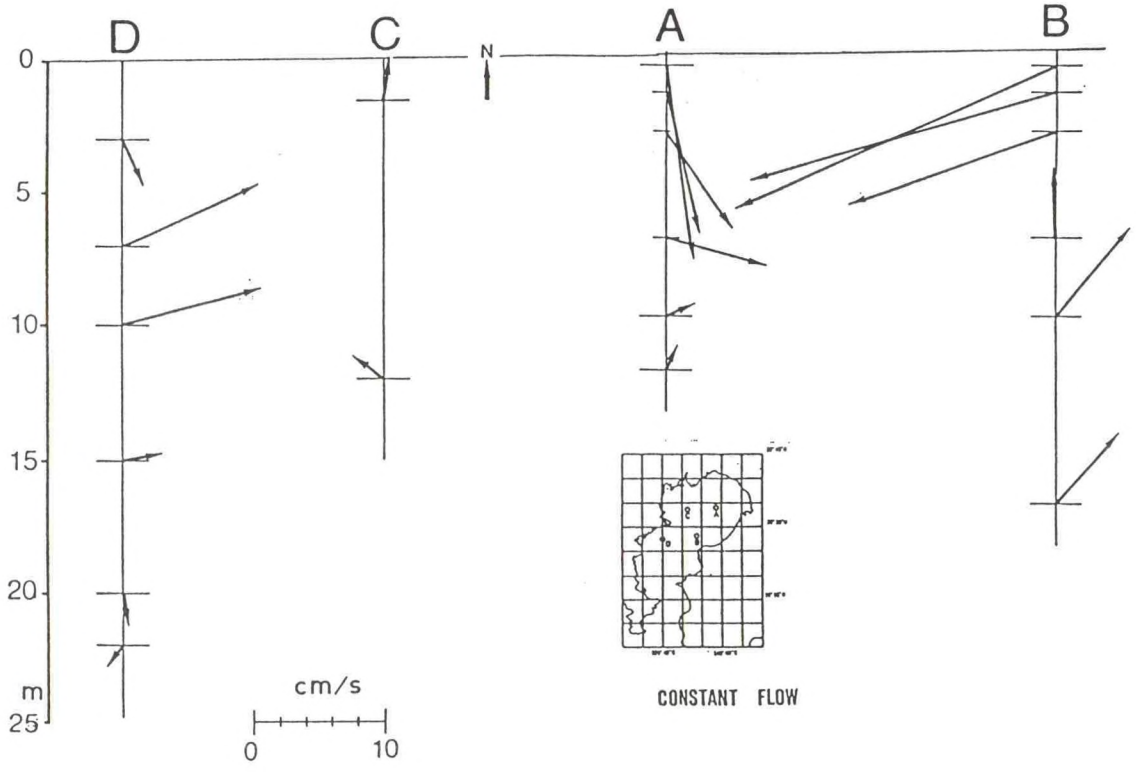
For the third step, in Fy 1990, we are carring on the development of the 3-dimensional numerical simulation model of wind-driven circulation, which can express the effects of sea water stratification.

In Fy 1991, the final year of this study, we make a plan of the field test of the numerical simulation model together with the monitoring system.

4. Conclusion

Advancing of the development of the coatal zone, more detailed and realtime information of the coastal current and sea condition will not be desired only for the safety of ship navigation but also for the preservation of marine environment. In the case of marine disaster such as the oil spilling, those information will be essential for protection and our advanced monitoring system will increase its significance. Therefore we intend to advance the system aiming the more safety and more comfortable marine environment.

Figure 5.
Mean current in autumn.
Stratification was remained.



DATA BASE ON WIND AND WAVE OF THE NORTH PACIFIC

Iwao Watanabe
Ship Research Institute

INTRODUCTION

Wave climate is very crucial information not only in designing ocean going vehicles but also scheduling and selecting safer and an economical ocean routes. Ship Research Institute has been putting efforts for a long time to collect and publish such information for the use of the naval community. After ten years since the last publication in 1980 of the wave statistictics of the North Pacific Ocean, it became urgent to assemble new kinds of wave climatic chart to meet requirement arising from new design method of marine vehicles. Thus a three year project has been launched in 1989 by SRI under the joint collaboration with the Japan Ship and Ocean Foundation (former Japan Foundation for Shipbuilding Advancement).
The general plan of this project was presented at the last meeting of UJNR/MFP in Seatle. Since then, much progress has been made on the project. The work is in the final stage of the threee year project and still under way to complete the data base system and to publish wave climate chart. This paper describes briefly present stage of the project and how the collaboration between USA and Japan under this panel has contributed to this program.

OVERVIEW OF THE PROJECT

The objective of the project is to build comprehensive data base system on wave climate of the North Pacific Ocean based upon as many data sources as obtainable at present. Wave reports from oceangoing vessels and offshore buoys are the main part of the data source, as well as hindcasted time history of waves in the ocean.
After verifying its accuracy, the collected information will be analysed to compile wave statistics which are of the practical interests and also constitute the main part of the data base system. The data base system gives easy access to such complicated information as wave histogram for a specified sea lane on a certain month or season and so on.

DATA COLLECTION

Three kinds of data are at hand for our purpose to compile long-term wave climate of the North Pacifc.(fIg.1) One is the weather report from ocean going vessels, another is report by buoys deployed in the remote sea from the shoreline. The last one is, known as wave hidcasting, wave data through numerical simulation on wave generation, evolution and propagation by wind data in the ocean.

Ship Reports

Thousands of voluntary ships report weather, wave and other meteorological information at their point regularly for meteorological agencies which are responsible for data collection as signed by WMO. Japan Meteorological Agency (JMA) is the responsible body for the data collection in the North West Pacific Ocean and NOAA is responsible for the North East Pacific.

Athough the accumulated data have been analyzed for regular publication by the organizations, It has been felt that further analyses are necessary for the engineering purposes to get long-term wave climate for use of the ship design and so forth. In this project, those items essential to present purpose are selected out of reported information with respect to wind, wave and atmospheric climate.

We have finished to collect ship data covering the entire North Pacific in the period from 1974 to 1989 both from JMA and from NOAA/NCDC . It amounts to more than 4 million data for ten years.

Buoy Data

Wave measurement by offshore buoys has been thought to be one of the most accurate means to know wave characteristics in the ocean. There are a buoy system operated by JMA around the vicinity of Japan and another large buoy network in the North Eastern Pacific Ocean operated by NOAA. It was decided to include data from both buoy systems to our data source. More than half a million Data from 6 JMA bouys and 13 NOAA buoys for ten years are now in our data base. Locations of all the buoys of which data taken are shown in Fig.2.

Hindcasting

Hindcasting is a powerful tool to get information on waves. in the otherwise unavailable areas. It is free from such regional restrictions as buoy and ship reports have. We have conducted hindcasting for the whole North Pacific Ocean in the past ten years. With use of recently revised wave model and appropriate wind data, the simulation was made at more than 1000 mesh points covering whole North Pacific as shown in Fig.3. at every 6 hour interval. Total number of generated wave data is more than ten million for a period of ten years.

DATA VERIFICATION

Although buoy system is widely believed to give most reliable wave information of the ocean, its weak point is that it only covers limited locations in the ocean. On the other hand, the wave data reported by ships cover wide area of the ocean. But they are said to be biased for the smoother sea state and shorter wave components possibly due to the practice for safer routing. Verification is crucial to utilize the ship reports as a reliable wave data source.

The ship data are now being compared and verified with information from reliable measurement, in addition to cross-examination among their own climatic information derived simultaneously.
One of our scheme to check reliability of derived ship reports is to see if the reports are contaminated by noises arising in the course of data transfer. By plotting the consecutive reports of the same ship as in Fig.4, we have found that the data with excessively steep waves are not reliable since such data appears as a spike (isolated high wave) in the most cases.

DATA BASE

All the data derived in a manner described in preceeding sections are now fed into data base system which was structured in a work station. The merit of introducing the data base system is easiness of data verification and data acquisition by users of their desired information. The statistical analyses has been made by using functions of the system.
The data may be retrieved in one or grouped zonal categories on monthly, seasonally ,annually or all time period. Although primary information of the data base are statistically analyzed distribution or histogram of wave, wind and other climatic information, the data base will give us on demand an access to elementary information if it is desired. Some examples of the statistics are shown in Fig.5 which shows joint probability distribution among wave height and period.

CONCLUDING REMARKS

The project has been done as planned so far. Final products of this project are publication of summary wave statistics of the North Pacifica and data base in magnetic media usable on personal computers. They will come out by the end of March of the next year.

We would like to express our gratitude to supports given by Mr. Joseph Vadus and Ms. Pam Rubin of NOAA in locating ship and buoy data of NOAA which forma a core part of this data base sysytem. Also our thanks are due for supports extended by JMA.

References

1) McCall, Jerr C.;"ADVANCES IN OCEAN DATA COLLECTION SYSTESMS" , pp182-190, Conference Record of THE 15th MEETING U.S.-JAPAN MARINE FACILITY PANEL,May 1988.

2) National Data Buoy Center,;" NDBC DATA AVAILABILITY SUMMARY", AUGUST 1989.

