OCEAN SPACE UTILIZATION: THE BLUE REVOLUTION

Patrick K. Takahashi
University of Hawaii
Honolulu, Hawaii, U.S.A.

Joseph R. Vadus
National Oceanic and Atmospheric Administration
Washington, D.C., U.S.A.

ABSTRACT

Over fifty participants from the United States, Japan, France, South Korea and other nations from government, industry and academia participated at a workshop during PACON '92 to discuss the potential of Project Blue Revolution. Proposed was a one hectare (about 100,000 square feet) integrated ocean resource development and management floating platform for operation around the turn of the century at a cost of $500 million. The conference argued that in consideration of the potential economic and environmental benefits to mankind, the cost of this incubator plantship can be well justified compared to current and planned mega space and military projects. The potential for international cooperation is excellent, with a proposed next step to be a jointly funded development of a strategic plan.

WORKSHOP ORGANIZATION

The special workshop on ocean space utilization for the Blue Revolution was co-chaired by Joseph Vadus of the National Oceanic and Atmospheric Administration and Patrick Takahashi of the University of Hawaii and the Pacific International Center for High Technology Research. Six presentations were made by:

- Koichiro Yoshida of the University of Tokyo on his work with designing floating structures;
- Haruo Yamamoto of Kajima Corporation reporting on the activities of the Floating Structures Association of Japan;
- Craig MacDonald of the Hawaii Department of Business, Economic Development and Tourism on the marketing of ocean resource products and research capabilities;
- Joseph Vadus of NOAA on international programs;
- George Hagerman of SEASUN Power Systems, who sent a set of viewgraphs reporting on a study he was completing for the State of Hawaii on wavepower (this report is available from the State of Hawaii Department of Business, Economic Development and Tourism); and
- Patrick Takahashi, who overviewed the Blue Revolution concept (Takahashi and Matsuura, 1991).
After the initial panel presentations, questions were posed to arrive at consensus directions. A following section summarizes these responses.

**HISTORY OF PROJECT BLUE REVOLUTION**

When then President Ronald Reagan proclaimed the national Exclusive Economic Zone (EEZ—the 200 nautical mile region adjacent to territorial land) in 1983, he doubled the jurisdictional area of the Nation and made Hawaii, in combined land-sea domain, the second largest State in the Union. The USA has the largest EEZ in the world, of which 85% is located in the Pacific Ocean. This EEZ space holds high promise for development in tune with nature to enhance national productivity (National Science Foundation, 1986).

Since the Proclamation, Hawaii has hosted a myriad of ocean resource conferences, workshops and gatherings, and in parallel, has become the national R&D center for ocean energy, seabed resource recovery, open ocean mariculture, next generation floating structure design and the integration of these elements into a comprehensive program (Takahashi and Yuen, 1989). The Governor of the State of Hawaii, John Waihee, in the Foreword of the Governor's 1986 Symposium on Ocean Science and Technology remarked, “These Proceedings are rich with a variety of information on the ocean. They cover the research that is necessary to know the potential the ocean represents, the technology that will allow Hawaii to employ the ocean to its advantage and the commercial application of that technology to produce economic development and jobs for our people” (State of Hawaii, 1986). U.S. Senator Daniel Inouye (D-Hawaii) has been particularly active in supporting this endeavor, as summarized in his article on “The American Blue Revolution—A Solution for the 21st Century,” published in the September 1992 issue of *Sea Technology* (Inouye, 1992).

The Pacific International Center for High Technology Research has begun the process of developing a team to plan for such as project. The Hawaii State Legislature in 1992 created a Research Professorship for the Blue Revolution at the University of Hawaii to help guide the research that can provide fundamental input to the pre-commercial project.

A major international marine incubator enterprise such as Project Blue Revolution now has a greater probability of success because several active national and international ocean resource programs have been initiated. In Great Britain, their “Wealth From the Oceans” program has been managed since 1990 by the Department of Trade and Industry (DTI) in cooperation with the private sector. The Science and Technology Agency of Japan has prepared and initiated a strategic plan for ocean technology. In the United States, the National Science Foundation and National Oceanic and Atmospheric Administration brought together 35 national ocean specialists in June of 1992 to prepare a proactive report entitled “Ocean Resources 2000: Planning for Ocean Resource Development and Management” (McKinley, 1992).

**SUMMARY OF VERY LARGE FLOATING STRUCTURE PROJECTS**

Koichiro Yoshida and Haruo Yamamoto surveyed the examples of VLFSs in Japan. Among them include:

- Kamigoto Islands Crude-Oil Storage Base and Barge System;
• five year at-sea experiments of the semisubmersible, Poseidon, for meteorological and oceanographical data acquisition and proof of safety and reliability of design method;

• floating concept for Kansai New International Airport; and

• concept of a ring-shaped semi-submersible for creation of business space in Ise Bay.

In addition the Floating Structure Association has established task forces for feasibility studies on the following:

• floating airport;

• floating facilities for waste disposal;

• integrated floating port facilities, including techno-superliners;

• floating resort / sports facilities;

• oceanographic research base;

• multi-purpose floating cities; and

• floating highways.

The Floating Structures Association of Japan was formed in July 1990 to promote social capital development through ocean space utilization. One hundred and fourteen leading companies, including contractors, shipbuilding, financial and real estate firms are represented.

The Japanese government has for 1993 allocated $386 million for marine R&D, with the Ministry of International Trade and Industry ($107 million), Science and Technology Agency ($97 million) and Ministry of Agriculture, Forestry and Fisheries ($84 million) being the largest spenders. In comparison, it was reported that the U.S. National Oceanic and Atmospheric Administration has a budget of $1.3 billion, IFREMER (France) $190 million, Alfred Wegener Institute for Polar and Marine Research (Germany) $400 million, and the Natural Environment Research Council (United Kingdom) $220 million. (It was later mentioned in the follow-up discussion that the National Aeronautics and Space Administration has an annual budget of around $14 billion.)

Joseph Vadus reported on mega-projects announced for Japan and Korea:

• Obayashi Corporation ECOLAND project (1000 hectare marine city in harmony with nature to accommodate 45,000 people at a cost of $100 billion over 25 years);

• Tobishima Corporation Pan Japan Sea Tap Plan to build a square floating multipurpose city in the middle of the Japan Sea for international access and cooperation from Japan, China, CIS and Korea (4 KM x 4 KM breakwater structure, which would contain a floating 1 KM radius habitat for up to 100,000 people at a cost of $250 billion over a 25-year period);
• Osaka marine corridor plan for the Kansai region (a multi-stranded, multifunction cable used to provide high-speed trains for passenger and cargo transport, pipelines for oil, gas, water, air, power and communications, a 20-year plan at a cost of about $220 billion); and

• KORDI multi-purpose marine town development for Pusan (580 hectare artificial island spanning a time frame of 13 years at a cost of about $6.4 billion).

**WORKSHOP RESULTS**

**What are the major applications (commercial foci) for Project Blue Revolution?**

There was a strong sense that definitive products or services must be delivered, and that the private sector was a key component. The model served by the Floating Structures Association of Japan with more than 100 companies and five banks might be considered in developing an international team. Among the applications discussed included an integrated incubator plantship, waste management facility, energy generation platform, seabed minerals refinery, ocean ranching homeport and an observatory for ocean research. The R&D capability, however, has to be a secondary consideration to complement the commercial product or utility service.

