Zeitschrift: IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht

Band: 14 (1992)

Rubrik: Special session 2: Offshore fixed and floating structures

Special Session 2

Offshore Fixed and Floating Structures

Constructions en mer amarrées et flottantes

Verankerte und frei schwimmende Meeresbauwerke

Organizer:	Chr. J. Vos, The Netherlands
Chairman:	R Halsall Canada

Leere Seite
Blank page
Page vide

Offshore Technologies in Japan to Exploit the Ocean

Technologie japonaise pour l'exploitation des océans

Neue Japanische Technologien zur Erschließung des Meeres

Takayoshi OTA
General Manager
Shimizu Corp. Eng. Div.
Tokyo, Japan

Takayoshi Ota, born 1943, received his civil engineering M.D. from the Kyoto University. His experience covers a broad spectrum from harbour construction projects to development of ocean energy resources and marine ranching. Takayoshi Ota, now in a construction company, is responsible for strategy and planning of civil and marine engineering projects.

SUMMARY

There are expectations for the ocean to be exploited for space, energy resources, biological, and mineral resources going into the 21st century, and the offshore engineering for these will be required to deal with problems concerning the increasingly diversified uses of structures and needs in siting. Recent public opinion for provision of facilities friendly to the environment, needs to be satisfied. In this paper, a number of examples of new technologies and structures being worked on based on such concepts – new types of breakwaters, marine ranches, wide-area clean-up engineering – will be described.

RESUMÉ

Il est fort probable que le milieu, les ressources énergétiques, biologiques et minières des mers puissent être exploités par l'homme dans sa marche vers le 21ème siècle. Il lui faudra donc recourir à des techniques de constructions en mer, afin de maîtriser les problèmes liés à la diversification sans cesse croissante des structures à réaliser et des besoins d'aménagement des sites en résultant. La tendance actuelle de l'opinion publique semble tendre dans le sens d'installations plus favorables qu'hostiles à la protection de la nature et de l'environnement. Ce rapport expose divers exemples du développement de nouvelles techniques et structures fondées sur cette conception plus écologique, comme de nouveaux types de jetées, des fermes marines, des méthodes de nettoyage de grandes surfaces.

ZUSAMMENFASSUNG

Es wird erwartet, daß auf dem Wege zum 21. Jahrhundert die Meere zunehmend für Raum und als Energiequellen wie auch wegen ihrer biologischen und Mineralschätze ausgebeutet werden. Dafür sind moderne Technologien erforderlich, die es erlauben, die mit der zunehmenden Vielfalt in der Anwendung von Strukturen und der Suche nach geeigneten Bauplätzen verbundenen Probleme zu lösen. Außerdem muß danach gestrebt werden, die neuerdings von der Öffentlichkeit gestellten Anforderungen und umweltfreundlichen Anlagen zu erfüllen. In diesem Bericht wird eine Anzahl von Beispielen von erarbeiteten neue Technologien und Bauten wie neuartigen Wellenbrechern, Farmen im und auf dem Meer und Verfahren zum Säubern ausgedehnter Gebiete beschrieben.

1. INTRODUCTION

Ocean space abounds in infinite possibilities, and attention is being focused on it as the last remaining unutilized space. There is a great variety of development projects planned in Japan. Projects presently under construction are, for example, a) Kansai International Airport, the first international airport in the world to be on an offshore artificial island, b) The Honshu-Shikoku Bridges, large-span bridges connecting islands of the Inland Sea of Japan, and c) Tokyo Trans-Bay Highway to cross Tokyo Bay by long bridges and underwater tunnels (Fig.1). Environmental impact assessments have been conventionally made in connection with such offshore development projects using marine space, and such assessments related to ocean space involve various difficulties such as described below.

When effects on the marine environment are to be considered, what must first be done is to predict the effect on the boundless natural system of the sea and to aim for coping with the situation beforehand. In such case, a considerable problem is determining the scope of the environmental impact assessment. Furthermore, there has recently been a rising concern in society about protection of the natural environment such as by regulation of large-scale leisure facilities development and tackling the problem of the global environment on an international level. As can be understood from the oil spills in the Persian Gulf in the Middle East, the effects of the spills will spread with time, and it is said more than one hundred years will be required for a return to the former natural condition.