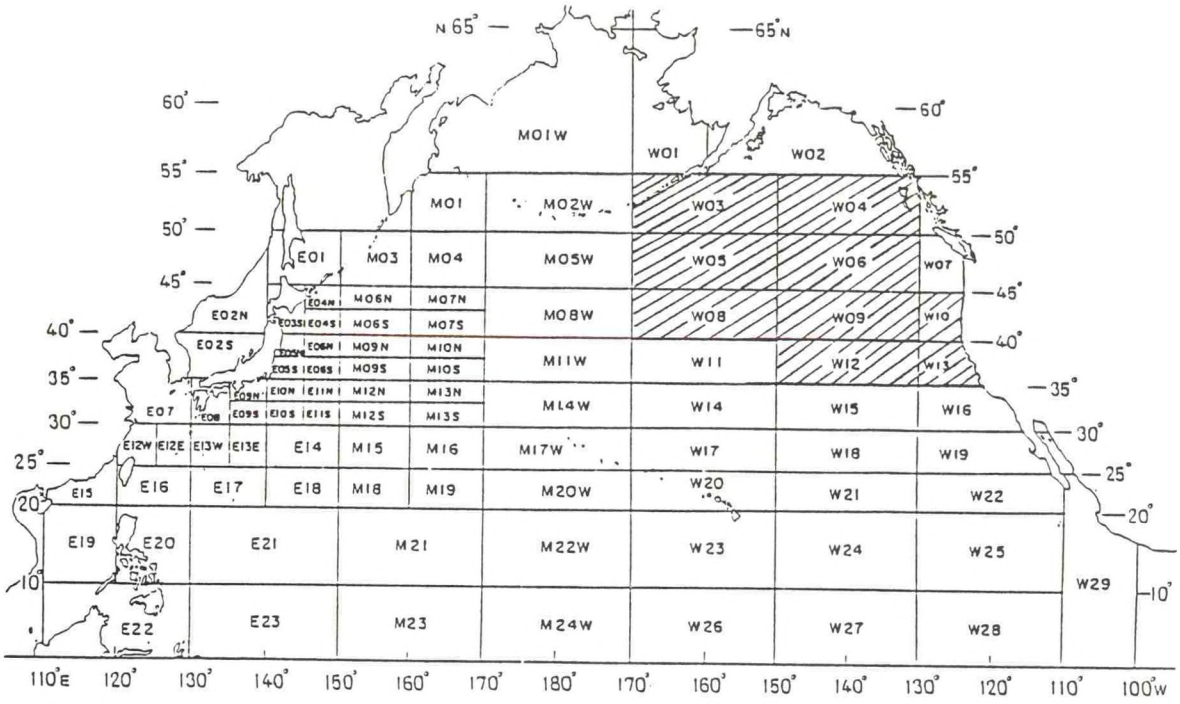


Fig.1 Zoning of the North Pacific for wave statistics

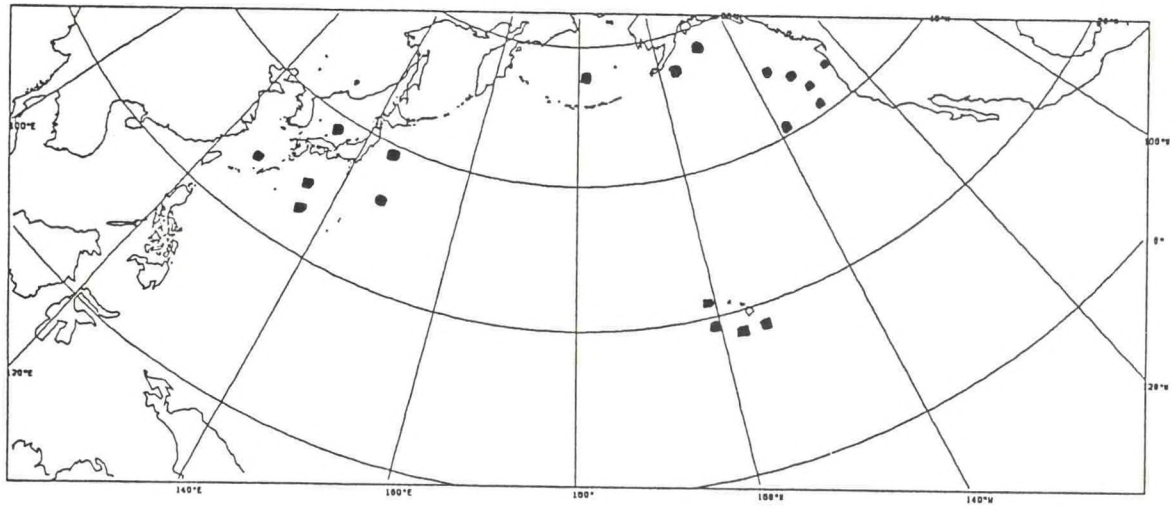


Fig.2 Location of offshore bouys of which data are taken

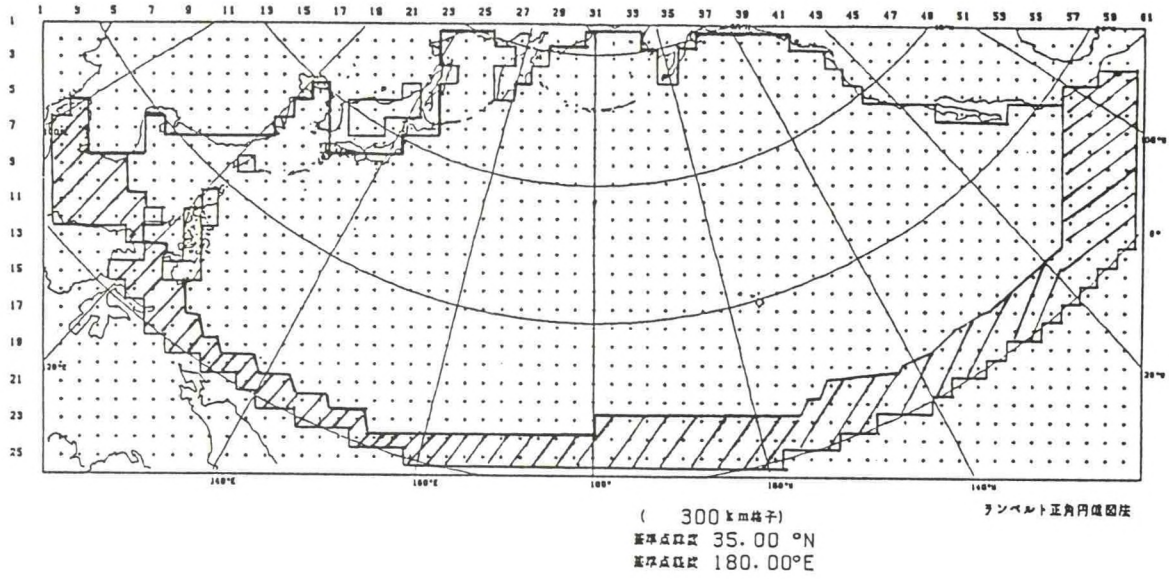


Fig.3 Grid plan of Hindcast

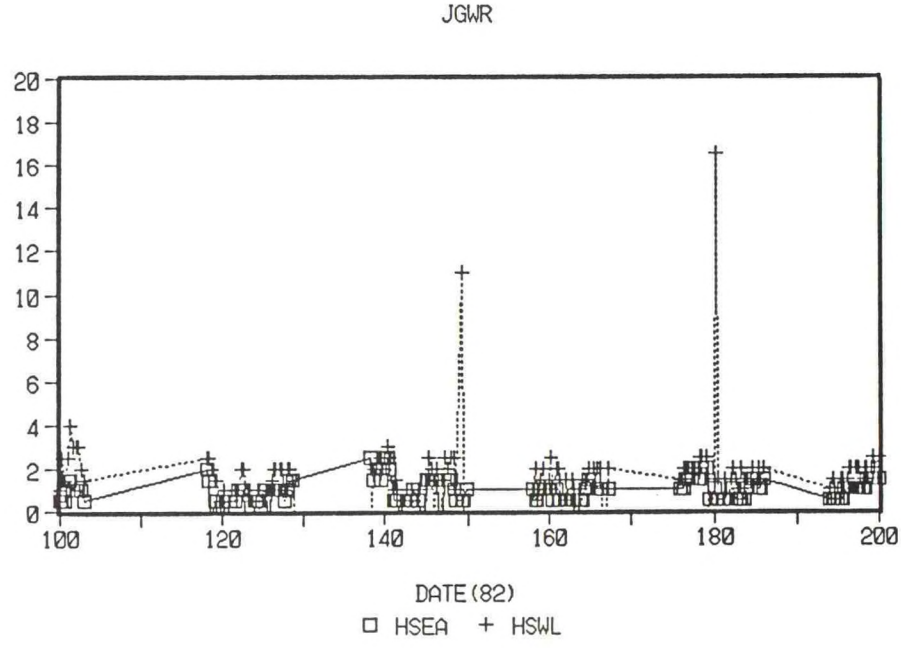


Fig.4 Time history of wave reports by the same ship

WAVE HEIGHT - WAVE PERIOD (WAVE)

SHIP DATA

1974-1983 All seasons

MULTIPLE AREA

DATA NUMBER 3974651

MEAN OF WAVE HEIGHT 2.26 M

MEAN OF WAVE PERIOD 6.46SEC

PERIOD (SEC)

HEIGHT (M)	0-	5-	6-	7-	8-	9-	10-	11-	12-	13-	14-	calm	TOTAL
14.75-	1	255	120	59	126	58	385	69	94	48	193	8	1416
		0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.04
13.75-		17	18	20	27	31	27	16	23	10	39	1	229
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.01
12.75-		23	17	13	57	19	75	22	50	27	59	2	364
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.01
11.75-		105	82	45	126	89	606	91	151	65	197		1557
		0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00		0.04
10.75-		167	108	65	113	95	229	73	154	39	166	2	1212
		0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00		0.03
9.75-	7	354	295	285	635	531	962	298	668	203	557	2	4797
	0.00	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.02	0.01	0.01		0.12
8.75-	18	260	343	363	800	602	1078	371	609	217	564		5225
	0.00	0.01	0.01	0.01	0.02	0.02	0.03	0.01	0.02	0.01	0.01		0.13
7.75-	13	330	543	620	1718	1070	2229	574	1253	381	788	1	9520
	0.00	0.01	0.01	0.02	0.04	0.03	0.06	0.01	0.03	0.01	0.02		0.24
6.75-	35	987	4882	2614	5502	2981	5001	1438	2583	769	1528	3	28323
	0.00	0.02	0.12	0.07	0.14	0.08	0.13	0.04	0.06	0.02	0.04		0.71
5.75-	72	2473	3530	4000	12324	5582	9869	2901	5095	1285	2339	2	49472
	0.00	0.06	0.09	0.10	0.31	0.14	0.25	0.07	0.13	0.03	0.06		1.24
4.75-	205	5693	9717	10182	32704	14984	21269	6145	7854	1927	3250	22	113952
	0.01	0.14	0.24	0.26	0.82	0.38	0.54	0.15	0.20	0.05	0.08	0.00	2.87
3.75-	1333	17952	40253	40012	90307	37689	37392	9545	11339	2922	4624	15	293383
	0.03	0.45	1.01	1.01	2.27	0.95	0.94	0.24	0.29	0.07	0.12	0.00	7.38
2.75-	9844	74283	149059	121392	167315	54760	47545	11879	12964	3584	6642	31	659298
	0.25	1.87	3.75	3.05	4.21	1.38	1.20	0.30	0.33	0.09	0.17	0.00	16.59
1.75-	60915	306413	326296	187204	192011	54768	45901	10577	12711	4876	11759	59	1213490
	1.53	7.71	8.21	4.71	4.83	1.38	1.15	0.27	0.32	0.12	0.30	0.00	30.53
0.75-	203600	565334	245587	100648	97448	25537	24483	5273	8993	5088	12592	100	1294683
	5.12	14.22	6.18	2.53	2.45	0.64	0.62	0.13	0.23	0.13	0.32	0.00	32.57
0.00-	93691	137259	15917	4502	5904	1326	2561	603	1188	553	1596	7638	272738
	2.36	3.45	0.40	0.11	0.15	0.03	0.06	0.02	0.03	0.01	0.04	0.19	6.86
calm		132	2		3	1	8	1			3	24842	24992
		0.00					0.00					0.63	0.63
TOTAL	369734	1112037	796769	472024	607120	200124	199620	49876	65729	21994	46896	32728	3974651
	9.30	27.98	20.05	11.88	15.27	5.04	5.02	1.25	1.65	0.55	1.18	0.82	100.00
MAX	17.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	18.50	
PERIOD	3	5	6	7	8	9	10	11	12	13	14	0	

DATE (MAX HEIGHT) 00h 09-FEB-75

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Fig.5 Scatter diagram of Wave Height and Period for the N.Pacific for 10 years

The Present Status of the Okhotsk Program

Hokkaido Tokai University
Masanao Oshima

The planning of the Okhotsk Program was initiated in 1986 in so-called AQUAMARIN project sponsored by the Japan Science & Technology Agency.The actual study works has been carried out in the Okhotsk Program Committee of Research Institute of Ocean Economics.

The general concept of the Okhotsk Program including Okhotsk Tower is explained in the attached paper, '"Okhotsk Program" on the Japanese coast of the Okhotsk Sea'. The tower was originally planned to be set up at water depth of 50 meter and about five miles away from shore. The investment in this program was supposed to be made by a joint venture composed of the Hokkaido Local Government, the Mombetsu City Government and private sector with a long term loan from the Japanese Government. But it was found that the construction cost of the tower in tne original scheme would be too large and it would be difficult to pay back the loan.

Therefore, the original plan had to be revised to meet the financial conditions and series of economic feasibility studies of various plans were conducted for the location of the tower which is a major part of the investment and includes facilities for various researches, social education and sightseeing. The revised plan shown in the attached paper is considered to make access easier with the tower at shallower and nearer location from shore. Finally in 1990 it was decided to locate the tower 40 meter away from

the tip of harbour wave-breaker which is protruding about 800 meter from shore

The tower will have about 10 meter water depth and connected to the end of the breakwater by a bridge for easy access of sightseeing people. The reason for this bridge connection is easy transfer of common people to the tower especially in ice-free seasons when considerable wave height is encountered at sea sometimes. The location and interim design of the tower and its bird'eye view are shown in the attached sheets. The final design of the tower is at present under study and may change to some extent.

The final locaion of the tower will affect some of research items which were originally contemplated, but they will be pursued as far as possoble in areas of oceanography, ocean biology, ice engineering, marine aquaculture, and so forth. In future, offshore research tower of smaller scale but at deeper depth may be planned to supplement the present tower design and location as shown in attached sheet upon needs in scientific and engineering researches.

The Sea Ice Science Center which is a kind of science museum in Mombetsu was already completed on shore nearby and opened to public in February 1991. The Okhotsk Tower is scheduled to be completed in 1993 including land base facilities.

We are looking forward to the completion of the Okhotsk Program and we are very gratefull to those of you who have been encouraging us in promoting the project.