**What are some of the socio-enviro-political justifications for the project?**

A key selling feature of Project Blue Revolution relates to the environmental benefits that can accrue. Early public education of the concept could be key to long term success. Among the justification points for operation on the open ocean include:

• reduction of stress in near coastal waters;

• removal of certain industries and processes away from populated regions so that any wastes can be recycled;

• good potential for total systems development in harmony with nature;

• creation of new fisheries and biomass plantations to help feed the world and provide alternative sources of cleaner energy;

• possibility of easier and more workable permitting and regulatory approvals, thus, minimizing delays; and

• the prospect for enhancement of the environment should the various proposed options for global warming remediation prove to be successful.

**What are some effective examples for establishing a consortium for government, industry and academic partnership?**

Japan’s Government-Industry cooperative efforts, Apollo and the space shuttle are some examples which have succeeded because of these partnerships.
What is the potential for international partnership?

There was a unanimity of opinion that the potential was good. The end of the Cold War reduced military expenditures and opens to question the sensibility of major space projects. The ocean is a last frontier ideal one for economic development with a commons that needs to be protected for the world. There was a sense that cooperation can be developed if mutual benefits can be shown.

Where should be the locus of operation?

The location of the initial platform will no doubt be driven by funding. However, site selection criteria need to be established to pick a best international site, or one that is ideally mission oriented.

What is the optimal size?

Again, to a good degree the amount of dollars will determine the scope of the program and design. One concept is to start small and modularize. Another is to pick a mission and design to an operational need. From an engineering standpoint, ultimate scale-up requires a practical modular size. A 100,000 square foot (or one hectare) platform was deemed as a good design point for incubator applications.

What are some possible strategies for funding an internationally cooperative project?

Before international funding can succeed, there must be a credible feasibility and marketing plan. While a B-2 bomber might cost nearly $1 billion and the Space Experiment could cost up to $50 billion, the military-aerospace industry already exists to propose and lobby for such expenditures. In Japan there are industrial alliances such as the Floating Structures Association capable of managing such a project. On the surface, in the United States, there is no equivalent organization or Federal agency equipped to start and implement this type of enterprise. However, the recent reduction in defense needs, coupled with a call for dual applications—current civilian and long-term military—might stimulate a hybrid organization where Federal funds can be earmarked for specific economic development projects in the spirit of the transcontinental railway system, which opened up the West.

Is the use of Japan’s “Aquapolis” applicable? Others?

There was a general feeling that past generation platforms, or even naval craft, were too costly from a maintenance standpoint. There are new materials, equipment and designs that can be marshalled for the 21st Century.

What should be the source of energy?

All options should be initially studied, but OTEC has particular advantages because of the nutrient-rich fluids useful for co-product development. Wave energy conversion can be added to produce energy while absorbing wave forces to ease forces on the platform.
Who should be the lead organization?

A cooperative feasibility study group should be established. The lead organization will thus depend on the specific application, location, and funding sources. A multinational consortium, or organization with international contacts might be best for this purpose.

What are some other factors requiring consideration?

Little, if any, consideration has been given to the regulatory and policy environment within which the floating platform would operate when ready for deployment. The implications of State (3-12 miles), Federal (EEZ to 200 miles) and International territorial sea conflicts need to be addressed. Regulatory considerations are also raised in regard to whether the platform would be bottom moored or surface propelled. These matters are essential to business planning and risk assessment as they entail potential “hidden” costs and uncertainty that need to be identified as soon as possible in the strategic planning process.

Future activities?

Plan for and hold a more comprehensive and structured workshop with greater industrial involvement. This meeting should also involve representatives from the environmental groups. The session co-leaders, Vadus and Takahashi, were charged with a task to organize and follow-up on these activities.

CONCLUSIONS

The overall conclusions were:

• An optimal size is about one hectare, which can be built, tested, and operated for about $500 million.
• A target date of the Year 2000 is reasonable.
• There are huge food, energy, materials and ocean space benefits, with a potential for positively affecting the environment.
• International cooperation will facilitate progress.
REFERENCES


A STUDY ON SALT DAMAGE; PRODUCTION OF SEA-SALT PARTICLES

Kenji Hotta
Nihon University
Chiba, Japan

Soichiro Ogawa
Tokyo Electric Power Service Co. Ltd.
Tokyo, Japan

ABSTRACT

Damage resulting from sea-salt particles present in the air increases every year. The damage of these particles may extend to unexpected areas such as human health, vegetation and soil. According to the questionnaire survey done by the author, along with gradual reduction of the natural coastline by replacing with artificial coastal structure such as breakwaters, the damage resulting from salt particles is growing at even a faster pace than before.

Theoretically, it is explained that the most important factor in the generation of the sea-salt particles is air bubbles which rise to the surface of the ocean, burst, and release hundreds of tiny particles containing sea-salt nuclei into the air.

In this paper, using a high-volume air sampler to compare different types of coastal formations, an attempt was made to determine the characteristics of sea-salt particle generation.

INTRODUCTION

Damage resulting from sea-salt particles present in the air increases every year. The damage of these particles may extend to unexpected areas such as human health, vegetation, and soil.

General research into salt damage has been carried out in a variety of areas. From an engineering standpoint, studies have been done concerning subjects such as 1) the corrosion mechanism affecting buildings and other facilities or equipment, 2) the design of corrosion resistant materials, and 3) the method of diagnosis of corrosion as well as corrosion-related maintenance. From a scientific standpoint, research has been directed towards areas such as 1) the mechanisms which generate sea-salt particles that cause salt damage, and 2) the transportation of sea-salt particles by the wind.

Sea-salt damage is on the increase. Moreover, a questionnaire survey carried out by the authors of this paper has revealed that along with the gradual reduction of natural coastline by replacement with artificial coastal structure such as breakwaters and other man-made structures, the damage resulting from salt particles is growing at an even faster pace than before (Hotta and Matsumoto, 1989). The present research is, therefore, concerned with obtaining fundamental data that will help avoid such damage, and assist in drawing up proposals for projects to develop a comfortable living environment in coastal areas. Using a high-volume air sampler to compare different types of coastal formations (artificial and natural beach coastlines), an attempt was made to determine
the characteristics of sea-salt particle generation. The primary results of this research are presented.

**EXPERIMENTAL METHOD**

**Generation and Dispersal Mechanisms of Sea-Salt Particles**

Theoretically, it is explained that the most important factor in the generation of sea-salt particles is air bubbles which rise to the surface of the ocean, burst, and release hundreds of tiny particles containing sea-salt nuclei (each approximately $10^{-14}$ to $10^{-15}$ gm) into the air (Asakur and Miyazaki, 1989). As Figure 1 illustrates, once airborne, the wind easily carries these particles to land.

![Diagram of sea-salt particle transportation](image)

**Figure 1. Transportation process of the sea-salt particles**

**Measurement Method**

Measurements were carried out in two steps as follows:

Step 1: In order to grasp the difference between the quantity of sea-salt particles produced at the ocean surface and at the coast, measurements were carried out at both locations, and results were compared (Figure 2).

Step 2: The quantity of sea-salt particles and its relationship with wind speed and wave height factors was investigated by comparing various measurements taken at sandy beaches and behind breakwaters (Figure 3).