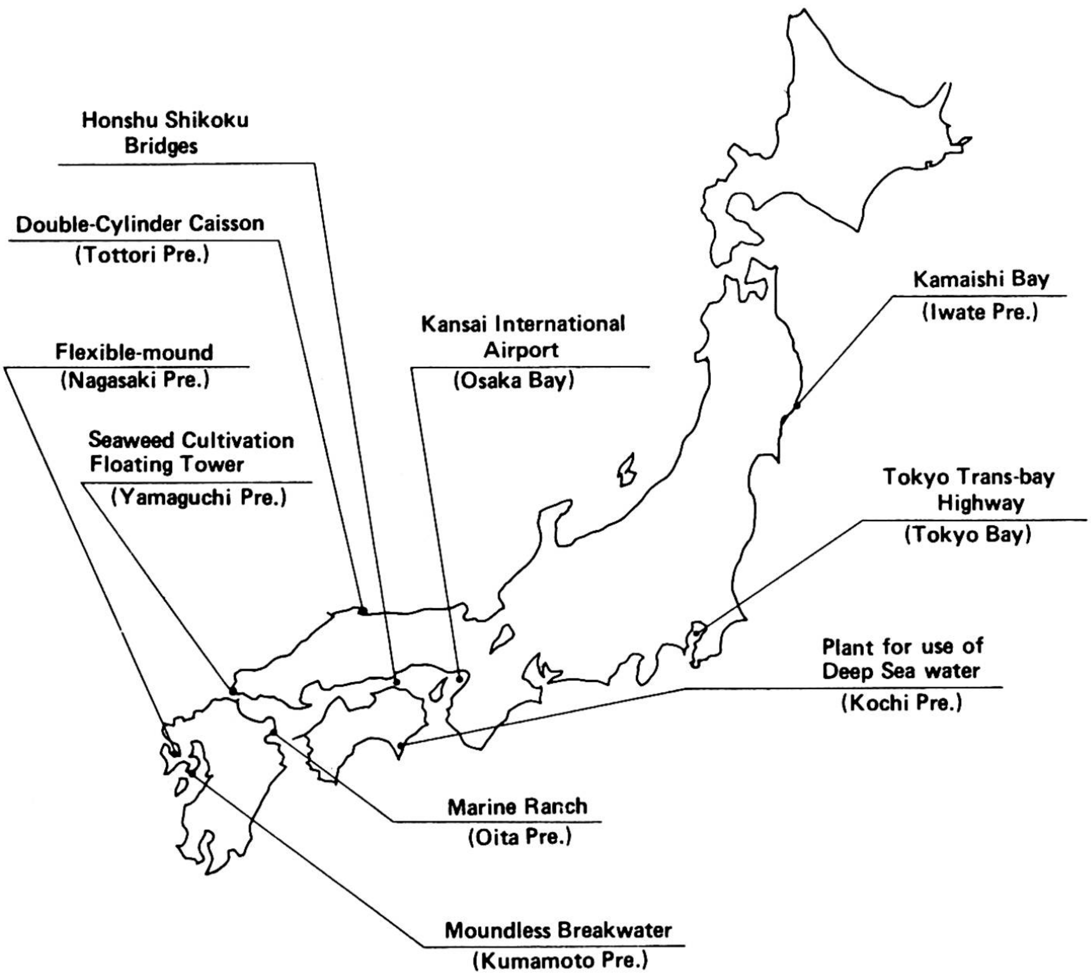


Fig.1 Offshore project map in Japan

Next, it is necessary for the effect on fisheries to be predicted and to provide measures to deal with the situation. Still further, considerations must include the influences on the fishing industry and the people's diet. The regional economy in marine development and the compatibility of pursuing convenience in daily life and the posture to protect the natural environment are becoming increasingly important in recent ocean space development. In the offshore engineering from now on, research and development for dealing with even more severe marine conditions will be necessary. Furthermore, it is needed "not for only unambitious assessment of the impact of construction to be made, but planning of marine development done from the aspect of more positively, in other word, 'creating an environment readily compatible with everyday life of people and natural ecology in addition to the original purpose'."

This paper, therefore, will present a number of cases of R&D and engineering being promoted in Japan, although not yet to an adequate degree, aiming for attainment of new technologies and structures in step with such thinking.

2. NEW TYPES OF SEA AREA CONTROL STRUCTURES

Structures for controlling waves and currents include breakwaters, and training jetties. With the waterfront development of recent years, particularly, with the increased popularization of marine leisure activities, R&D is going on concerning breakwaters for great water depths and for extra soft ground from the consideration of more efficient use of the coastal sea area, and concerning structures capable of managing the sea area while protecting the natural environment and scenic views from the desire to create a more favorable marine environment. A number of examples will be described below.