図－2　洋上タワー設置想定地

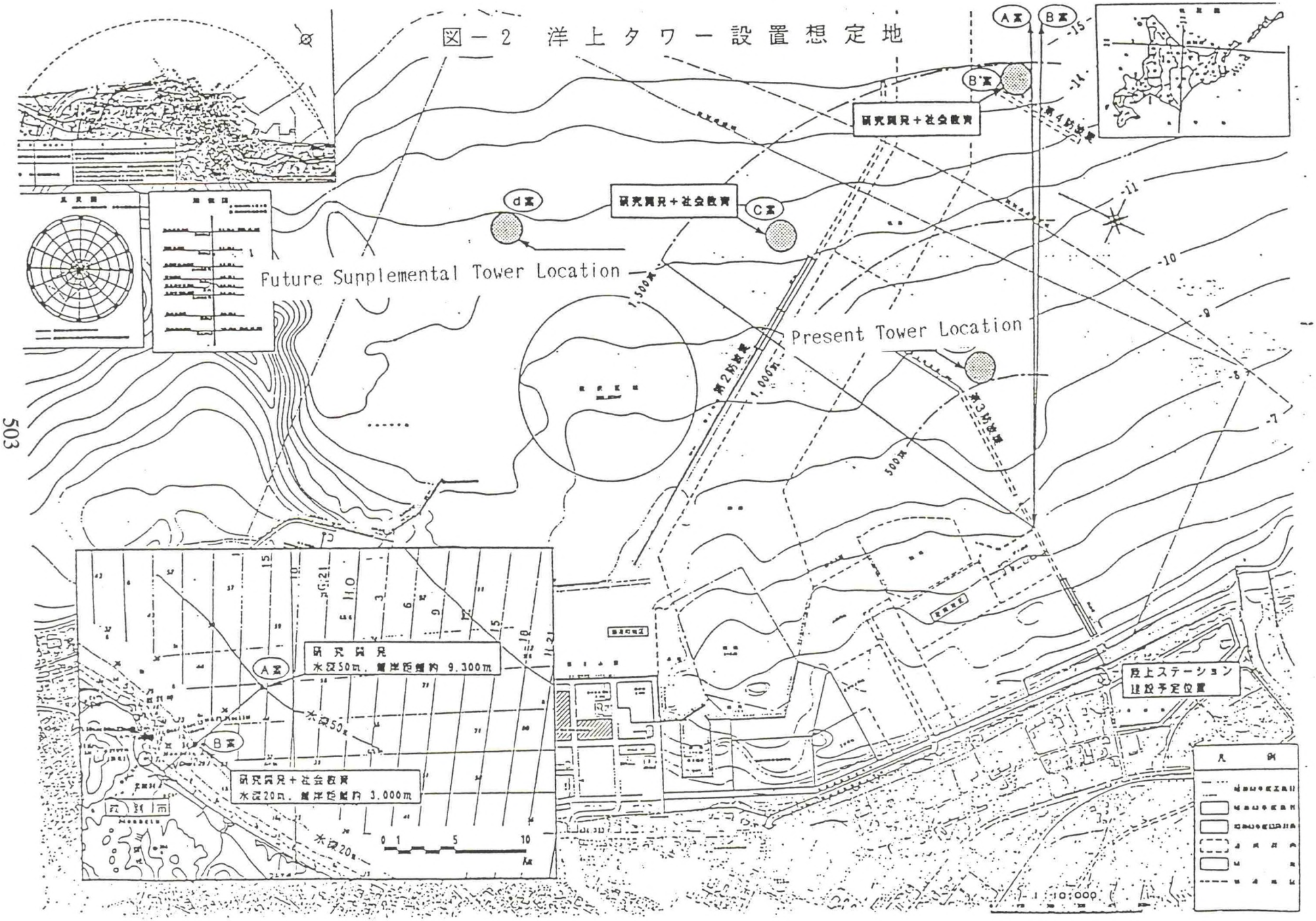
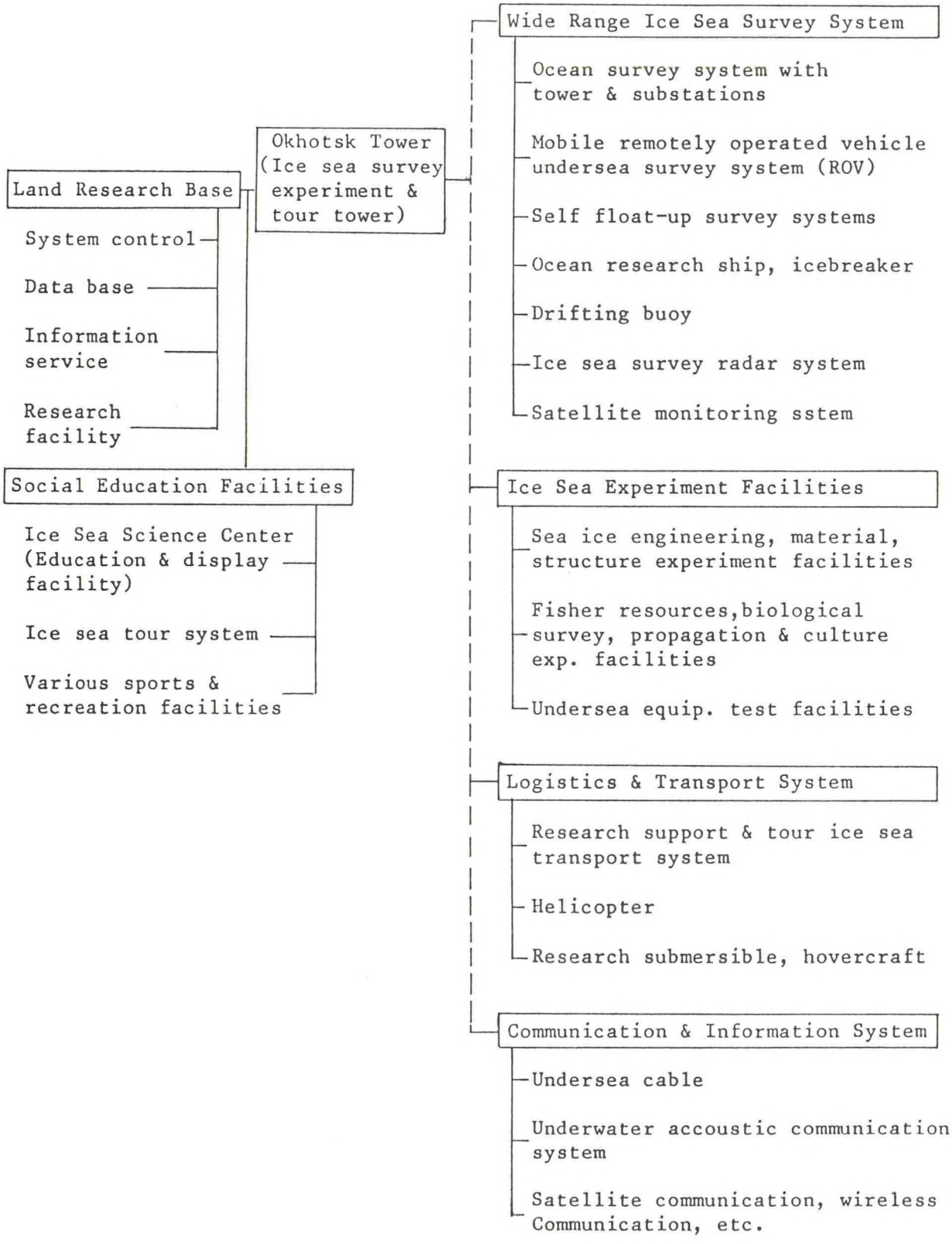


Table 1 Total system of the OKHOTSK PROGRAM





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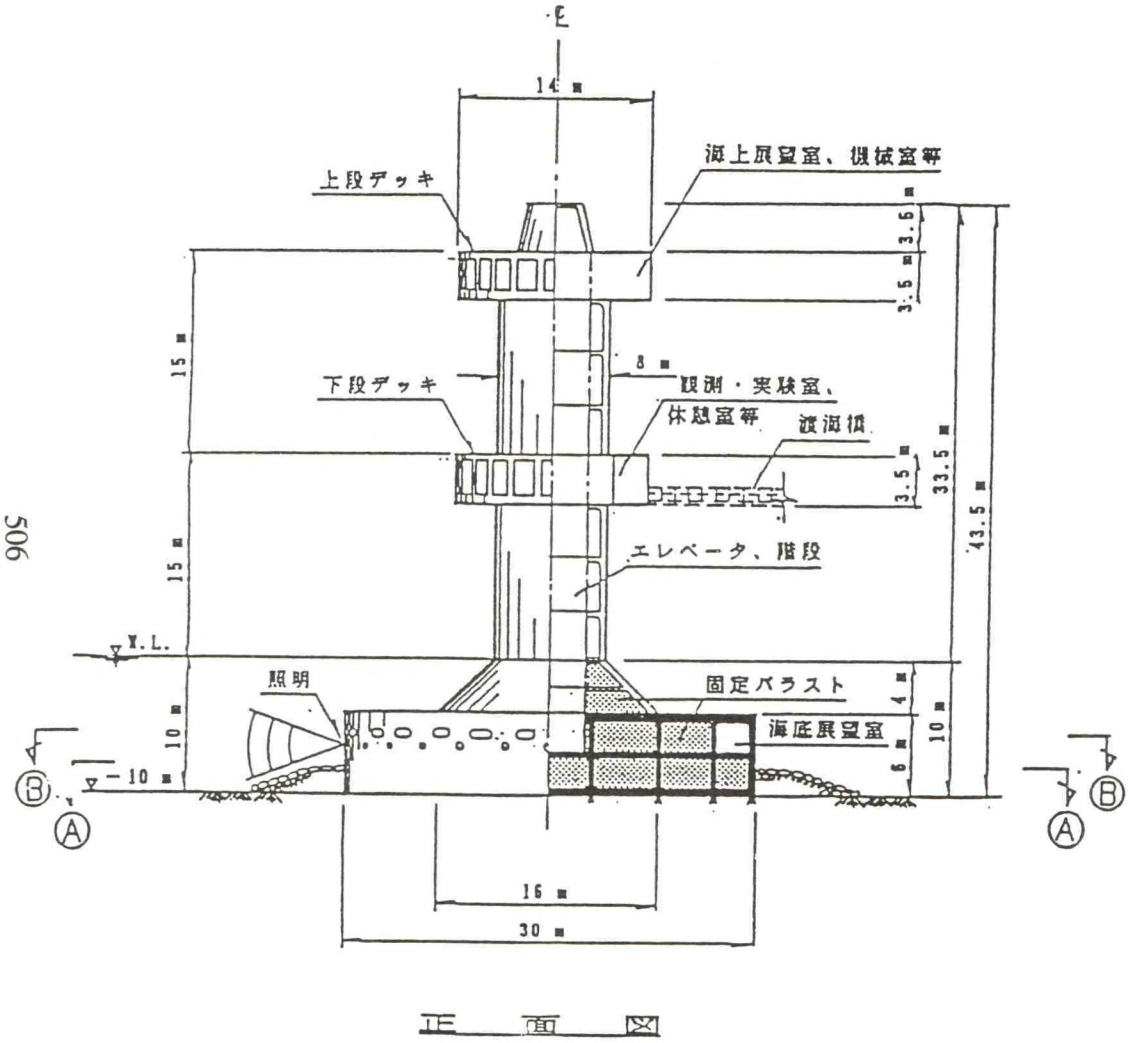

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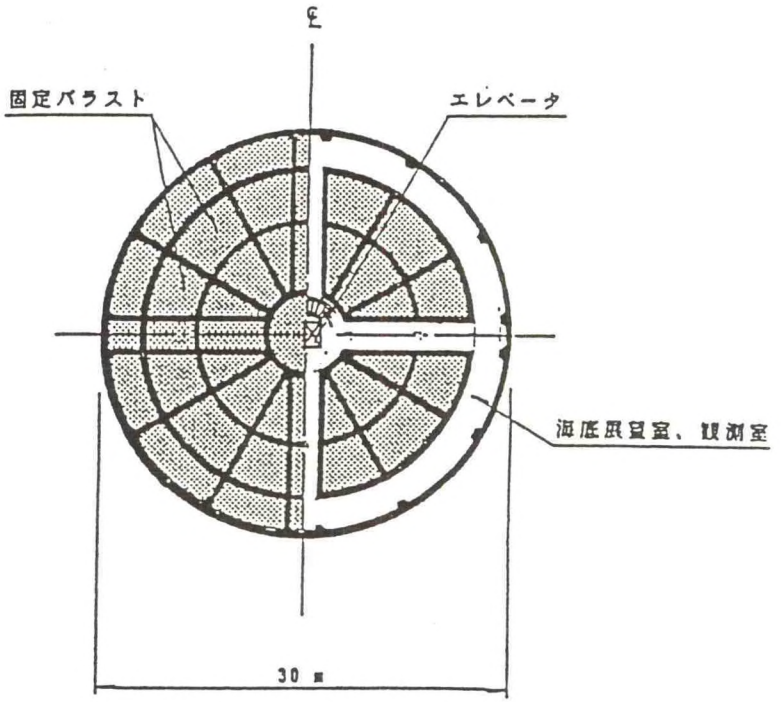

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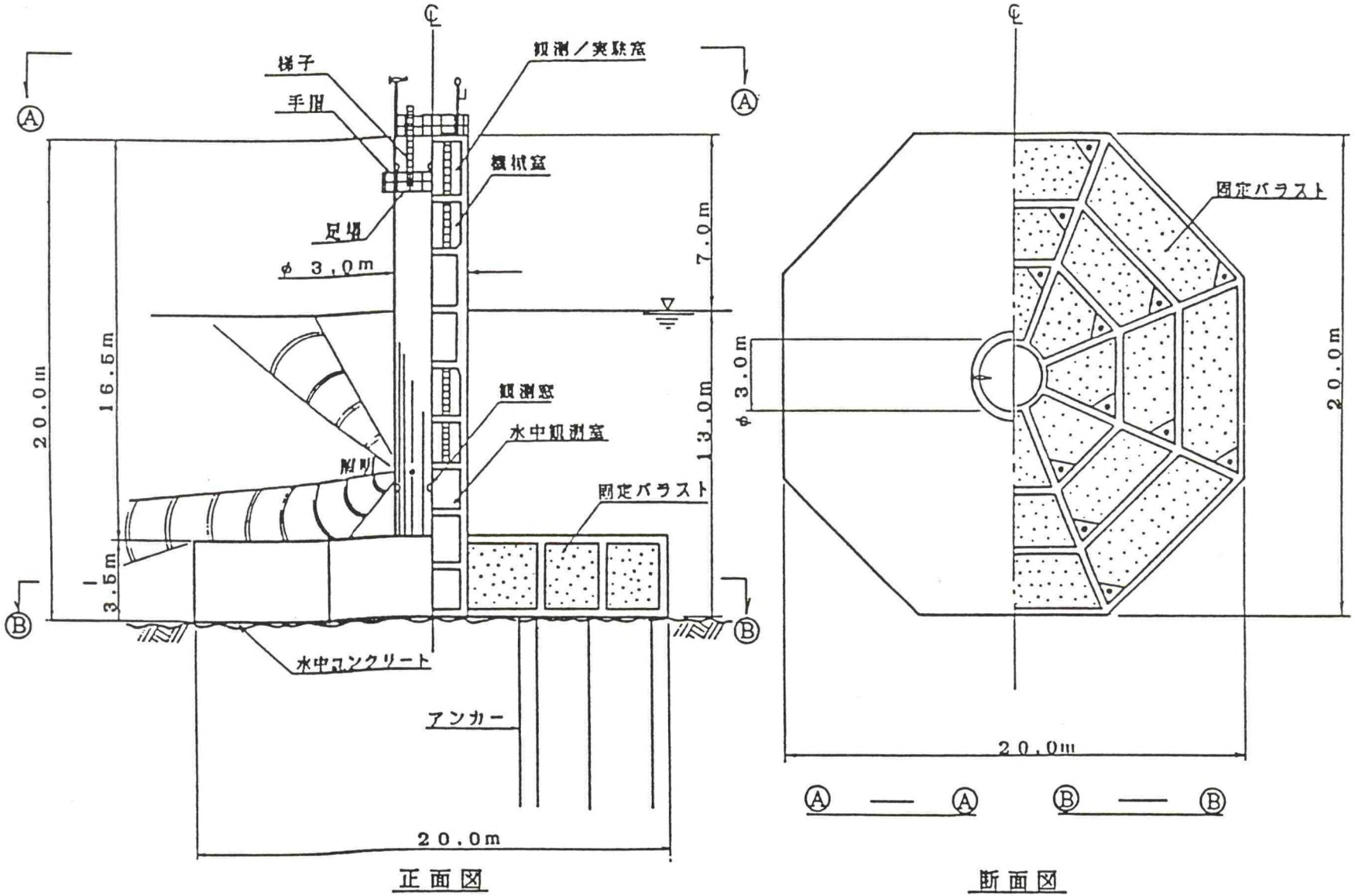
Fig. 1 Present Tower Design Concept



Future Research Tower concept －13m （d案）

2. Abstract of the project plan schedule

Execution of the Okhotsk Program is divided into two aspects, i.e. completion of survey and science and technology research systems, and various research and development projects utilizing the Program facilities.