Measurements were carried out according to the method illustrated in Figure 3. First, a device...
for collecting sea-salt particles (high-volume air sampler) was set up behind a wave-breaking point, in a horizontal position, facing the ocean, and within 160 degrees to the wind direction. Only when the wind blows from the ocean to the beach, sampling was carried out for a period of one hour. The air was passed through filter paper, following which the amount of chloride ions absorbed by the filter paper was measured and analyzed by an absorptiometry method (Kashimoto, 1984). The measured quantity of sea-salt particles was expressed in terms of suction volume of the air per hour (mg/m³). Conditions pertaining to wind direction, wind speed, and wave height, prevailing at the time of the sample were also measured.

RESULTS AND CONCLUSIONS

Step 1: Determining the quantity of sea-salt particles in the ocean air and at the coastal air

As can be seen in Table 1, measurements were reported during the measurement period when wind direction was within the set-up ranges.

November 26, December 3, 10:
Condition A - light wind, low waves (no breaking of waves at sea), hardly any waves spilling over the rock breakwater.

December 17:
Condition B - medium winds, medium waves (at sea, at measurement number 10 & 11), whitecaps occasionally visible, rough seas causing waves to spill over the rocks at breakwaters.

As shown in Figure 4, under Condition A, measurements of airborne sea-salt particles obtained both at sea and at coastal areas varied to a certain degree, but there was only a slight difference in quantity.

According to the results obtained under Condition B, while observations at sea were similar to those under Condition A, those at the coast revealed a considerable increase in particles. Coastal measurements under these conditions were approximately 4.4 to 7.1 times as great as those taken at sea.

Observations at Step 1 can, therefore, be summarized as follows:

Under conditions such as Condition A, airborne sea-salt particles are found at sea as well as at coastal areas. A certain amount of chloride is, therefore, always present in the air.
Table 1. Results of measurement

<table>
<thead>
<tr>
<th></th>
<th>Date</th>
<th>Time</th>
<th>Wave Heights (cm)</th>
<th>Fishing pier</th>
<th>Coastal area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Amount of NaCl (mg/m³)</td>
<td>Wind Speed (m/s)</td>
</tr>
<tr>
<td>---</td>
<td>---------</td>
<td>------------</td>
<td>-------------------</td>
<td>-----------------</td>
<td>---------------</td>
</tr>
<tr>
<td>1</td>
<td>91/11/28</td>
<td>13:30-14:30</td>
<td>17.0</td>
<td>0.0331</td>
<td>1.25</td>
</tr>
<tr>
<td>2</td>
<td>91/11/28</td>
<td>14:40-15:40</td>
<td>20.0</td>
<td>0.0156</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td></td>
<td></td>
<td>0.0244</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>91/12/03</td>
<td>10:50-11:50</td>
<td>10.0</td>
<td>0.0321</td>
<td>1.88</td>
</tr>
<tr>
<td>4</td>
<td>91/12/03</td>
<td>12:00-13:00</td>
<td>15.2</td>
<td>0.0097</td>
<td>2.14</td>
</tr>
<tr>
<td>5</td>
<td>91/12/03</td>
<td>15:15-16:15</td>
<td>16.0</td>
<td>0.0057</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td></td>
<td></td>
<td>0.0158</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>91/12/10</td>
<td>10:35-11:35</td>
<td>13.0</td>
<td>0.0386</td>
<td>1.84</td>
</tr>
<tr>
<td>7</td>
<td>91/12/10</td>
<td>11:45-12:45</td>
<td>14.5</td>
<td>0.0200</td>
<td>2.24</td>
</tr>
<tr>
<td>8</td>
<td>91/12/10</td>
<td>12:55-13:55</td>
<td>15.5</td>
<td>0.0146</td>
<td>1.68</td>
</tr>
<tr>
<td>9</td>
<td>91/12/10</td>
<td>14:30-15:30</td>
<td>13.5</td>
<td>0.0045</td>
<td>1.39</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td></td>
<td></td>
<td>0.0194</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>91/12/17</td>
<td>10:50-11:50</td>
<td>67.5</td>
<td>0.0152</td>
<td>7.86</td>
</tr>
<tr>
<td>11</td>
<td>91/12/17</td>
<td>12:00-13:00</td>
<td>60.5</td>
<td>0.0115</td>
<td>6.75</td>
</tr>
<tr>
<td>12</td>
<td>91/12/17</td>
<td>13:10-14:10</td>
<td>49.0</td>
<td>0.0111</td>
<td>6.04</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td></td>
<td></td>
<td>0.0126</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td></td>
<td>0.2117</td>
<td></td>
</tr>
</tbody>
</table>
However, under Condition B, there was a large difference between the results obtained at sea and at the coast. This is probably because there was little tendency for the waves to break at sea. In other words, the breaking of waves is considered to be a key factor in the generation of sea-salt particles.

At sea, wind speed and wave height have little effect and the measured quantity of sea-salt particles remains fairly uniform and small, relative to measurements taken at the coast. On the other hand, the quantity of sea-salt particles at the coast grows along with the increase in wind speed and wave height. As shown in Table 1, sea-salt particles produced at sea ($A_1$) and at the coastline ($A_2$) are dispersed in the atmosphere and driven towards coastal ($C$) and inland regions by the wind when we assumed that volumes reported in Table 1 are relative to "1" for the quantity measured at sea:

$$A_1 + A_2 = C$$

**Condition A**

1 (low) (very low quantity similar at the coast to that obtained at sea) 1 (low)  (1:1)

**Condition B**

1 (low) (much higher volume quantity at the coast compared to that at sea) 6 (high)  (1:6)

**Step 2: Determining quantity of sea-salt particles at sandy beaches and breakwaters**

There were 23 measurements reported at sandy beaches and 21 at breakwater locations during the measurement period with wind direction in the set-up ranges.
Relationship between sea-salt particles and wind and wave conditions

As shown in Figure 5, a high correlation between quantity of sea-salt particles and wave height was observed at both sandy beaches (r = 0.8420) and breakwaters (r = 0.8350). On the other hand, in regard to the relationship between sea-salt particles and wind speed, Figure 6 shows that there is a slight correlation at sand beaches (r = 0.5597) but a low correlation at breakwaters (r = 0.2299).

Since observed quantities of sea-salt particles are greatly influenced by wave height (the higher the waves, the greater their breaking action), it is reasonable to conclude, as indicated in Step 1 above, that a very important factor in the generation of sea-salt particles is the breaking action of waves. However, in regard to wind speed, it is not so much the generation of sea-salt particles as the distance and the area over which they become dispersed that is directly influenced by the wind.

Model equations

Figure 5 shows model equations stating the relationship between the quantity of sea-salt particles and wave height, based upon the values obtained through experimental observations.

1) Sandy beaches: quantity of sea-salt particles (Y₁) wave height (X₁)

\[ Y₁ = 0.00561 + 0.00091X₁ \]  \hspace{1cm} (1)

Determinant coefficient \( R² = 0.7089 \)
Multiple correlation coefficient \( R² = 0.8420 \)

2) Breakwaters: quantity of sea-salt particles (Y₂) wave height (X₂)

\[ Y₂ = 0.00089 \times 1.09147X₂ \]  \hspace{1cm} (2)

Determinant coefficient \( R₂ = 0.8320 \)
Multiple correlation coefficient \( R₂ = 0.9122 \)
Characteristics of sea-salt particles at sandy beaches and at breakwaters

Figure 7 shows regression lines derived from model equations for both locations.

\[ Y_2 = 0.00089 \times 1.00147^{x2} \]

\[ Y_1 = 0.00581 + 0.00091x_1 \]

Figure 7. Regression curve by wave height and NaCl

Whereas a linearly increasing trend in the quantity of sea-salt particles measured at sandy beaches corresponds to an increase in wave height, at breakwaters, there tends to be an exponential increase in sea-salt particles.