2.1 Challenging the Deep

A breakwater presently under construction at the port of Kamaishi, Iwate Prefecture, is at a location of water depth as much as 63m, and is drawing attention as the breakwater having the greatest depth in the world. This breakwater, as shown in Fig.2, consists of a foundation mound of rubble-stones from the sea bottom to a water depth of 20 to 30m, with 31 large caissons each 30m in length, width, and height, weighing 16,000t installed on the mound for a composite breakwater.

In manufacture of the caissons, since these are of extra-large size, they cannot be made at one place in a single operation, and therefore, build-up is done in sequence starting from a 6,000-t floating dock and moving from first to fifth offshore concrete placement stations. Construction was begun in 1988, and the third caisson have been installed so far. Completion of the whole project is scheduled for 1998. Upon completion, people living near the shore will be relieved from the fear of tsunamis, the waters inside the bay will be calmed, and navigation of watercraft made safe. Multipurpose ocean utilization will be promoted and a great contribution made to coastal development.

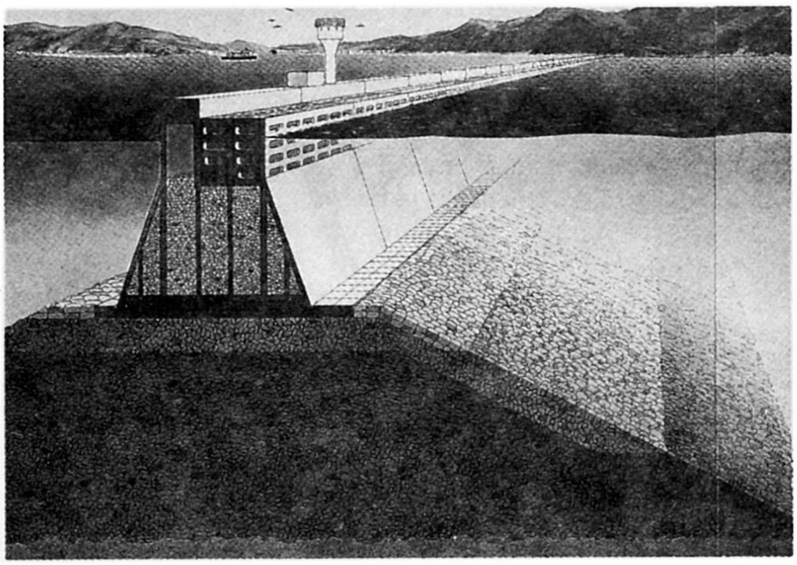


Fig. 2 Breakwater installed at great water depth (Courtesy of Ministry of Transport)

2.2 Overcoming of Soft Seabed

This new type of breakwater with wide footing requires no ground improvement (Fig.3). The adhesive force between the structures bottom and the ground surface underneath, and the horizontal resistance of piles are working against sliding enabling the breakwater's weight to be reduced. On-site proving tests were completed in 1986, and such a break -water has been in practical use at Kumamoto Port since 1988. The construction period required for this type of breakwater is expected to one-forth of that for a conventional gravity type and the cost one-seventh. Studies are being continued with the aim of achieving further improvements.