(1) Completion of the system facilities

Construction of the system facilities is to be divided in two stages, and the core facilities are constructed in the first stage and other ancillary facilities to be developed are constructed in the second stage. Facilities in the second stage are to be constructed as part of research projects.

The first stage (1st to 3rd year)is to provide:

The Okhotsk Tower, Land Research Base, education information and display facilities, logistic system, ice sea technology and engineering research facilities and wide range ocean survey system installed on the Tower. (See Table 2)

The second stage (4th year and on)

Other systems are to be provided as necessary.

(2) Various research and development projects

In the fourth year, the basic facilities including the Tower are to be offered to users utilizing these facilities. Various government research bodies, universities and colleges, private industries are to start their research and development projects.

The first stage project of the OKHOTSK PROGRAM has been approved by the Japanese Government for its partial funding.

And action programs for this project are now under preparation for this fiscal year of 1989. The completion of the project of first stage will be expected in around 1992 - 3.

(3) Pack Ice Barrier

The present gravity type pack icebarrier installed at shallow shoreline has been proven very successful to stop large ridges with deep keel. And at other steeper shore line some floating pack ice barrier at further offshore is desired by fishery people. This will prevent large pack ice lumps from coming into saline lagoons open to sea, and avoid the damage of marine culture system in the lagoon.

Furthermore in future, a proposal is conceived to protect major part of coast line of the Okhotsk Sea by pack ice barriers to form local landfast flat ice zone inside along the coast which can protect aquacultural fishery and ship route zone.

(4) Ice Sea Transitting Tourism

The OKHOTSK TOWER previously mentioned will provide ice sea ship tour around the tower, but much longer sea route along the Okhotsk Sea coast will be explored by ice breaking sightseeing ships in some future.

For this aim, economical seasonal ice breaking ship design has to be developed to provide round-year economical operation of ship specially designed for local Okhotsk Sea coast ice conditions.

CONCLUSION:

Now a new era is opening when international cooperations are needed in all aspects of worldwide human activities concerning political, economical, environmental, social issues, etc. As for Okhotsk Sea which lies between Japan and U.S.S.R., we can observe some cooperative relationships are being promoted in recent years. For example, it was reported that long time pending Sakhalin oil development project is finally proceeding and joint development of marine living resources are making progress for the Okhotsk Sea. Ferry service between Sakhalin and Hokkaido has also started this year.

In light of the background mentioned above, we are certain that our Okhotsk Program will also make a great deal of contribution to promote international collaboration in research and study on ice sea science and technology in the world. All of our facilities for the Program including the Okhotsk Tower will be completely open for researchers of any country who wish to use the facilities for their studies.

We think that the importance of the research and study on the Okhotsk Sea will increase more and more to cope with our common issues -- global environmental problems, marine resources management and science and technology exchange between East and West.

We really hope that many people join our workshop to discuss the above mentioned issues.

—Wet Catalytic Oxidation Process for Wastewater Treatment—

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Abstract

This paper presents a technology for wastewater treatment and its recycling in the controlled ecological life.
The catalytic wet oxidation process planned to be applied in the system is a method of wastewater treatment using a newly - developed solid catalyst.
By means of using the catalyst under high temperature and pressure (200 ~ 270℃, 40 ~ 90 kg/cm²G), concentrated ammonia, COD (Chemical Oxygen Demand), and BOD (Biological Oxygen Demand) components and suspended solids in wastewaters can be simultaneously oxidized and treated with high efficiency in a single step without dilution.
The pollutants are converted into harmless N_2, CO_2 and H_2O, and besides, the wastewater is decolored, deodorized and sterilized.
This technology is now at the stage of commercialization.

1. Introduction

The catalytic wet oxidation process is designed to treat wastewater with the aid of a newly developed catalyst. This is a new wastewater treatment process whereby concentrated ammonia, COD, BOD components and suspended solids in various kinds of wastewater can be simultaneously oxidized and treated with great efficiency in a single step without dilution.
The pollutants are converted into harmless N_2, CO_2 and H_2O, while the wastewater is decolored, deodorized and disinfected.
Water treated in this process can be fully recycled to meet industrial requirements.
To date, the process has proven its applicability to more than 40 kinds of wastewater. These include sewage, night soil and industrial wastewater from pharmaceutical, paper, textile, dyeing, food and petrochemical plants as well as from coal gasification and liquification.
An 11,000-hour (approximately) catalyst life test on gas liquor from a cake oven, containing undecomposable components difficult to treat with conventional biochemical processes, demonstrated continuous catalytic activity.
To data, the process has been refined to commercial grate through the construction and operation of a test plant, evaluation of catalysts, confirmation of equipment, materials and a chemical engineering approach to scaling-up.

Comparison of this Process with Conventional Processes

The conventional noncatalytic wet oxidation process, called the Zimmerman Process after its inventor, has been widely applied to the treatment of wastewater containing concentrated COD components. It is now used at over 80 plants in Japan and over 300 plants abroad.
However, the Zimmerman Process has these drawbacks: the COD removal rate is not high and ammonia components can hardly be removed. This process thus requires combinations of diverse formulae for advanced treatment.
In the wet oxidation process, this limitation has been overcome by the successful development of powerfully acting catalysts.
The catalytic wet oxidation process features economy and continuous, stable operation.
We hope this process will be adopted at many plants for energy efficient treatment and reuse of wastewater.

2. Catalytic Wet Oxidation Process

(1) Overview

Fig. 1 shows the process flow. Raw wastewater is pressurized by a booster pump, and after pH adjustment with an alkaline solution as required, preheated by hot reactor effluent via an exchanger. After pressurization by a compressor, the air (oxygen) required for the reaction is mixed with the wastewater and fed to the furnace.
Note that if the COD concentration in the wastewater is high, the heating furnace can be by-passed except during start-up because the high temperature required for reaction can be obtained via reaction heat.
Fig. 2 shows the interrelation between the amount of organics in the wastewater and the amount of heat required [1] (autogenous point: COD 10 g/l). In this process, reaction heat derived from COD and from ammonia effectively contributes to the heat balance. Table 2 shows the heat output of various substances.
The contaminants (COD, ammonia, etc.) admitted into the catalyst-packed reactor at specified in T able 3.
As shown in Table 4, COD components are decomposed into carbonic acid gas or water via an intermediate product, which is low molecular weight carboxylic acid. Waste gas discharged from the reactor contains neither NOx nor SOx and is odor free. The mixed gas-liquid stream output from the reactor is cooled and the heat recovered before being separated into gas and liquid as required and discharged out of the system.

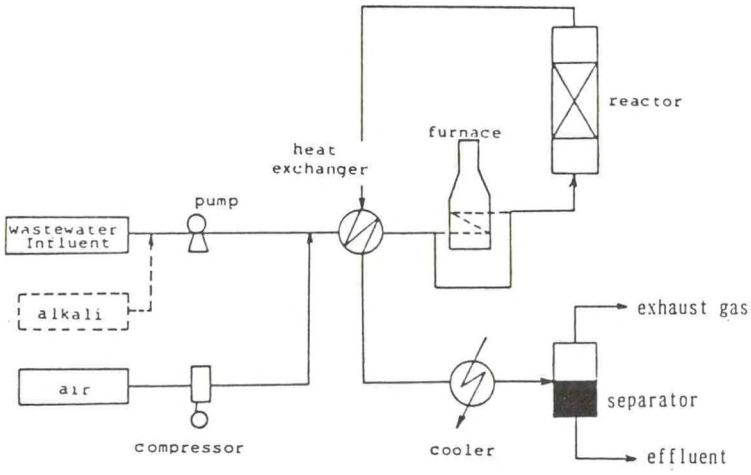


Fig. 1 Schematic Process Flow

Table 1 Conditions of Reaction

	Range
Temperature (℃)	200 ~ 300
Pressure (kg/cm^2G)	15 ~ 100
SV (1/hr)	0.5 ~ 10
Air ratio (vs. theoretical value)	1.05 ~ 1.2

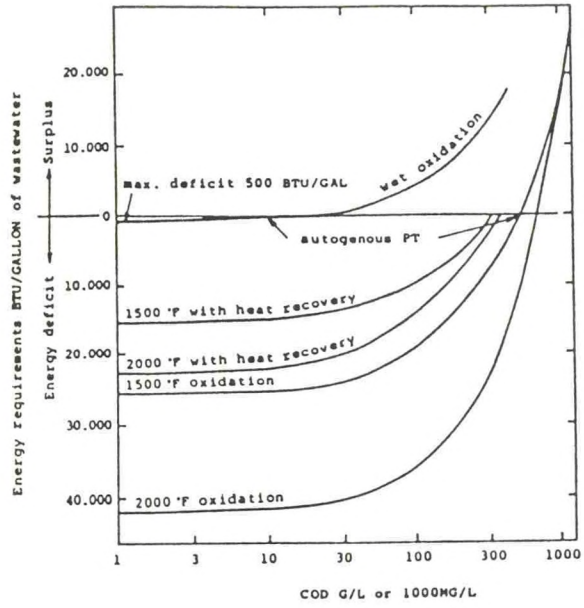


Fig. 2 Amount of Organic in the Wastewater; heat requirement (comparison of wet oxidation and combustion processes)

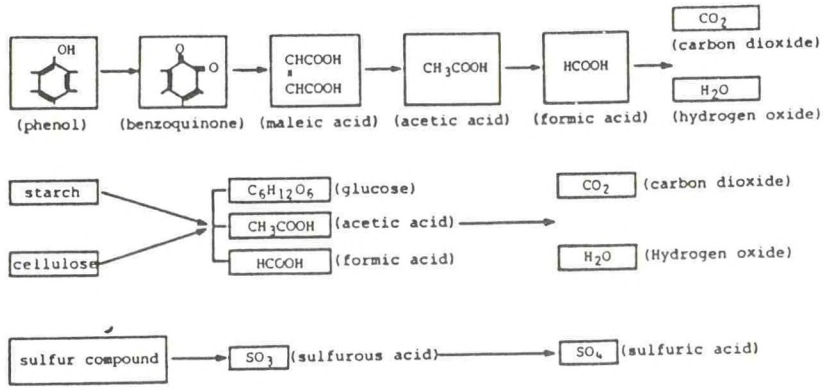
Table 2 Heat Output of Various Substances

Substance	Combustion heat	
	Kcal/kg	Kcal/kg (oxygen consumption)
Acetic acid	3,485	3,270
Oxalic acid	668	3,750
Pyridine	8,310	3,280
Phenol	7,608	3,260
Ethanol	6,806	3,400
Cellulose	3,744	3,490
Sulfite effluent	4,390	3,320
Sewage active sludge	3,635	3,040
Alanine	4,379	3,248

Table 3 Decomposition Reaction

1) Nitrogen compounds (nitrogen compounds, such as of ammonia, cyanide etc.) → Decomposed into N_2, H_2O and CO_2 Ex. $NH_3 + 3/4O_2 \rightarrow 1/2N_2 + 3/2H_2O$
2) Organics (hydrocarbon, common BOD, COD components, etc.) → Decomposed into H_2O and CO_2 Ex. $C_6H_5OH + 7O_2 \rightarrow 6CO_2 + 3H_2O$
3) Sulfur compound (sulfide, rhodanate, thiosulfate, etc.) → Decomposed into SO_4, salt, H_2O and CO_2 Ex. $(NH_4)_2S_2O_3 + 7/2O_2 \rightarrow N_2 + 2H_2O + 2H_2SO_4$ $NH_4SCN + 7/2O_2 \rightarrow N_2 + H_2O + CO_2 + H_2SO_4$
(Remarks: Combustible s.s. components are decomposable as above.)

Table 4 COD Reaction Mechanism



〔2〕 Conditions of Reaction

The conditions of reaction vary with the kind, concentration and type of contaminants in the wastewater and with the targeted water quality. Ordinarily, the requirements shown in Table 1 are applied.

2-1) Temperature and Pressure

The higher the temperature and pressure, the greater the reaction rate. Sufficient pressure must be applied to keep the water in liquid phase. A reaction rate nearly proportional to partial oxygen pressure, enriching the oxygen-to-air ratio in favor of the former, or use of pure oxygen could lead to reduced temperature and pressure.

2-2) Reaction Time

Prolonged reaction time (ordinarily, 0.1 to 2 horus) can enhance the decomposability of contaminants in the wastewater.

2-3) Amount of Oxygen

Such contaminants can be decomposed by a volume of oxygen 1.05 ~ 1.2 times the theoretical value derived from the decomposition reaction formula above.

2-4) pH

As the ammonia compounds (including organic nitrogen compounds) in the wastewater turn into nitrogen gas and the sulfur compounds into sulfate ions, pH is lowered. Therefore, an alkaline solution is added either before or during the reaction to adjust effluent pH to 5.8 ~ 8.6, to be safely discharged.

〔3〕 The Treatment of Wastewater (gas liquor) from Coke Oven

Fig. 4 shows the result of long and continuous test of activity using a plant(wastewater treatment capacity 6 m^3/ day. See Fig. 3) equipped with 12-inch reactor(6500 mm high)
A newly-developed catalyst for this process is very stable and the result of approximately 11,000-hour continuous test of life using coke over liquor showed no change in its activity. The concentration for COD and ammonia was 6200 ppm and 2500ppm, respectively. Under the operating conditions of 250℃temperature, 70 kg/cm^2G pressure and 20minutes reacting time, COD and ammonia, concentration in the treated water remained nearly at 100 ppm and 70 ppm, respectively.