For both locations, there are points at which trend changes in the quantity of sea-salt particles occur (A: Figure 7). When waves are smaller than at point A, the quantity of particles is larger at sandy beaches although the difference between the quantities measured at the two locations is small. Beyond point A, as wave height increases, there is a sharp rise in the quantities measured near breakwaters as compared to those measured at sandy beach, and the difference between quantities measured at the two locations also increases.

Under normal conditions, the quantity of sea-salt particles measured behind concrete blocks (cement breakwaters) is about 1.5 to 2.0 times that measured near a sandy beach. As wind speed and wave height increase, this difference in quantity grows to a factor of 5 times or possibly even more. This strongly suggests that where breakwaters are constructed, there will be an accompanying increase in salt damage.

The quantity of sea-salt particles at coastal areas varies according to whether the coastline in question consists of sandy beaches or breakwaters (different compositions of coastline) with the breakwater coastline having the large quantity. This is believed to result from the different breaking action of waves characteristic of these different types of coastline.

In this research, a method of determining the impact of sea-salt particles in terms of detecting and measuring in the coastal regions, which have not been cleared yet, is basically established.
Action to preserve beaches as well as the increased utilization of coastal areas is likely to increase in the future. Accordingly, the need for constructing breakwaters will also increase. As a result, it is likely that salt damage will be increasingly aggravated (Hotta, 1989; Ogawa, 1991).

In this respect, and for the maintenance of all types of facilities and vegetation found near coastal regions, as well as for the preservation and amenity of human activities in such residential areas, the present research has provided useful basic data.

The model equations contained herein are only useful for these particular data collection sites. Continuing these measurements by increasing the number of samples, improving the accuracy of the model equations for additional measurements, and carrying out measurements of sea-salt particles present in other areas, will provide data that is more universally useful and applicable.

REFERENCES


DERIVING PUBLIC BENEFITS FROM PRIVATE MARINA DEVELOPMENT

M. Carolyn Stewart and Valerie W. McMillan
Office of State Planning
Honolulu, Hawaii, U.S.A.

ABSTRACT

Hawaii is currently experiencing an increased interest in private marina development. All of the proposed marinas will require the use of public resources, e.g., dredging of entrance channels and breaching of the shoreline. The State of Hawaii Office of State Planning has drafted guidelines for the planning and development of private marinas. Of importance to the development of these guidelines was the "public trust doctrine," the body of law establishing that all tidelands and navigable waters are subject to a "public trust" for the benefit of the state's citizens with respect to certain rights of usage, particularly those of commerce, navigation, and fishing. Based on the principles of the public trust doctrine, the draft guidelines call for the maximization of public benefits from the use of public trust resources in the development of private marinas. The Hawaii Coastal Zone Management Program has been named the lead agency for determining and negotiating the public benefits to be required of each private marina development. This responsibility entails formulating a mechanism for cooperating with the developers and incorporating various agencies' concerns, developing criteria for evaluating public benefit proposals relative to the public trust resources affected by specific projects, and selecting the type and amount of public benefits to be required of each proposed marina.

INTRODUCTION

Hawaii is currently experiencing an increased interest in marina development. Much of the demand is being generated by private developers planning major residential or resort complexes for which marinas will serve as a featured attraction. Many of the marina proposals call for the blasting of fast lands for the creation of the marina basin. However, even these marinas, developed solely on private lands, will require use of public resources, such as the dredging of entrance channels and the breaching of the shoreline. The public's right to the use and enjoyment of shoreline and ocean resources is embodied in the public trust doctrine. Marina development is a controversial issue in Hawaii and elsewhere, in part because it entails the private use of public trust resources for private gain. This paper discusses the public trust doctrine as it relates to marina development in Hawaii.

THE PUBLIC TRUST DOCTRINE

The concept of public trust is derived from Roman law, which assured all citizens access to air, running water, the sea and seashore. In other words, the public had an unalienable right to certain land and water resources, held in stewardship by the state. This concept has evolved and been refined over the ensuing 1500 years; and, its essence is embodied in a body of law known as the Public Trust Doctrine:

The Public Trust Doctrine provides that public trust lands, waters and living resources in a State are held by the State in trust for the benefit of all
of the people, and establishes the right of the public to fully enjoy public trust lands, waters and living resources for a wide variety of public uses (Slade, 1990).

The Public Trust Doctrine applies both to publicly and privately held shorelands and submerged lands. While the private title to the lands (jus privatum) may be conveyed to private ownership, the public title (jus publicum) remains vested with the State and cannot be abdicated. "With little exception, the public's jus publicum rights are dominant to a private owner's jus privatum rights" (Kelly and Slade, 1991). Even though owners may hold legal title to the trust lands, waters and living resources as private property, they may not prevent the public from using these resources vested with jus publicum rights.

A number of cases have helped clarify the public trust doctrine in Hawaii. In addition, the Hawaii Constitution recognizes the State's responsibilities as steward of these public trust resources. Article XI (1) states:

For the benefit of present and future generations, the State and its political subdivisions shall conserve and protect Hawaii's natural beauty and all natural resources, including land, water, air, minerals and energy sources, and shall promote the development and utilization of these resources in a manner consistent with their conservation...All public natural resources are held in trust by the State for the benefit of the people.

Originally, the public trust lands were those subject to the ebb and flow of the tide. This definition has evolved to include the lands beneath other navigable water bodies that do not experience tidal fluxes, such as large lakes. In many states, the landward boundary of public trust lands extends to the ordinary high water mark. In Hawaii, the ordinary high water mark, or ma ke kai, is interpreted as the upper reaches of the wash of the waves, other than storm and tidal waves, usually evidenced by the edge of the vegetation growth, or the upper limit of debris left by the wash of the waves (Chapter 205A-1 Hawaii Revised Statutes; In Re Ashford, 50 Haw. 314, 315, 440 P.2d 76, 77 (1968); In Re Sanborn, 57 Haw. 585, 594, 562, P.2d 771, 777 (1977)).

Navigation, commerce and fishing are the traditional uses of public trust lands and waters protected by the Public Trust Doctrine. Current uses that may also be protected include recreation, environmental protection and scenic beauty. The Supreme Court decision in Phillips Petroleum v. Mississippi (1988) extended state interest in lands beneath tidal waters to include bathing, swimming, recreation and mineral development. In Hawaii, State v. Zimring (58 Haw. 106, 566 P.2d 725 (1977)) also specified that both commercial and recreational uses are included in the term "navigation."

MARINAS AND THE PUBLIC TRUST DOCTRINE

Marina development is both consistent and inconsistent with the Public Trust Doctrine. Marinas may improve public access to trust resources by providing slips,
ramps and other related boating services. However, marinas may also hinder access to public trust resources by providing only exclusive use of a shoreline or boating facility.