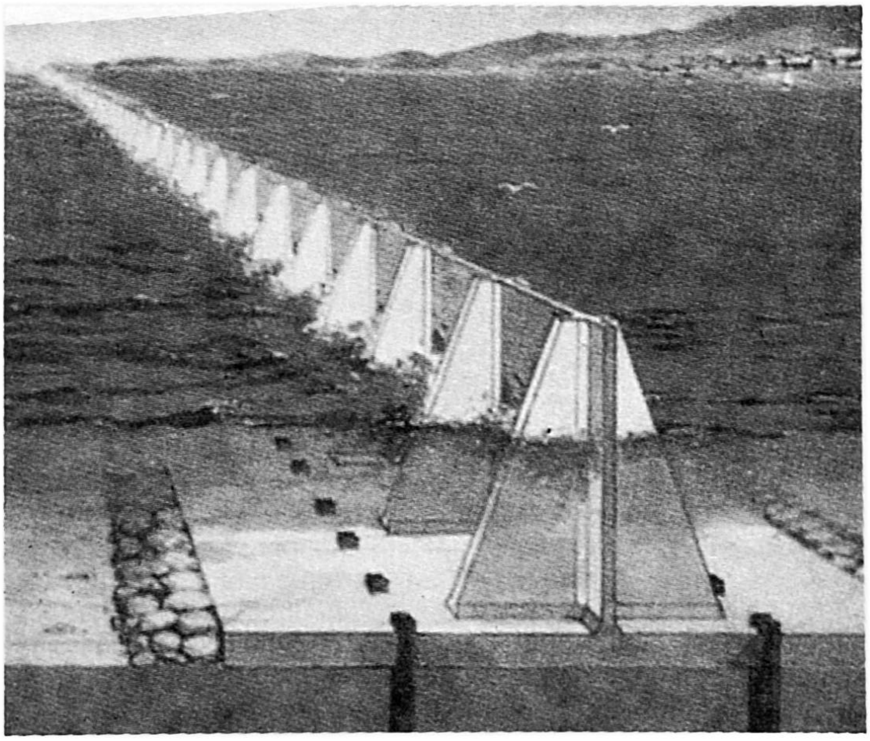


Fig.3 Breakwater installed directly on soft seabed. (Courtesy of Ministry of Transport)

2.3 Flexible-mound

Flexible-mound is a wave control structure of a completely new concept. It consists of a flexible membrane bag of approximately semi-cylindrical shape made of fiber-reinforced hard rubber. Conventional submerged breakwaters break up waves passing across to dissipate their energy, whereas Flexible-mound itself deforms due to incident waves, and through the two effects of the secondly waves (radiation waves) formed by the deformation interfering with waves incident and passing across, and the energy damping by movement of the membrane, the waves at the back side of Flexible-mound will be smaller. It will suffice for the cross-sectional area to be about one-fourth compared with a conventional submerged breakwater so that exchange of sea water occurs more easily, while moreover, there is no obstruction to navigation of watercraft.

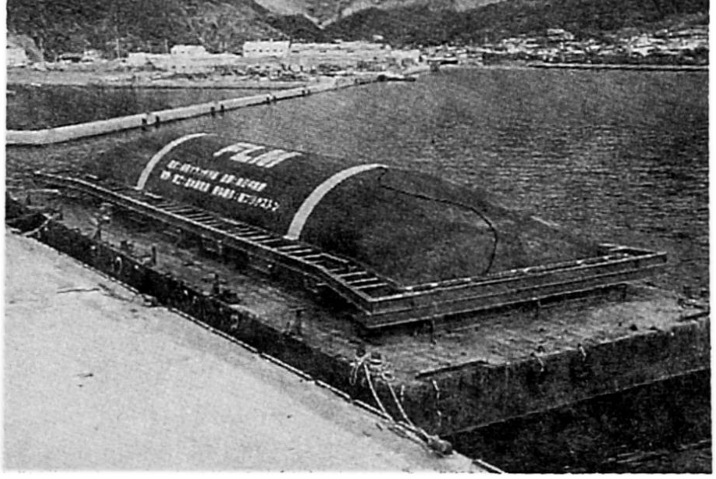


Fig.4 Flexible-mound during airtightness test on a barge (40m(L) x 9m(W) x 3m(H))

Figures 4 and 5 show the airtightness test of it being conducted on a barge and the image of Flexible-mound installed at Omura Bay in Nagasaki Prefecture in 1991. This Flexible-mound is filled with sea water during a storm as shown in Fig.6 for dispating of waves incident from the mouth of the harbor, while during normal times, the sea water is discharged from the bag and the crest is lowered to the level of the sea bottom for a system allowing regular liners and sight-seeing boats to freely navigate the harbor entrance.