Capacity: Originally 6 m^3/d, currently scaled up to 60 m^3/d
(Successfully completed under state subsidy granted by the Agency of Industrial Science & Technology, MITI in 1979)

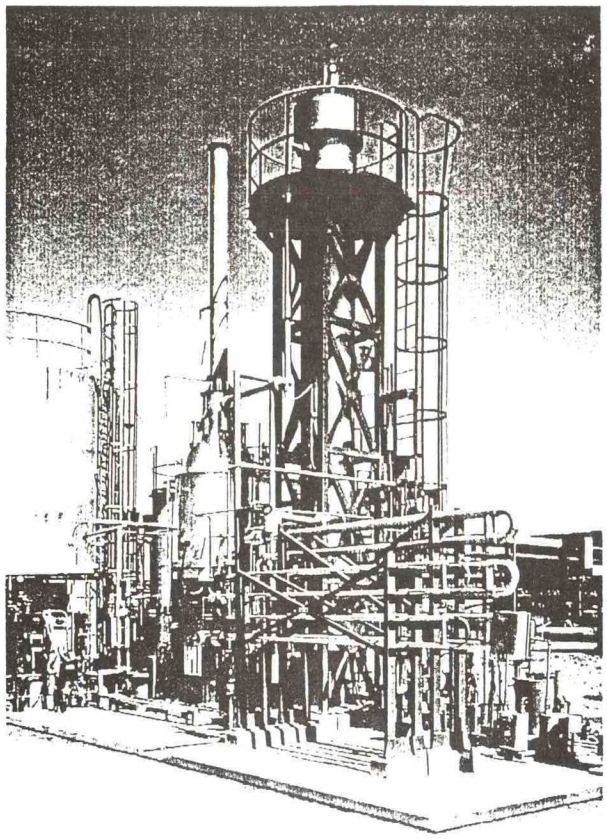


Fig. 3 Appearance of Test Plant

Operating conditions		
	Temperature	250 °C
	Pressure	70 kg/cm²G
	SV reaction time	3 Hr^{-1} 20 Min
	Sample	Coke oven gas liquor

Initial concentration of sample	COD	NH_3-N
Average	6,240	2,520
Max	7,270	2,910
Min	4,480	2,400

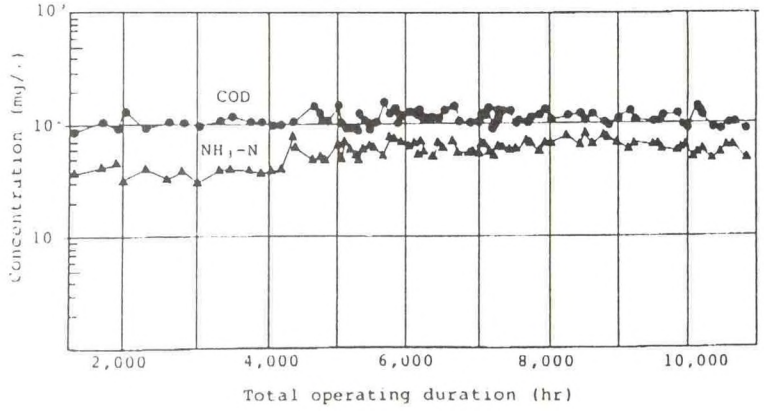


Fig. 4 Continuous Activity Test Results: Gas Liquor

〔4〕 Treatment of night soil

Several techniques to treat night soil have been developed and commercialized, including the Zimmerman and other biochemical processes. Table 5 and Fig. 5 show the results of treating night soil, collected in T--City, using our new process. Specifically, this new process removed COD, ammonia and suspended solids, etc., to less than 10 ppm in a single step without dilution. Odor and color were also removed, in addition to adequate disinfection. This process dose not generate sludge, and dispenses with secondary treatment facilities. We are planning to expand the application of this nondilutive process to night soil treatment on a commercial scale.

Table 5 Example Test Results on Night Soil

Operating conditions	Temperature	℃	250	250	250	280
	Pressure	kg/cm²G	70	80	90	90
	Initial pH	—	9.0	9.0	9.0	9.0
	Reaction time	Hr	1.0	1.0	1.0	1.0
Item	Raw wastewater		Effluent	Effluent	Effluent	Effluent
pH	6.85	—	7.2	6.9	7.0	7.3
COD(M_n)	4,900	mg/ℓ	34	4	3	4
NH_3-N	3,090	mg/ℓ	2	2	2	6
TOD	26,600	mg/ℓ	555	N.D	N.D	N.D
TC	7,100	mg/ℓ	890	730	700	520
TOC	6,200	mg/ℓ	340	50	N.D	20
BOD_5	15,300	mg/ℓ	518	71	24	7
P	100	mg/ℓ	1.9	3.1	1.1	0.7
SS	20,000	mg/ℓ	1.9	2	N.D	N.D

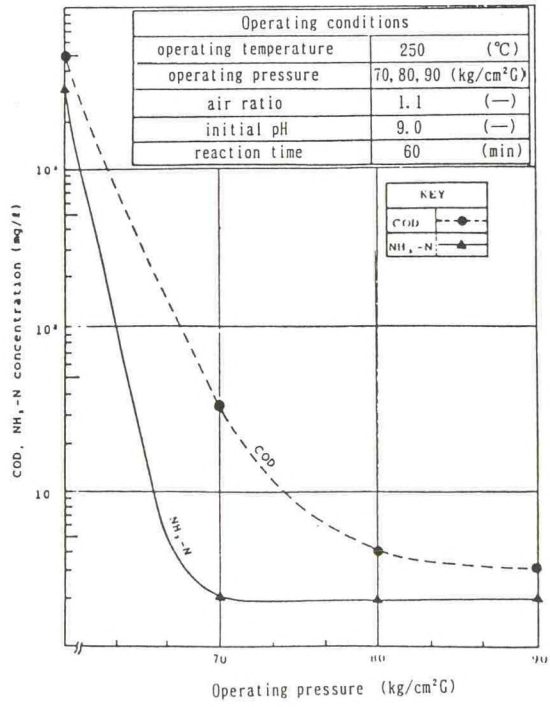


Fig. 5 Typical Test Results on Night Soil

〔5〕 Features of the Catalytic Wet Oxidation Process

In conclusion, the features of this process are as follows:

(1) Process

1) Advanced single process treatment
2) Simultaneous removal of pollutants in the wastewater, i.e., ammonia, COD ,BOD SS, etc., without dilution
3) Simultaneous odor and color removal
4) No NOx nor SOx, turns pollutants into harmless nitrogen gas, carbon dioxide and water
5) No sludge generation or like byproductts

(2) Economy

The running cost is less than that of conventional process.

(3) Operation

Stationary state is usually reached 1 to 3 hours after start-up. Stable, continuous and automatic operation despite variations in water quality.

(4) Installation space

The equipment is small and compact, requiring little installation space.

(5) Scope of application

This process can be applied to various industrial effluents.

(6) Other

1) Allows reuse of effluent.
2) Eliminates need to treat exhaust gas.
3) Effective utilization of reaction heat eliminates the need for heating fuel.

〔6〕 The Conclusion

We have so far briefly seen the catalytic wet oxydation process. The confirmation has been made on the applicability of the process, testing more than 40 kinds of wastewater. Besides the case of highly decomposing pollutants altogether and dischanging them directly by setting a certain condition, it is possible to desalinate and put them into recycle, effectively using the pressure in process series and connecting them with reverse asmosis. I would be happy if the technology presented here could serve somehow for the wastewater treatment and its recycle in the controlled ecological life support system.

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Effect of Coastal Features on Seawater Quality

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Introduction

Eutrophication, caused by the excess nutrient inflow, is one of the most sever problems for water quality in inner bays in Japan. Internally produced organic as well as inflow organic substances from surrounding cities, effects badly to such water quality as smells, water color and turbidity, oxygen concentration at bottom layer and organic accumulation on the bottom surface. Species diversity will be lost and active species will become limited. Upwelling of the oxygen depletion bottom water sometimes causes fish-kill along coasts. Bottom shell also receives bad damages in summer. The royal road to improve water quality is to decrease nutrient concentration so as to eliminate organic synthetic activities by phytoplankton. Numerical simulation models which include nutrient-organic interaction processes in coastal sea, have already been developed and applied to assess the effect of the various policy options.

This report discusses on the possibility of the local water quality improvement by promoting and enhancing natural activities on the coastal features and facilities. The natural activities mainly dealt here, are those of biofiltration by attached animals or benthal bivalves. Main concerned area is water surface along the coast ("water-front" area).

Water Quality system in Enclosed Bay -- Simplified Model Analysis

Effective counter measures may be changed due to the hydraulic conditions (flow advection, diffusion, or exchanging rate of water mass) or pollutant characteristics (loading rate, or degradation difficulty). Let us consider the change of water quality by a simplified model[1]. **Fig.-1** shows a simplified bay with one open mouth to outer ocean. Say V for water volume of the bay, C for water quality concentration in the bay, W for pollutant load to the bay, Q for net tidal inflow at flood tide from the outer mouth, and q for freshwater inflow from inland. Then, tidal outflow equals to Q+q at ebb tide. We can assume that pollutant concentration in outer ocean is zero, and that this bay is well mixed inside.

Also, let k as the purification rate in the bay water. Usually, this parameter k is defined as a first-order reaction rate. First-order reaction is expressed as;

$$dC/dt = -kC \qquad (1)$$

where t is time. For particulate settling, change of the particle concentration is

described as;

$$dC/dt = -(ws/h)C \qquad (2)$$

where ws is settling velocity, and h is water depth. Then, k means ws/h ratio. For microbiological degradation of the soluble organic, k means biodegradation rate itself. For particulate organic, k means sum of the each removal rate.

The change of pollutant mass in the bay is then expressed as;

$$\Delta(CV) = W - (Q+q)C - kCV. \qquad (3)$$

We set zero for the left hand side of the above equation so as to get the steady state solution for this system. Steady state concentration Ce is;

$$Ce = \frac{W/V}{(Q+q)/V + k} = \frac{W/V}{1/t0 + k} \qquad (4)$$

where t0 is hydraulic retention time of the water body, defined as $t0=V/(Q+q)$. Reverse number of t0 indicates degree/rate of water exchanging with outer ocean. When we consider Ce as mean summer concentration of nutrient, we roughly estimate organic concentration (COD) as a proportional value of Ce.

Looking at Eq.(4), we can easily point out measures for the decrease in Ce.

1) Ce is proportional to W. Cut-off of W makes Ce decrease linearly.

2) Ce is reverse proportional to the sum of exchanging rate and k. Promotion of exchanging rate and/or removal rate decrease Ce. Sensitivity of t0 or k to Ce changes with the combination of t0 and k values of the bay system.

In actual bays, there exists concentration slope/derivation inside the water body. The assumption of the above simplified model are not necessarily satisfied. **Fig-2** shows the summer COD distribution of the surface layer (0-5m) in Tokyo Bay. COD patterns are effected by boundary conditions, showing higher concentration at the inner bay near river inflow and lower at the open mouth. Besides, in enclosed bays, t0 becomes larger and tidal exchange rate (1/t0) is rather small. Mean t0 for whole Tokyo Bay is said to be ~50 days[2] for nutrients. Accordingly, k plays an important role for Ce improvement along the coastal area, especially the coast at the inner bottom of an enclosed bay.

Potential Effect of Biofiltration -- Literature Survey

Officer et al., (1982)[3] discussed the biofiltration effect of benthal bivalves community on phytoplankton concentration in shallow South San Francisco Bay. They pointed out that high dense community decreases the chlorophyll pigment concentration of the upper laying water effectively in summer. Gerritsen (1988)[4] discussed hydraulic effect for biofiltration efficiency in the actual field. He insisted that benthal community in shallower water has a larger chance to catch suspended organic detritus into shell valves. Winter (1978)[5] summarized physiological and natural conditions which alter

biofiltration rate of attached shells. Biological filtration rate varies in wide rage when it is measured by laboratory experiments. These values from laboratories can hardly be applied directly to the actual field. But, still there exists the possibility for us to apply these natural biofiltration activities to decrease particulate organic substances in concentration effectively.

Rate of Biofiltration -- Laboratory Experiments

Field observation was conducted to know the distribution of present coastal features of Tokyo Bay. **Fig.-3** shows the observation results. Most of the total coastal length are covered by the artificial features. Along this observation, species density of attached or benthal shells were also investigated from samples collected by divers. Some of the typical species were examined at the laboratory to get the biofiltration rate in flow-water system, under the similar conditions as those at the sampling sites (organic and particulate concentration).

The results of the filtration rate are listed in **Table-1** for some species. Using these rate and community density as well as community existing area, we can get apparent filtration rate for each coastal feature. Calculation results are tabulated in **Table-2** for 3 area in Tokyo Bay for summer. In this table, filtration rate is expressed as removal COD kg per unit coastal length in m (or per unit area in m^2 for marsh and beach) per SS concentration there per a day. This table suggests that improvement potential due to modification of the coastline can be estimated. If a new facility for coastal features has enough surface area to support high attached biomass, it will possess high biofiltration activity to improve water quality around it.

Estimation of the Improving Effect -- Numerical Experiments

A numerical simulation model has developed for the COD estimation in eutrophic bays. This 3-layer advection-diffusion model can express substance budget and cycles of phosphorus as well as organic(COD) and dissolved oxygen(DO), including photosynthetic process, degradation, settling, release from bottom sediment and reaeration at surface.

Numerical experiments are conducted by this simulation model[6]. Simulation of seawater quality was first carried out with present coastal features, then a vertical wall all along the coastline and thirdly with sandy beaches all along the coastline. The value of SS concentration required for the estimation of improvement rate in **Table-2** is calculated using a specific rate (SS/COD =1.584) obtained at the coastal area in this bay. This improvement rate is applied as a negative load along the coast in the model.