On the one hand, marinas may positively contribute to the public’s access to trust resources by enhancing access for navigation and fishing, as well as other recreational pursuits. These public benefits are particularly important in Hawaii, where many of the resident and tourist recreational activities are focused on the use of coastal and ocean resources. In fact, "the unprecedented growth of the commercial ocean recreation sector and the number of personal boats have significantly increased the demand for additional small boat harbor facilities" (Tarnas and Stewart, 1991). In other words, demand for marina facilities far exceeds supply. As of March 31, 1992, there were approximately 2900 recreational vessels statewide on waiting lists for slips at small boat harbors. To put this number in perspective, there are only 2200 slips total available in the State. Given the high cost of marina development in Hawaii, private marina development can fill a need in the State and, at the same time, improve the use of and access to public trust resources.

On the other hand, marina development and maintenance usually have some detrimental physical and ecological impacts on the coastal lands and waters. The physical alterations associated with marina development may impact water flow, coastal and marine wildlife habitat, water quality and public shoreline access. Clearly, dredging an entrance channel and breaching the shoreline to connect a marina created from fast lands to the ocean represent irrevocable changes to public trust resources and constitute uses of these resources for private profit. The resources of submerged lands potentially impacted during dredging - coral reefs, other marine life habitats and surf breaks, for example - are public trust resources used for fishing and recreational purposes. Breaching the shoreline interrupts lateral access along the shore and the public's ability to recreate on the beach. Creation of a navigational channel may also disturb swimming and nearshore navigation along the shoreline.

Herein lies the dilemma and challenge faced by the Hawaii State government. There is a need to balance the public benefits derived from the use of public trust resources with the private use of and profit from those same resources. Therefore, when the State grants the use of public trust lands to private owners, it is obligated to assure that these lands are "used by the private owners in such a manner as not to unduly interfere with the public's several rights under the public trust doctrine and so as to promote the public interest" (State of Hawaii, 1991).

DRAFT GUIDELINES FOR PRIVATE MARINA DEVELOPMENT

The State of Hawaii, Office of State Planning (OSP) has drafted guidelines for private marina planning and development to assure protection of the public interest while fulfilling recreational boating needs. In addition to minimizing the potential environmental and socio-economic impacts of marina development, marina developers are expected to provide benefits to the public for the use of the public trust resources. Examples of public benefits that could be agreed upon between the State and a private marina developer include:

\[\text{2Adapted from Hawaii (1991).}\]
(1) Direct cash payments;
(2) Public use at public marina rates;
(3) On-site preservation of natural resources;
(4) Off-site public boating facilities;
(5) Recreational facilities;
(6) Ocean resource use enhancement;
(7) Public access; and
(8) Public water safety and rescue programs.

Contributions such as these will ensure that the public benefits from the private use of public trust land and water resources. By negotiating a public benefits package with the marina developer, the State upholds its trustee responsibilities.

The Hawaii Coastal Zone Management (CZM) Program has been named the lead agency for determining and negotiating the public benefits to be required of each private marina development. The CZM Program is ideal for this endeavor because of its comprehensive coastal planning and policy development role, and its on-going coordination role between various government agencies. With regard to the public benefits determination process, the CZM Program responsibilities entail:

(1) formulating a mechanism for cooperating with the developers and incorporating various agencies’ concerns;

(2) developing criteria for evaluating public benefit proposals relative to the public trust resources affected by specific projects; and

(3) selecting, for each proposed marina, the type and amount of public benefits to be required of each developer.

The CZM Program will submit public benefits recommendations to the Board of Land and Natural Resources. As the steward of State land and waters, the Board will review and act on public benefits reports during its deliberations on permit applications or lease requests associated with marina development.

The public benefits process has not yet been tested. However, it is expected that applications for permits to develop one or more private marinas will be filed within the next year.

CONCLUSION

The controversy surrounding private marina development sparked the concept of requiring public benefits from developers using public trust resources. However, marinas are not the only private uses of public trust resources. For example, some shore protection structures, such as groins and some revetments, are built at least partially seaward of the shoreline, in the public trust area. Others, built inland of the shoreline, can negatively affect the public trust by exacerbating erosion of the beach area.
It is possible that these uses of the public trust resources may also be subject to the public benefits requirement in the future. In addition, uses of or impacts to other public resources by private interests - such as pollution of ground water - may also warrant a similar program for compensating the public. Therefore, what has begun as a response to a particular use of the public trust may have far-reaching consequences for public resources management. However, the immediate challenge for the CZM Program is to devise a process that is fair and equitable, to both the developer and the public, for determining the public benefits to be required relative to the public trust resources affected.

REFERENCES


PAN JAPAN-SEA TOTAL OCEAN NETWORK PROJECT:  
DOUBLE-STAGE MERRY-GO-ROUND

Ko Tomino  
Tobishima Corporation  
Tokyo, Japan

ABSTRACT

Eastern Asia can be defined as comprising the South China Sea, East China Sea, 
Japan Sea, and Okhotsk Sea. The five nations along the Japan Sea—Japan, the Republic 
of Korea, the Democratic People's Republic of Korea, China, and Russia—possess great 
potential. This region has lately attracted considerable attention as a potential nucleus of 
development in the 21st century that will equal North America and Europe in scope.

The Pan Japan-Sea Total Ocean Network Project (TOP) is proposed as a way to 
link the five Japan Sea nations, which possess significant development potential, by a 
single marine network, and to promote broad-based exchanges with other economic 
blocs. To that end, a double-stage merry-go-round concept comprising macro (regional) 
and micro (local) merry-go-rounds is proposed. These will consist of clusters of local 
metropolitan facilities arrayed around the Japan Sea rim, and a new, international 
marine city to serve as their center, all linked by transportation networks. This paper 
offers a necessarily brief overview of the TOP project and its rationale (Figure 1).

INTRODUCTION

The broad purpose of the Pan Japan-Sea TOP concept is to contribute to global 
harmony through economic and cultural development of the entire region in cooperation 
among the nations bordering the Japan Sea. The primary goal of this plan is to overcome 
the barrier of physical distance within the region by creating a large-scale cross-border 
transportation network to foster the exchange of people and goods.

This can be accomplished by the creation of a marine city, called Acropolis, which 
will serve as a base for the entire area. Further, located around Acropolis will be a group 
of strategic cities, called Polis. Underneath each Polis will be a group of city facilities, 
called City, which will function as the base for the development of each area. Finally, a 
transportation network linking the entire area will be constructed.

The concept was named the Pan Japan-Sea Double-Stage Merry-Go-Round 
because the social infrastructure of this plan can be compared to a three-dimensional 
merry-go-round in terms of its schematic arrangement and function.

THE MACRO MERRY-GO-ROUND: A SUPER INFRASTRUCTURE TO 
MATERIALIZE INTERNATIONAL HARMONY

In this project, a gigantic circular transportation network running around the 
Japan Sea region will be constructed to link all areas. A group of strategic cities will be 
formed along the network to serve as footholds for the development of each area. 
Moreover, this circular network will support a broad range of international exchanges by
radially linking each strategic city with an international marine city to be constructed in the center of the Japan Sea.

Figure 1. Pan Japan-Sea Map

The project will provide an excellent distribution network by employing state-of-the-art transportation systems, such as linear motor car and other land, sea, and air transportation facilities, e.g., by construction of international airports, ports, new canals, and so on, in each strategic city. The construction of the Mamiya-Soya-Tsushima Straits crossing road, which will provide all-weather connecting transportation, is part of the project. The trip around the Japan Sea by linear motor car will take half a day, while the trip from the marine city in the Japan Sea to each strategic city will take several hours by high speed boat or about one hour by airplane (Figure 2).

INTERNATIONAL FREE CITY: ACROPOLIS

Acropolis, the core of the Pan Japan-Sea area, is an international free city that will regulate the distribution functions for other economic blocs as well as manage the harmonious development of each of its areas. This city will be jointly administered by the five nations along the Japan Sea, and thereby promote extensive global business activity.
BASES FOR INTERNATIONAL EXCHANGE: POLIS

The Polis will be the bases for routine exchanges, transcending ideology and race, among nations along the Japan Sea. They will form gateways for socialist countries to participate in Western economic bloc activities.
INTEGRATED TRANSPORTATION NETWORK

The Japan Sea is a vast enclosed sea area connected to other oceans by four straits: Mamiya, Soya, Tsugaru, and Tsushima. The total length of the Japan Sea is approximately 1,000 km, and the circumference is 6,000 to 7,000 km. The integrated transportation network envisioned by this plan will efficiently link the entire area by state-of-the-art transportation systems such as linear motor cars, high-speed boats, and other systems.

THE MICRO MERRY-GO-ROUND: CREATION OF ATTRACTIVE AREAS BY STATE-OF-THE-ART ASSESSMENT TECHNOLOGY

Making the best use of their features, the base cities (Polis) will function as industrial bases for agriculture, fisheries, resources, high technologies, etc. Farther in the future, these bases will become highly advanced information cities engaged in dynamic economic activities. Arranged around these base cities there will be urban facilities (City), including recreation facilities suited to the local natural environment, tradition, and culture. Together, these facilities will form a micro merry-go-round that will contribute to the development of the area.

COMPOSITION OF THE CITIES

The cluster of urban facilities (City) essential for the formation of local infrastructures will emerge in each base city. These cities will feature business-related areas such as financial and commercial districts, and industrial and resource storage areas, as well as people-oriented areas, such as research, education, and resort areas, offering healthy and prosperous living environments.

CREATION OF POLIS AND CITIES GIVING PRIORITY TO THE NATURAL ENVIRONMENT

The Japan Sea is in effect an enclosed sea area. Should it be contaminated by the wastes generated due to development of the region, the damage would be serious. To prevent such an event from taking place, the project will apply state-of-the-art "green" technology from the outset in order to preserve the environment. Therefore, the creation of environment-and-human-friendly Polis and Cities will be pursued based on the environmental characteristics and traditions of each area.

REGIONAL TRANSPORTATION NETWORK

A transportation network extending throughout the region is planned that will connect the base cities by a circular linear high-speed rail network. The first stage of the project will be the construction of trunk lines for transporting products. This will be followed by expansion of transportation facilities into surrounding regions by upgrading or expanding the existing infrastructure, or by creation of trunk lines between cities. This development will be implemented in coordination with the overall development of each region.
INTRA-AREA DEVELOPMENT PROCESS

At the beginning of the project, five types of micro merry-go-rounds will be arranged in each base city around the Japan Sea so as to utilize each country's production element. Each micro merry-go-round will add other base city functions depending on its development level, and ultimately it will have a function equivalent to that of the Japanese Pacific Belt area. By this means it will equalize the standard of living and services throughout the entire region.

PRODUCTION ELEMENT OF EACH COUNTRY

Each country has its own production element, as follows:

- **Japan**: Advanced technologies and financial capital
- **Russia**: Abundant natural resources in its Far East region
- **China**: Agricultural products and labor force in three north-eastern provinces
- **South Korea**: Intermediate technologies and financial capital
- **North Korea**: Mineral products and labor force

THE JAPAN SEA ACROPOLIS: CREATING THE IDEAL INTERNATIONAL MARINE CITY WITH A BENEFICIAL ENVIRONMENT

As the nucleus of the transportation network and economic activities of the Japan Sea economic bloc, the Japan Sea Acropolis (Figure 3) will be jointly administered by every country involved. It will thereby realize the principle of international harmony across a broad field.

*Figure 3. Overall view of Acropolis*
Japan Sea area, at a depth of 280-300 m, at 135 degrees east longitude and 39.2 degrees north latitude. The construction process will be as follows: First a 4 km square breakwater will be built on the ridge. An artificial island of 314 million square meters will be built in the center of the breakwater.

Acropolis will accommodate several types of facilities. The upper part of the man-made island will contain a group of facilities with international functions, serving as the base for a wide variety of economic activities as well as residences. In the lower part, waste disposal facilities such as sewers will be built. This zone will also function as an ocean farm (Figure 4).

![Marina facilities - Acropolis](image)

Figure 4. Marina facilities - Acropolis

Airplane runways and other transportation facilities, such as loading and unloading areas for ships, will be constructed on the upper part of the surrounding breakwaters (Figure 5). Moreover, this area will function as a storage base with several types of storage facilities. It will include a capacity for 300 million kiloliter oil tanks, equivalent to Japan's oil consumption for 16 months. Thus, equal distribution of resources among the nations will be achieved.
The main energy source for Acropolis will be an ocean thermal energy conversion plant. It is estimated that approximately 800,000 kw of power can feasibly be generated from June to October by installing eight 100,000 kw generators. When superconducting technology makes efficient storage systems possible in the future, ocean thermal energy conversion alone will be sufficient to meet the energy requirement of each facility in the man-made island (Figure 6). It will also be possible to supply electricity to strategic cities. Furthermore, plan also includes exploration of several other marine energy resources as well as the desalination of sea water using biotechnology. In other words, the Japan Sea Acropolis will be a product of human dreams across a variety of advanced technologies.

CONCLUSIONS

The primary goals of the Pan Japan-Sea TOP concept are to build a cosmopolitan city, Acropolis, that will function as a center for economic and cultural exchanges among nations that border on the Japan Sea, and to establish a distribution base to serve the entire region. Clearly, the TOP project can provide an extremely significant stimulus for economic and cultural development, both locally and internationally, in an environmentally sound manner. It can also serve as a major vehicle for further development in all areas.

The estimated total cost and the time required to realize this concept is 33 trillion yen over a period of 15 years. At present, we are actively promoting research and development of relevant technologies.
ACKNOWLEDGMENTS

It has been my great fortune to have received the substantial cooperation of a number of persons in the course of bringing this paper to completion. First and foremost, I would like to take this opportunity to express my sincere gratitude to Professor Takeo Kondo (Marine Architecture Engineering, Department of Science and Engineering, Nihon University), for his considerable guidance in a number of areas.

I would also like to express my thanks to Ms. Yoko Fujita (President, Fast International Co., Ltd.), who has undertaken the task of translating this paper.
REFERENCES


Terai, K. 1986. The whole picture of gigantic projects. TBS Britannica.


DEVELOPMENT OF A FLOATING-TYPE BUILDING MOORED IN A COASTAL AREA

Masami Matsuura, Kunihiro Ikekami and Kazuo Masuda
Mitsubishi Heavy Industries, Ltd.
Nagasaki, Japan

ABSTRACT

Floating-type buildings will be moored for a long time in a specific site, and will be used by a number of people. At the design stage, therefore, it is important to determine the design criteria from the points of view of safety and comfort. In the present development, referring to investigations on vibration of high buildings and conducting human response tests by using a forced oscillating carriage, design criteria was decided in terms of acceleration of motion of a floating-type building.