Based on the COD values of the first case for present features, COD increment is estimated due to the change of features. COD increase in the upper layer is shown in **Fig-4 and 5.** Assuming that the whole coastline is vertical wall, COD increases 1.2mg/l in the inner

area and 0.4-0.5 mg/l in the central of the bay. In the case where the whole coastline is sandy beach, COD decreases up to 1.5 mg/l at inner most area of Tokyo Port. All these difference occur due to the difference biofiltration activities along the coast.

Cautions should be paid to the uncertainty of the community filtration rate and of the simulation results also. We can roughly estimate potential effects of the features or types of coastal facilities which will promote biological purification activities and will improve water quality.

Conclusion

Improving potential due to the change of coastal features is examined using a numerical model and biofiltration data. Effect of coastal features on seawater quality may be significantly large, if the facility is well designed to maintain high density of attached biomass on its wide surface area under proper environmental condition. For higher accurate estimation, more data on the biological activities and investigations about the organic removal mechanisms on the surface of the coastal features are both required.

Important discussions and suggestions are received from Dr.Horie, director of Marine Hydraulics Division, Port and Harbour Research Institute. The author expresses his sincere thanks to these contributions.

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Figures and Tables

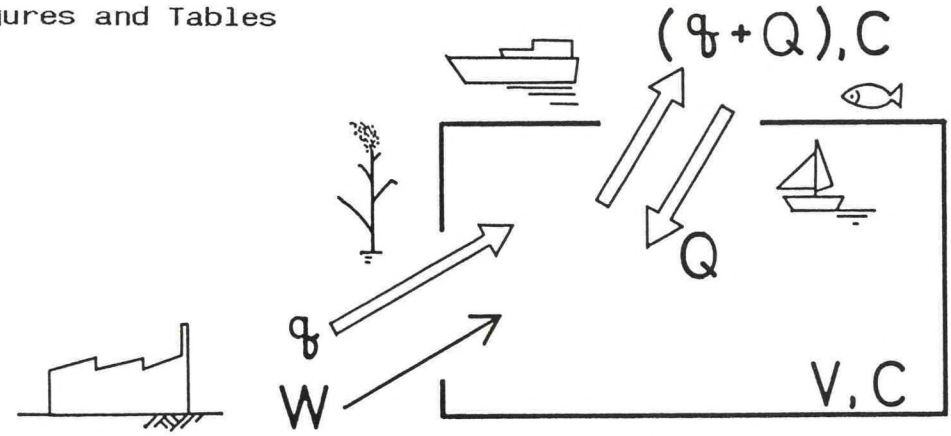
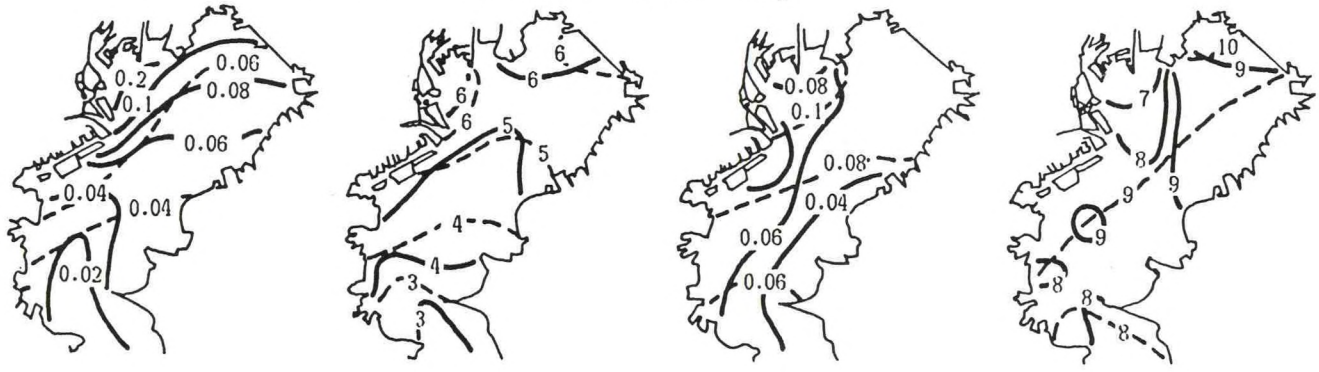
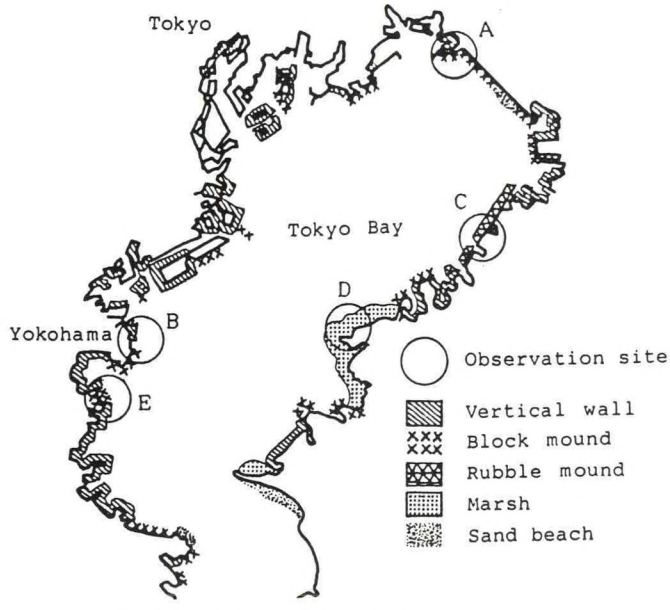


Fig.-1 Schematic diagram for model bay



O-P COD PO_4-P DO

Fig.-2 Water quality distribution in surface layer of summer Tokyo Bay (dotted line: numerical simulation results, solid line: observation results)



Fig,-3 Present coastal features of Tokyo Bay

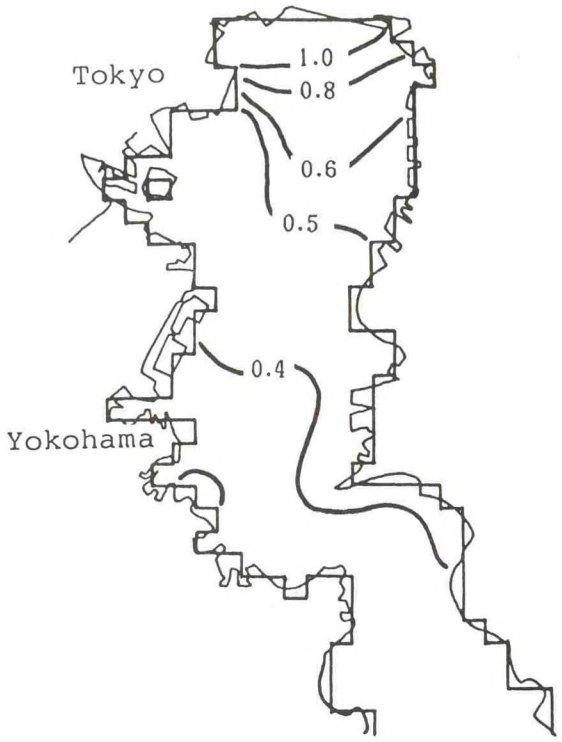


Fig.-4 Change in COD in upper layer due to different coastal features (The entire coast is assumed vertical wall.)

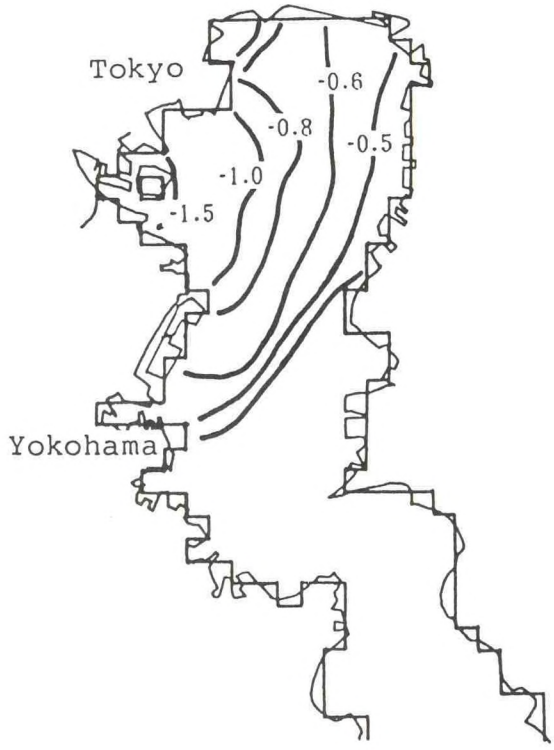


Fig.-5 Change in COD in upper layer due to different coastal features (The entire coast is assumed sandy beach.)

Table-1 Observed filtration rate for some sampled species

species(size)	filtration rate (ml/ind/h)	literature range (ml/ind/h)
Chthamalus stellatus (1mg)	3- 5	2- 15
Mytilus edulis (30-55mm)	80- 210	500-3000
Rudilapes philippinanum (30-40mm)	100-1000	600-1500

Table-2 Removal COD due to coastal features in Tokyo Bay
(unit: COD-kg/unit coast length/ SS /day for line features)
(unit: COD-kg/unit area/ SS /day for marsh and sandy beach)

coastal feature	inner bay	central bay	bay mouth
vertical wall (kg/m/SS/d)	0.10	0.48	0.0094
block mound (kg/m/SS/d)	0.54	1.84	0.023
rubble mound (kg/m/SS/d)	0.64*	0.64	0.64*
muddy marsh (kg/m2/SS/d)	0.0024	0.0003	0.0067
sandy beach (kg/m2/SS/d)	0.0013*	0.0013	0.0013*

* As observation sits for "rubble mound" and "sandy beach" are limited to the central bay area only, the same value as that at central bay is applied to the other area.

ENVIRONMENT IMPROVEMENT ENGINEERING METHOD USING DREDGED EARTH AND SAND

1. Introduction

Due to the rapid economic development and the remarkable concentration of population to cities through the high economy growth period after the war, environment has been worsened enough to produce the serious conditions the threatening people's health and the living environments. To cope with it, tackles with pollution problems were initialized in the decade from 1955 to 64 in answer to the strong social requests demanding prevention of the pollutions. In the decade from 1965 to 74, the institution for the environmental administration was completed in outline in the light of prevention of pollutions.

In the decade from 1975 to 84, as shown in the OEDC Report stating about Japan's environmental policies that" Japan won in the fight of environmental control, but it has not yet gained a victory over the war to enhance the quality of environment", "amenity", "creations of environment", "comprehensive policies" in addition to prevention of pollutions became important issues for the environmental administration. In pursuit of "creation of the tasteful and comfortable spaces", the environmental administration of Ports and Harbours Bureau has been executing various projects to arrange "Comprehensive Ports and Harbors Spaces" where the functions of "physical distributions", "productions", and "lives" are well harmonized.

In this paper, we would like to introduce a harbor environment administration at harbors and seas called the Sea Blue Project aiming at "creation of comfortable spaces", in particular, preservation and improvement of bottom sediments, water, and marine life with sand covering engineering method.

2. The Sea Blue Project

When surveying the recent social conditions around ports and harbors, it is considered that, backed by increasing needs for qualitatively affluent, tasteful, and high quality life environments, and the expanding demand for leisure activities the requests to arrange the port and harbor spaces as amenity spaces and recreation spaces will continue in future in order to further highten and expand the living functions of port and harbor spaces.

Urged by this trend, Ports and Harbors Bureau of Ministry of Transport is proceeding in research and realization of a project, called the Sea Blue Project with the image of blue water, which will bring more comfortable sea area surroundings and promote more hydrophlic use by means of purification of water and bottom. At present, for the purpose of execution of the sea Blue Project, development of technology for purification of water and bottom is in progress extensively incorporating the state-of-the art technique.

3. Research on Sand Covering Engineering Method

Since the fiscal year of 1979, Ports and Harbors Bureau of Ministry of Transport has been conducted survey and research for the purpose of purification of the bottom sediments at the contaminated sea areas.

3.1. Survey and Research on Purification of the Bottom Sediments

As shown in the structure in Fig. 1, following problems were examined.

- Grasp of the actual conditions of sea area environment: water, bottom, marine life, release of pollutants from bottom sediments etc. of closed type sea areas
- Estimation and examination of project effects: contaminant mechanism of closed type sea areas, examination of purification engineering method, effects of purification measures etc.
- Examination of plans of bottom purification works: investigation of approximate project costs etc.

This report mainly refers to the survey results on Mikawa Bay and Suoh Sea (the Inland Sea).

Fig. 1 Structure for the Study and the Research on the Bottom Sediments Purification

- Actual conditions of sea area environment

Table 1 shows the main features of the five sea areas of Mikawa Bay, Tokyo Bay, Osaka Bay, Hiroshima Bay, and Suoh Sea, which are taken up for this survey, and Fig. 2 and Fig. 3 show the geographical conditions of Mikawa Bay and Suoh Sea respectively.

COD and phosphorus inflow load at Mikawa Bay and Suoh Sea are in the almost similar level, and they are considerably low compared with those at Tokyo Bay and Osaka Bay. As for the ratio of COD released from the sediments to the inflow load, Suoh Sea shows the remarkably large figure of about 10, and Mikawa Bay shows the larger figure than the other three seas. It indicates the necessity ofmeasures against the bottom sediments.

Table 1 Main Features of Five Sea Areas

Fig. 2 Location, Sea Bed Configuration of Mikawa Bay, and the Position of Verification Work

Fig. 3 Location, Sea Bed Configuration of Suoh Sea, and the Position of Verification Work

3.2. Outline of Verification Works and Follow-up Examinations on Effects

For reduction of COD released from bottom sediments dredge of sludge or sand covering on the bottom sediments is considered effective. In particular, it is considered that sand covering engineering method restricts release of organic matters and metrient salts by covering sediments on the sea bottom with good quality sand. Also, the improvement effects as shown in Fig. 4 is considered by purificating the bottom sediments. Accordingly, not only improvement of water of the sea area but recovery of marine life be expected. To verify, the effects, the trial sand covering works were carried out at Mikawa Bay and Suoh Sea. The outline of works is summed up in Table 2,

and the execution points of the trial works are shown in Figs. 2 and 3.

Fig. 4 Improvement Effect and Influence of Bot tom Purification on the Ocean Ecosystem

Table 2 Outline of Verification Works

To demonstrate improvement effects on the bottom at the two trial work sites, Fig. 5 (Within Kannda Port) shows the periodical changes of the surface layers of the bottom sediments of sand covered zone and Fig. 6 (Off Khowa Port) shows the changes of vertical distribution of the bottom sediments. The results show that COD content at the sand coverage zone just after sand coverage reduce remarkably compared with that at the original ground, but, as time passes, COD content on the sand covered surface tend to increase gradually on account of sedimentation of floating mud. However, the figure is still low compared with that on the original ground, and increase of COD is limited to the extreme surface of the sand covered zone. It is found that, the effect is still kept even after 21 months have passed since sand coverage.

Fig. 7 (Off Khowa Port) and Table 3 (Within Kannda Port) shows the periodical changes of benthos at the trial work site. The results show the existing quantity of benthos at the sand coverage zone largely surpasses that at the original ground in terms of both of the number of individuals and the wet weight. Moreover, the number of the sorts is high at the sand coverage zone. it is inferred that the benthos become affluent both in quantitatively and qualitatively owing to sand coverage.

Fig. 5 Periodical Changes of COD in the Surface Layer of the Bottom Sediment (Within Kannda Port)

Fig. 6 Changes of Vertical Distribution of COD (mg/g dry weight) in the Bottom (Khowa Port)

Fig. 7 Periodical Changes of Number of Individual and Sort of Benthos (Off Kowa Port)

Table 3 Comparison of Benthic Biota at Sand Coverage Zone and at Deposit Zone (within Kannda Port)

For examination of growing conditions of shells on the sand covered zone, shells were transplanted inside and outside of the sand coverage zone and the growing conditions were compared at Suoh Sea. Table 4 shows the comparison of growing conditions of short-necked clams for 22 months since transplantation at the sand covered zone and the original bottom. This table tells that the death rate of short-necked clams at the sand covered zone is lower than that at the original bottom, so it is considered that the sand covered zone is more suitable for growing of short-necked clams. On the other hand, little diffference is observed as to the growth. This is because the difference of natures (organic matters and reducibility) of the bottom largely influences on the death rate and more favorable environment for shell is maintained at the sand covered zone, whereas both zones equally receive the influence of water which is concerned with feed supply.

Table 4 Comparison of Growing Test Results on Short-Necked Clams at Sand Covered Zone and at Original Bottom Zone

3.3 The Marine Environment Improvement Work

Based on the results of the study and verification works concerning purification of the bottom sediments, the Marine Environment Improvement Work was established in the fiscal year of 1988 as a measure for restoration of water and bottom quality and recovery of affluent marine life by covering on the sea bottom or beaches with good quality sand at the sea areas of which sediments are contaminated.

At present, for execution of this work, superior quality sand among the sand dredged from waterways and anchorages is used as material to cover on the sea bottom and beaches for economic reasons.

As shown in Figs 8 and 9, there is a dredging plan of water way and anchorages near the contaminated sea areas at each of Mikawa Bay and Suoh Sea, the two sea areas referred to in this paper. Thus, execution of the Marine Environment Improvement Work is planned for creation of comfortable environment utilizing good quality dredged earth and sand coordinating with these dredging works. At Suoh Sea, the sand covering work was set about in the fiscal year of Show 63 (1988). Since the sand covered zone is smaller than the deteriorated bottom mud zone, the sufficient improvement is not expected at the whole of the sea area. But, taking account of utilization of dredged earth, the project was put into practice at the bottom where contamination is particularly advanced. Upon confirmation of the effects, the project will be enlarged in future for improvement of environment of the sea area as a whole. In addition, at the contaminated sea area with sedimentation of sludge in ports and harbors, budgetary assistance have been granted for the works of seashore purification utilizing good earth and sand expecting the similar effects.

Fig. 8 The Contamination Sea Area and the Place Where Dredged Earth and Sand Is Generated (Mikawa Bay)

Fig. 9 The Contamination Sea Area and the Place Where Dredged Earth and Sand Is Generate (Suoh Sea)

As of the fiscal year of 1990, this work has been executed at 2 general sea areas out of a harbor zone and at 2 harbors. Table 5 shows the outline of each plans.

Table 5 Outline of Plans of Marine Environment Improvement Project

4. Conclusion

1) Ministry of Transport has conducted the survey and research concerning purification of the bottom from the fiscal year of 1974 to the fiscal year of 1988. As a result of execution of the verification works using sand covering engineering method at Mikawa Bay and Suoh Sea and the follow-up survey, the following was verified regarding its effects.

i) Reduction of contaminant in the bottom
ii) Recovery of ecosystem at the sand coverage zone

2) Based on the above survey and research, the Marine Environment Improvement Project was started as a new environment betterment measure in the fiscal year 1988. This project aims to conduct sand covering on the polluted sea bottom and beaches using the sand of good quality at the contaminated sea area where sludge is accumulated, thereby create comfortable sea area environment.

3) In future, in addition to sand coverage and sludge dredging, new environmental technology such as sea water purification technoloty using biotechnology and sea water exchange system using ocean energy is expected to be put into practical use.

(Reference: "Proposal of Sea Blue Project utilizing natural action", a paper for the 14th Japan-U.S. Experts Meeting on the Management of Bottom Sediments Containing Toxic Substances, by Tadashi Hosokawa)

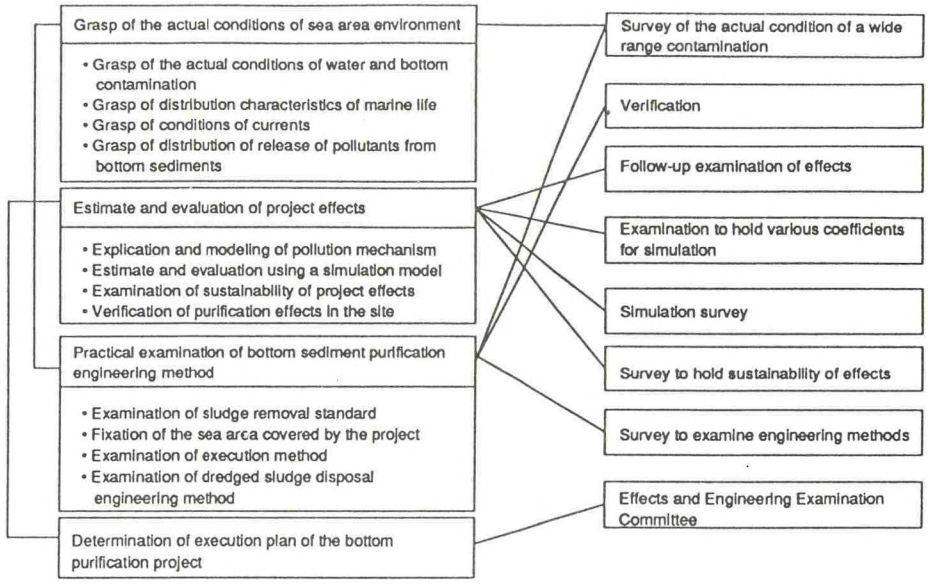


Fig. 1 Structure for the Study and the Research on the Bottom Sediments Purification

Table 1 Main Features of Five Sea Areas

Sea Area		Tokyo Bay	Mikawa Bay	Osaka Bay	Hiroshima Bay	Suoh Sea
Range (Zone)		Futtsu ~ Kannonzaki and northward	Nakayama Channel and eastward	Akashi Strait and eastward, Kitan Strait and northward	Ondo, Hayase, Hashirajima Strait, Moroshima Channel, Yashiro-shima, Ohshima Strait	Murotsu ~ Kunisaki ~ Moji and westward
Area (km^2)		1,000	510	1,400	1,000	3,000
Water Volume (m^3)		18 billion	4.6 billion	38 billion	25 billion	72 billion
Average Water Depth (m)		18	9	27	25	24
Geographical Features (Closed Type)		Joins the Pacific Ocean at Uraga Channel	Joins Ise Bay via Nakayama and Morozaki Channel	Joins Harima Bay at Akashi Strait and also join Kii Channel at Kitan Strait	Complicated geography dotted with several dozens of large and small islands	Joins Hibiki Sea at Kannon Strait and also joins Iyo Sea in south-east
Inflow Rivers	Main Rivers	Tsurumi River, Tama River, Sumida River, Ara River, Edo River etc.	Yahagi River, Toyo River, Shio River, Sakai River etc.	Yodo River, Yamato River etc.	Ohta River, Oze River, Nishiki River etc.	Saba River, Yamakuni River etc.
	Total Inflow Volume ($10,000m^3$/day)	2,600	1,200	6,000	1,100	1,600
Inflow Load Amount	COD (t/day)	285	50	285	70	50
	T – P (t/day)	22	4	30	3	1.1
Elution Amount	PO_4 – P (t/day)	6.3	3.3	13.7	13	9.7
	COD (t/day)	96	43	131	42	477
Average Water Quality	COD (mg/l)	4.3	3.2	1.8	2.1	0.8
	PO_4 – P (mg/l)	0.05	0.05	0.02	0.02	0.03
	O – P (mg/l)	0.05	0.03	0.02	0.02	0.006
	DO (mg/l)	13.3	9.2	7.2	6.9	6.5
Elution Amount	COD (t)	77,900	15,000	67,000	54,000	56,000
	PO_4 – P (t)	890	220	790	500	1,900
	O – P (t)	950	140	860	490	455
	DO (t)	240,000	42,000	270,000	170,000	470,000
High Content COD Bottom Sedimentation Zones		Deep in the bay, Off Haneda	Ahead of Kira, Kinuura Bay	Deep in the bay, the north-east portion	Deep in Hiroshima Bay, Kure Bay,	Ahead of Buzen, Kannda, Kitakyushu, and Ube
Fresh Water Flow/Water Volume (per day)		0.014	0.003	0.016	0.004	0.022
Released COD Amount/Inflow Load		0.34	0.86	0.46	0.60	9.5
Internal Production Rate of COD/Inflow Load		24	36	14	34	52

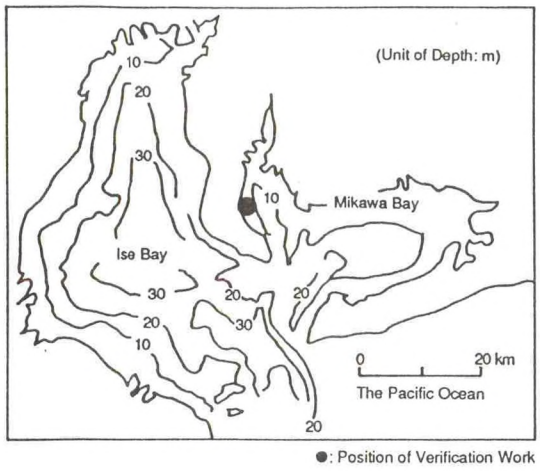


Fig. 2 Location, Sea Bed Configuration of Mikawa Bay, and the Position of Verification Work

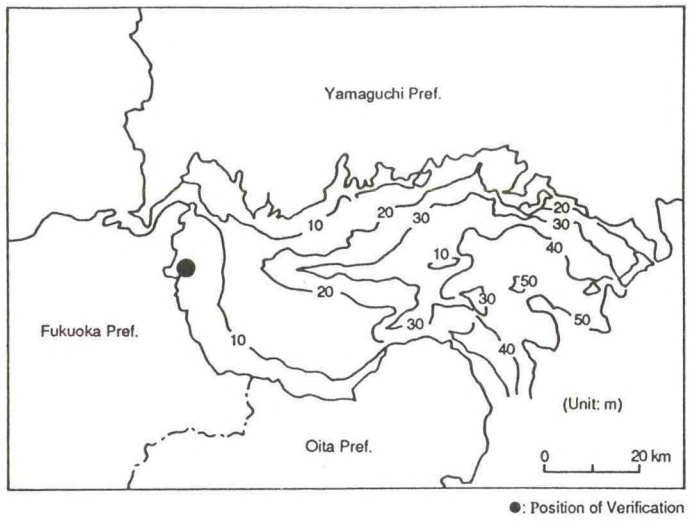


Fig. 3 Location, Sea Bed Configuration of Suoh Sea, and the Position of Verification Work