Based on the design criteria, a floating-type building mounted on a barge was designed for a hotel barge as a case study. Particularly, a mooring system and methods of motion reduction were studied theoretically and experimentally. Theoretical calculation is based on a time-domain simulation method including the effect of nonlinear reaction forces due to the mooring system. Tank tests with a 1/30 scale model were carried out to evaluate the mooring forces and motions in waves and wind. The results were discussed from the points of view of engineering feasibility.

INTRODUCTION

In viewing the prospects for effective utilization of ocean space, several new concepts have been proposed (for example, Yoshida, et al., 1990; Terai, 1990). Most of them consist of very large systems using huge floating or fixed structures and are investigated aiming at big developments in the future. On the other hand, a simple concept with high actuality in the near future is discussed in this paper aiming at creation of new space in coastal area. Utilization of ocean space as living and working space for citizen seems promising to provide new space for coastal countries like Japan. Various floating-type buildings are anticipated to be utilized as offices, hotels, recreational facilities and so on in the near future. Ocean space utilization by using floating-type structures should be promoted further in coastal areas where these kinds of structures are most feasible. Floating-type buildings have several advantages, for instance, lower cost and shorter period of construction than ocean space utilization by reclamation because of factory-built applied to main parts of structures.

Figure 1 shows an artist’s concept of a floating-type building, and it typically demonstrates the topic of the present study. This paper discusses some of the engineering feasibility studies for developing floating-type buildings. Figure 2 illustrates a floating-type oil storage system completed in 1988 at Kami-Gotob in Japan (Ikekami, et al., 1990; Shuku, et al., 1988). The entire system consists of 5 huge storage barges. It is now in full operation and each barge is filled with crude oil. Its mooring system consists of large dolphins and rubber fenders as shown in Figure 3. The present study is based on the experience in engineering of this project. Basically, the same technology can be applied to floating-type buildings. However, there are some different areas in the development of floating-type buildings utilized by many people. At the design stage,
Figure 1. Artist's concept of floating-type building

Figure 2. Floating-type oil storage system at Kami-Gotoh in Japan

Figure 3. Mooring system with dolphin and rubber fender in shallow water
therefore, it is important to determine design criteria from the point of view not only of safety but also of comfort.

In the present paper, reference to investigations on vibration of high building on land and conducting human response tests, design criteria is discussed for comfort. For a case study, a prototype design is introduced and examined based on assumed site and design conditions. Then, this paper presents a study on a mooring system and methods of motion reduction in order to suit the prototype to the design criteria by use of theoretical calculations and model tests. Finally, evaluations of floating-type buildings based on our concept are discussed from the points of view of safety and comfort.

**DESIGN CONDITIONS**

**Basic Design Condition**

Assumed basic design conditions are shown in Table 1. An assumed floating-type building consists of a barge-type floater and an upper structures, and produces space and facilities for a maximum of 2,500 people. For the case study a site was assumed to be in a coastal area, shallow water and rather calm sea, and Nagasaki Bay was tentatively selected, as shown in Figure 4. Site selection is very important in such developments and should be made essentially from the social and economical viewpoints as well as technical ones. However, the present paper describes an outline of the study focusing on the engineering feasibility of floating-type buildings.

![Figure 4. Tentatively selected site of the floating-type building for the present study](image)

**Environmental Conditions**

The assumed site is conveniently sheltered from ocean waves. However, there are waves generated in the bay by strong winds in storm conditions. Environmental conditions were determined based on data of the Meteorological Observatory located near the site. Two types of storm conditions were determined as shown in Table 2. Storm conditions corresponding to 100- and 5-year return period are used for discussion about safety and comfort, respectively. Tidal range must be taken into consideration in designing a mooring system, and the maximum value is 5.0 m above the lowest level of a tide level including the effect of harbor oscillations. Mean water depth corresponding to the lowest sea level is 8.5 m.
Table 1. Basic design conditions.

Barge type floater

Deck Area : 10,000 m²
Displacement : 30,000 ton

Upper structures

Floor Area : 25,000 m²
Capacity : 2,500 persons
Facilities : Hotel, convention hall, offices, restaurants, shopping plaza, parking spaces, etc.

Site condition

- Coastal area near land
- Shallow water
- Rather calm sea

Table 2. Environmental conditions.

<table>
<thead>
<tr>
<th>Environmental Condition</th>
<th>100 Year Storm</th>
<th>5 Year Storm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind speed (10 min. Mean)</td>
<td>42.5 m/s</td>
<td>27.5 m/s</td>
</tr>
<tr>
<td>Waves</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Significant wave height</td>
<td>2.0 m</td>
<td>1.3 m</td>
</tr>
<tr>
<td>Significant wave period</td>
<td>4.0 s</td>
<td>3.3 s</td>
</tr>
</tbody>
</table>

Design Criteria

Design criteria are considered from the points of view of safety and comfort. Design criteria for safety can be defined based on allowable force of the mooring system.

With respect to comfort, it is difficult to define design criteria, since comfort is related to human psychological responses and is unclear. There were several research projects about the relationship between vibration and human response introduced by Ikegami, et al. (1989). Figure 5 shows typical data of human responses based on a reference. Human responses vary according to magnitude of acceleration, but the influence of motion period is rather small on human responses. From this figure it can be seen that almost all persons notice accelerations beyond 10 gal. In environments with acceleration of 10 to 25 gal, persons are affected by the vibration but are able to work as usual.
In order to better understand human responses, tests were carried out by using forced oscillating carriage with horizontal motions as shown in Figure 6. The test results are summarized in Table 3. From the test results it can be stated that there were no problems in doing daily work in circumstances with accelerations from 10 to 25 gal.

From these investigations, it can be said that allowable accelerations are in the range of 10 to 25 gal. This guideline is also supported by data of vibration caused by a strong wind measured for existing tall buildings as shown in Figure 7. As a design criterion, acceleration of 10 gal is assumed tentatively for a 5-year storm condition. Acceleration of 10 gal is rather severe for floating-type structures; however, it was selected as a target value of the present study.

![Figure 5. Relationship between acceleration and human response](image)

Table 3. Results of human response test

<table>
<thead>
<tr>
<th>Acceleration</th>
<th>Human Responses, etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 gal</td>
<td>- Possible to notice slight motions occasionally</td>
</tr>
</tbody>
</table>
| 10 gal       | - Possible to notice motions  
              - No motion of water in a glass  
              - No problem in freehand drawing |
| 25 gal       | - Furniture with casters move  
              - No motion of water in a glass  
              - Slight difficulty in freehand drawing |
| 50 gal       | - No problem in standing up  
              - Slight influence on walking  
              - Not to feel danger |
Figure 6. Human response test

Figure 7. Vibration on tall buildings caused by a strong wind

PROTOTYPE DESIGN

Basic Design of Prototype

The principal dimensions of a prototype designed for the present study are shown in Table 4. Simplifying the problem, a barge-type floater and a square-type upper structure were adopted. For the mooring system, rubber fenders and mooring dolphins are arranged as shown in Figure 8. Figure 9 shows the cell-type rubber fender adopted in the study. As shown in Figure 8, the reaction force of rubber fender is kept almost constant after the deflection of the fender exceeds about 20% of the original length. It is possible, therefore, to transfer the mooring force to the dolphin without generation of excessive reaction even if the fluctuating loads due to waves and wind are superimposed on the steady loads. Design allowable deflection of the cell-type fender was assumed to be 35% strain in the present study. Because this mooring system based on rubber fenders and dolphins can keep the position of a floating structure within small horizontal displacements, it is convenient to access from land to moored floating structures by a bridge. Also, it is well adapted to mooring in shallow water and can allow for large changes of sea water level.

Motion Reduction Method

In order to polish up the prototype design and improve comfort, methods of motion reduction were examined. From several candidates of motion reduction methods, three types of simple and reliable methods shown in Figure 10 were selected and further investigations were carried out theoretically or experimentally. One is the case of increasing displacement by additional ballast in order to increase total mass of a floating body. Another is a mooring system with tandem fenders used to reduce fender reaction forces. The other uses a hydraulic damper added in the mooring system in order to increase damping forces.
Table 4. Principal dimensions of prototype

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>120 m</td>
</tr>
<tr>
<td>Breadth</td>
<td>96 m</td>
</tr>
<tr>
<td>Draft</td>
<td>2.54 m</td>
</tr>
<tr>
<td>Displacement</td>
<td>30,000 ton</td>
</tr>
<tr>
<td>Wind area</td>
<td>3,460 m²</td>
</tr>
<tr>
<td>Number of floors</td>
<td>14 floors above deck 2 floors under deck</td>
</tr>
</tbody>
</table>

Theoretical Calculation

In order to verify feasibility of the prototype design and the effect of the motion reduction methods described above, theoretical calculations were carried out. The nonlinear computer simulation program with a time domain motion analysis method was used in the study. This computer program has been developed by Fujii, et al. (1982) and was improved for the present study in order to take into account the effect of damping forces of the mooring system. Calculations were carried out in irregular waves and fluctuating winds corresponding to a 100-year storm and a 5-year storm. Bretschneider-Mitsuyasu's spectrum and Davenport's spectrum were used for irregular waves and fluctuating wind, respectively.

Figure 8. Modeling of floating-type building

Figure 11 shows the summary of calculation results. Maximum values of fender deflections, horizontal accelerations and roll motions are given in the figure as the results for each method of motion reduction as well as the basic case. Fender deflections are lower than design allowable value of 35% fender deflection in all cases; therefore, it is said that safety of the mooring system is proven. As mentioned above, the assumed target value of acceleration is 10 gal for 5 year storm condition. In the case of 2.54 m draft: the basic draft condition, horizontal accelerations are beyond 10 gal. Vertical accelerations are not shown in the figure but they are negligibly small. In the case of 4.5 m draft: the case of increasing displacement by additional ballast, motions are remarkably small in comparison with the case of 2.54 m draft. The motion reduction methods using tandem fenders and hydraulic dampers appear to be effective for the reduction of horizontal accelerations. As a result, it is confirmed that safety of the prototype is basically insured. Some motion reduction method must be applied in order to improve comfort of the prototype.
Figure 9. Cell type rubber fender

Figure 10. Concept of motion reduction method

<table>
<thead>
<tr>
<th>Motion Reduction Method</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional Ballast</td>
<td>Increase Mass</td>
</tr>
<tr>
<td>Tandem Fender</td>
<td>Reduce Fender Reaction Force</td>
</tr>
<tr>
<td>Hydraulic Damper</td>
<td>Increase Damping Force</td>
</tr>
</tbody>
</table>

Figure 11. Calculated results for various motion reduction methods
EVALUATION WITH TANK TESTS

Test Procedure

As an extensive investigation, model tests with a 1/30 scale model were carried out to evaluate the mooring forces and motions in irregular waves and fluctuating wind as shown in Figures 12 and 13. The tests were carried out in the Shallow Water Basin of the Nagasaki Research and Development Center, Mitsubishi Heavy Industries, Ltd. Regarding the model of the mooring system, nonlinear reaction force of rubber fender versus fender deflection: constant reaction force characteristics shown in Figure 9 were simulated by use of springs and weights as shown in Figure 14. Oil dampers were used in the tests aimed at examining the effect of hydraulic dampers on the absorption of motions, and simulated damper characteristics versus deflection speed are given in Figure 14. All data in the figure were converted to full scale values. Measurements were made for motion, acceleration and mooring forces.

Test Results

Figure 15 shows the measured maximum values of fender reaction forces versus fender deflection. In the figure the results are classified into two groups for 100-year storm conditions and 5-year storm conditions, respectively. Measured fender deflections were very small in comparison with the design allowable deflection of 35%. Therefore, it is said that safety for the mooring system of the prototype is confirmed. And, from this figure the remarkable effects of the hydraulic damper were observed on the reduction of motions and fender reaction forces. Figure 16 shows the measured results of horizontal accelerations acting on lower and upper floors. For our study, measured accelerations are beyond the assumed target value of design criterion 10 gal. In particular, accelerations on the upper floors are large due to the influence of roll motions. However, the prototype design seems to be improved as its accelerations to the same extent as existing tall buildings on land. From these results, it seems that acceleration of 10 gal is
Figure 14. Models of rubber fender and hydraulic damper

Figure 15. Measured mooring forces compared with the design allowable deflection

Figure 16. Measured accelerations compared with the proposed criterion
too severe for floating structures to exist in 5-year storm conditions. Twenty-five gal is proposed as the design criterion for acceleration related to comfort. Comparison of measured and theoretically calculated accelerations is shown in Figure 17 for mooring systems with and without hydraulic dampers. Calculated accelerations are slight larger than measured ones, but fairly good agreement is obtained between the calculated and the measured ones. Therefore, it is proven that theoretical calculations are useful as a design tool for these developments.

![Image of figure 17 showing comparison of measured and calculated accelerations](image)

**CONCLUDING REMARKS**

In the present paper, an engineering feasibility study on development of floating-type buildings was introduced. Because floating-type buildings will be utilized by many people, it was pointed out that design criteria must be taken into consideration from the points of view not only of safety but also of comfort. Maximum allowable values for motion accelerations were proposed as design criteria on comfort for a 5-year storm condition. Referring to investigations on vibration of high buildings on land and conducting the human response tests, design criteria was discussed for comfort. As a result of the study, acceleration of 25 gal for 5-year storm condition was finally proposed as the design criterion prescribing comfort of floating-type buildings.

As a case study the prototype design and the design procedure were introduced. Based on the prototype design, further investigations were carried out on mooring systems and methods of motion reduction in order to match the prototype to the design criteria by use of theoretical calculations and model tests. Regarding safety, it was confirmed that the mooring system with rubber fenders is feasible for floating-type buildings moored in coastal areas. With respect to comfort, it was confirmed that accelerations were the same as existing tall buildings on land. Therefore, it can be said that floating-type buildings based upon the prototype design are basically feasible for development of space for human activity. In order to further improve comfort of the prototype design, examples of motion reduction methods were described. Increasing displacement and the mooring system with hydraulic dampers or tandem fenders were introduced and discussed with respect to its validity to reduce motions and improve comfort.
REFERENCES