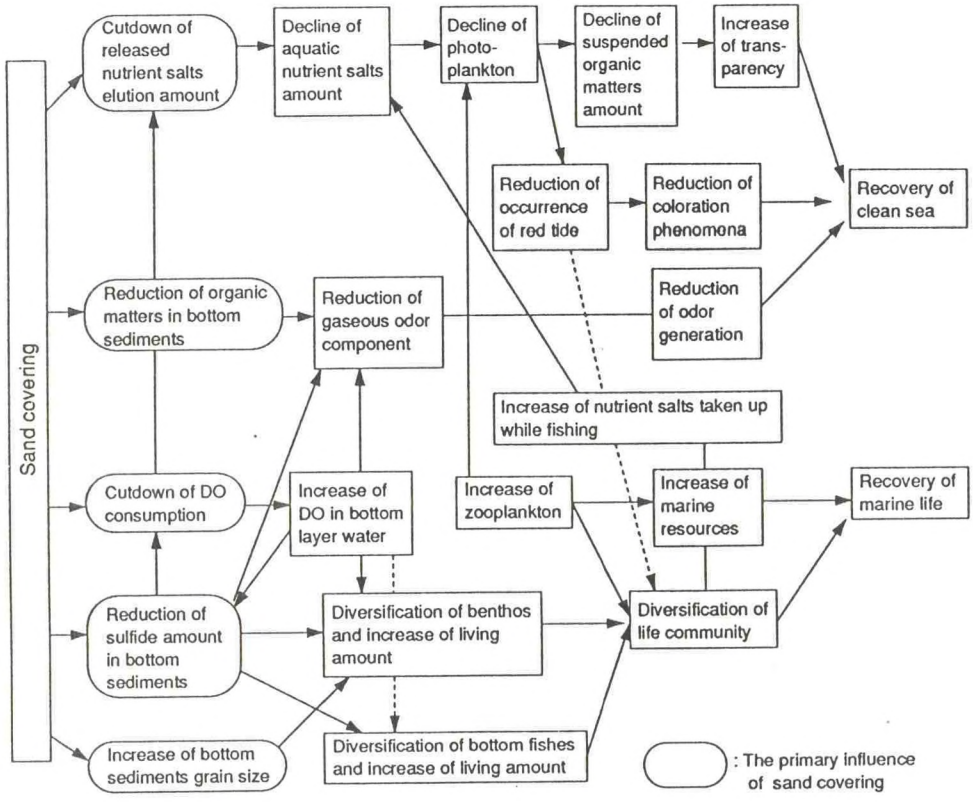


Fig. 4 Improvement Effect and Influence of Bottome Purification on the Ocean Ecosystem

Table 2 Outline of Verification Works

Sea Area	Mikawa Bay	Suoh Sea
Execution Site	Off Khowa Port	Within Kannda Port
Water Depth	DL – 5m	DL – 1m
Execution Time	June 1987	January 1987
Execution Scale	1.5ha (100m×150m)	900m² (30m×30m)
Thickness of Sand to Cover	0.5m	0.3m
Execution Method	Unloader Barge	Grove Dredger Direct Throwing Method

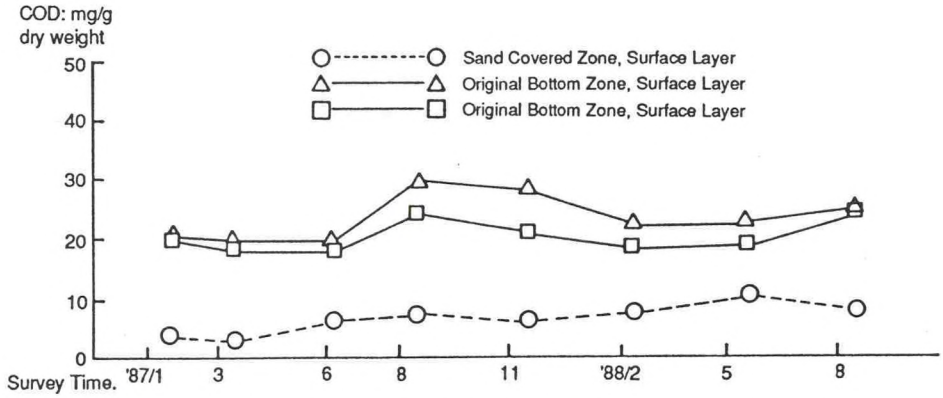


Fig. 5 Periodical Changes of COD in the Surface Layer of the Bottom Sediments (Within Kannda Port)

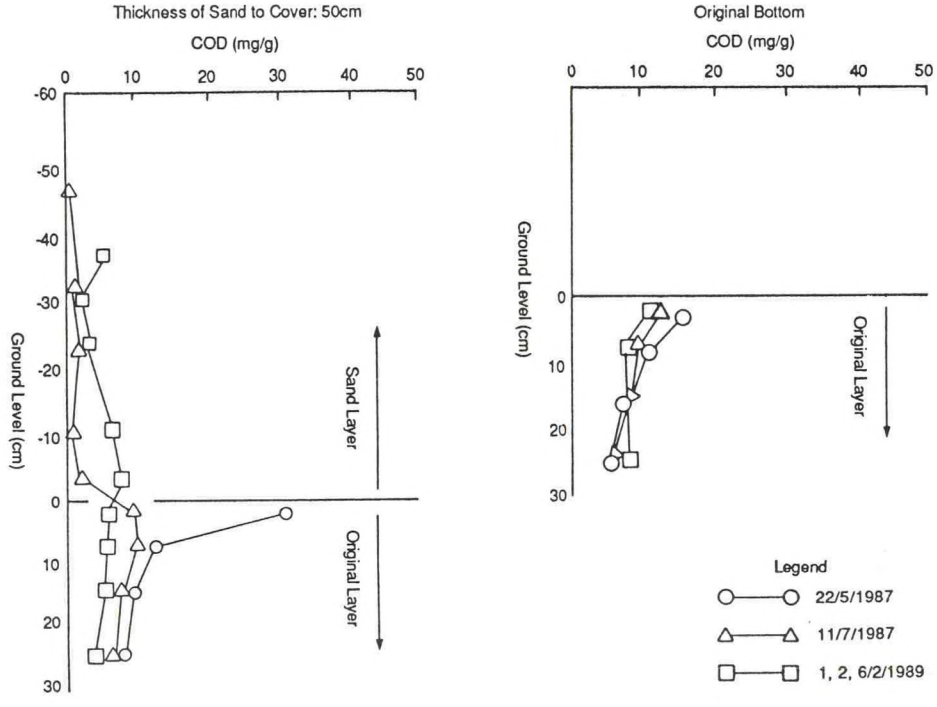


Fig. 6 Changes of Vertical Distribution of COD (mg/g dry weight) in the Bottom (Khowa Port)

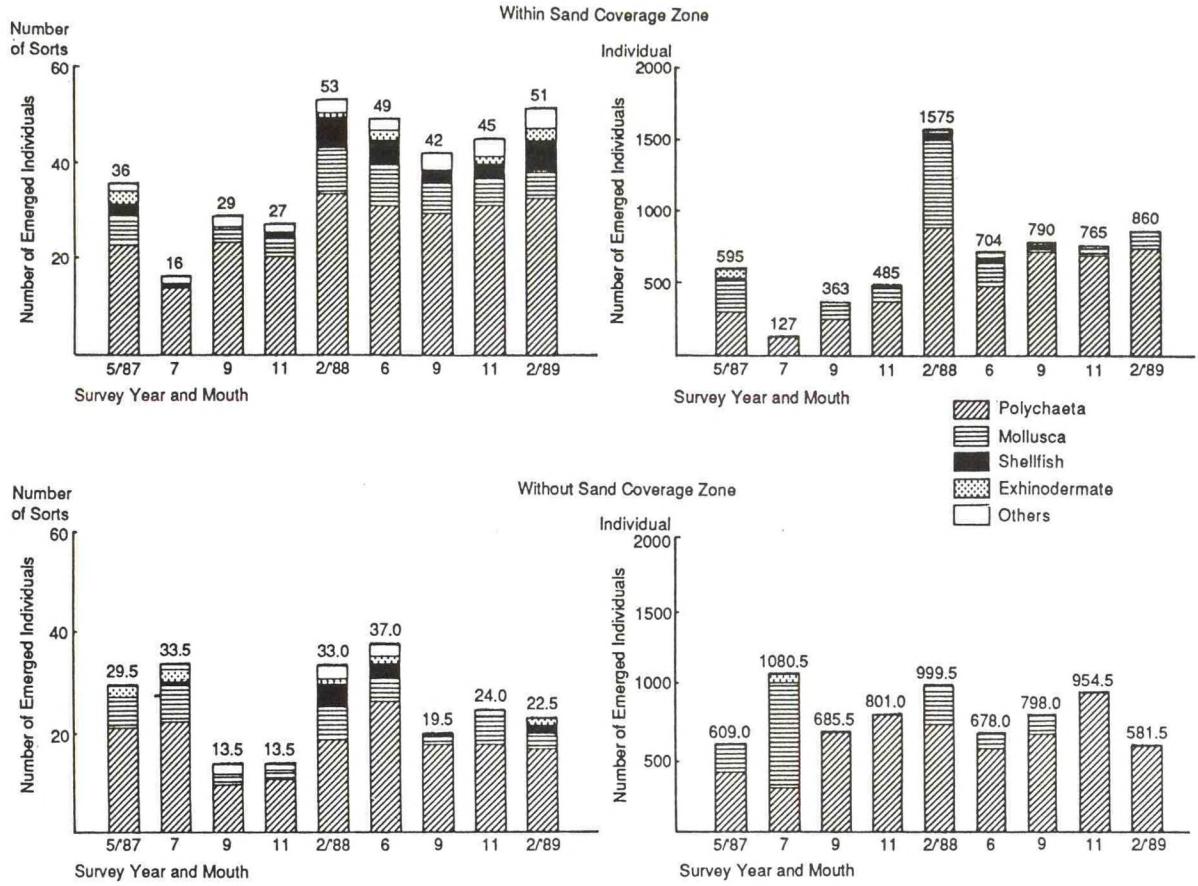


Fig. 7 Periodical Changes of Number of Individual and Sort of Benthos (Off Kowa Port)

Table 3 Comparison of Benthic Biota at Sand Coverage Zone and at Deposit Zone (Within Kannda Port)

Item \ Division	Sand Covered Zone, Average (Range)	Original Bottom Zone, Average (Range)
Number of Sorts	24.0 (10 ~ 46)	7.3 (2 ~ 13)
Number of Individuals (Individual/m^2)	2,185.4 (253 ~ 8,419)	239.9 (45 ~ 460)
Wet Weight (g/m^2)	530.72 (1.20 ~ 2,298.05)	127.40 (0.28 ~ 510.06)

Table 4 Comparison of Growing Test Results on Short-Necked Clams at Sand covered Zone and at Original Bottom Zone

Item \ Division	Sand Covered Zone	Original Bottom Zone, Re-transplantation*	
Death Rate (%/day)	0.001	0.004	0.004
Growth (mm/day)	0.020	0.019	0.020

Note: Re-transplantation in the original bottom zone shows the test results of re-trasplantation since all the short-necked clams re-transplanted in the original bottom zone died during the testing period.

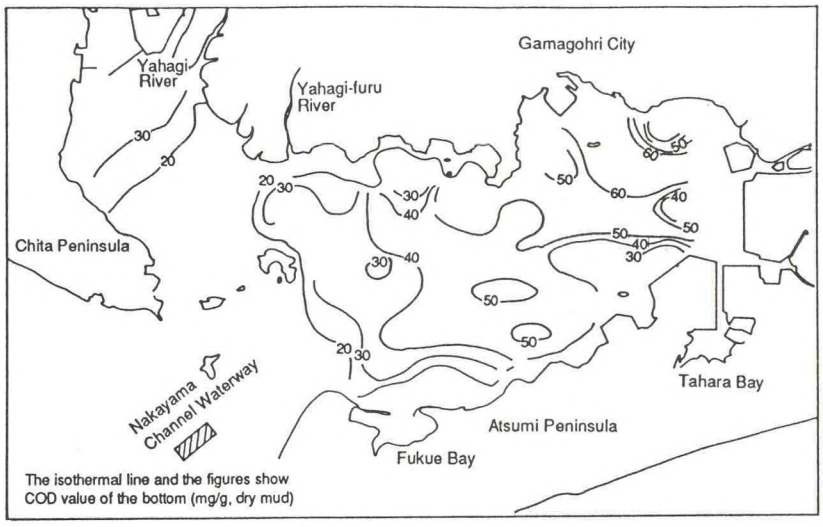


Fig. 8 The Contamination Sea Area and the Place Where Dredged Earth and Sand is Generated (Mikawa Bay)

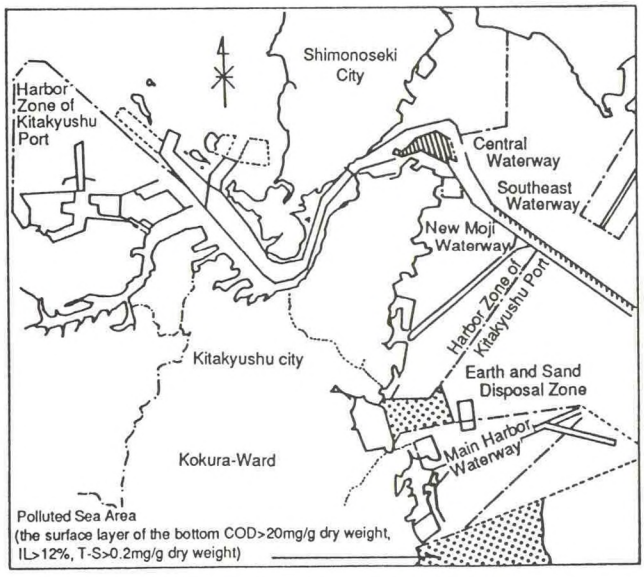


Fig. 9 The Contamination Sea Area and the Place Where Dredged Earth and Sand is Generate (Suoh Sea)

Table 5 Outline of Plans of Marine Environment Improvement Project

Sea Area (Name of Port)	General Sea Area (Without Harbor Zone)		Within Harbor Zone	
	Mikawa Bay	Suoh Sea	Tokuyama Kudamatsu Port	Itsukushima Port
Sand Covered Area (ha)	430	38.9	(39.3)	(7)
Volume of Sand to Cover (m^3)	2,580,000	155,700	170,000	70,000
Submerged Breakwater	—	—	1,680	300

Tokuyama Kudamatsu Port: Yamaguchi Prefecture
Itsukushima Port: Hiroshima Prefecture
Figures in parentheses shows the sand covered beaches