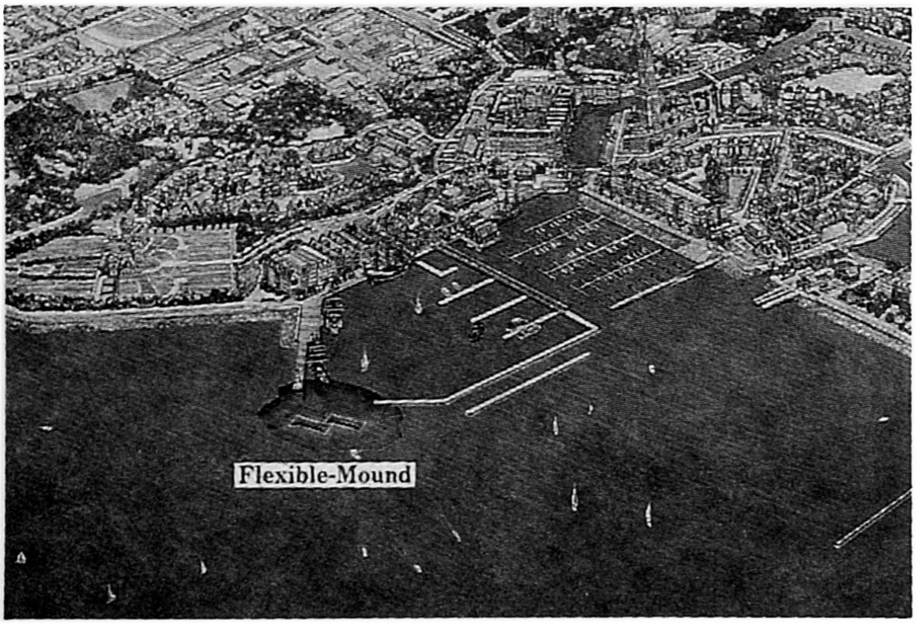


Fig.5 Image of Flexible-mound installation in Huis ten bosch

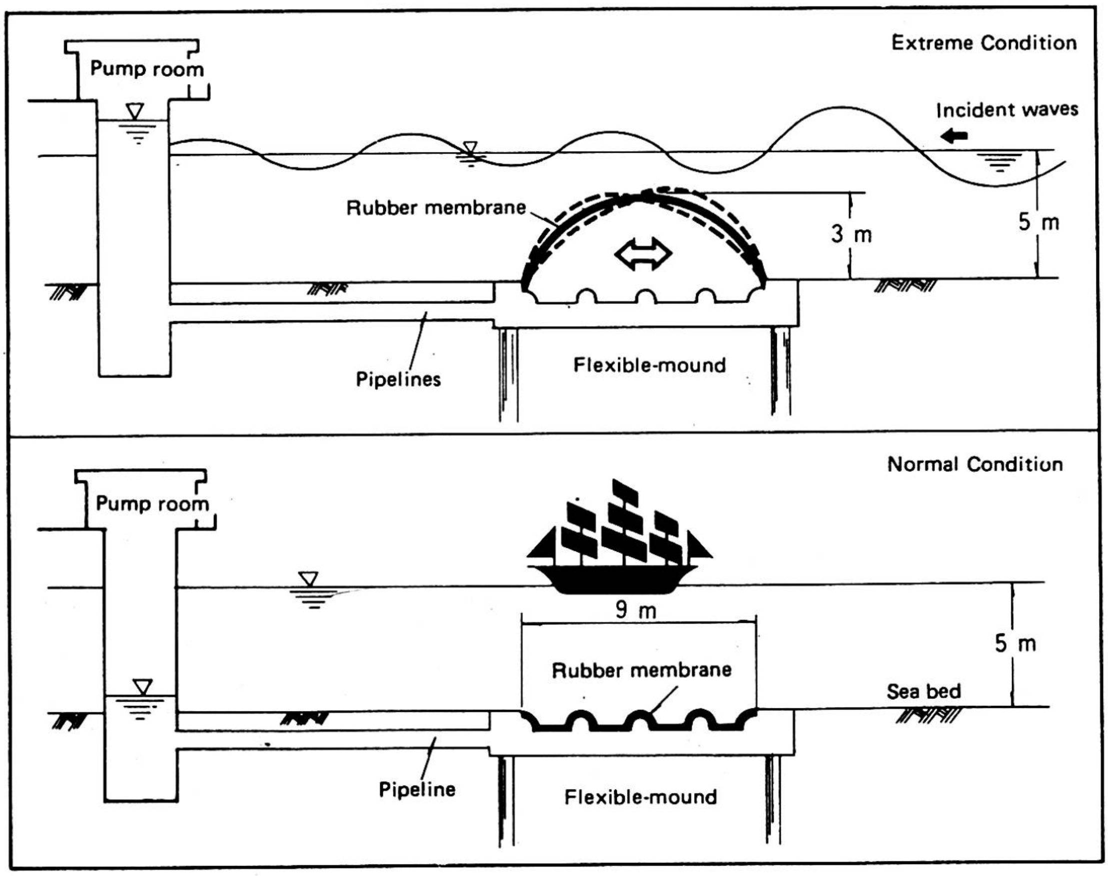


Fig.6 Conceptual drawing of Flexible-mound system

2.4 Double-cylinder Caisson-type Breakwater

The double-cylinder caisson is a new type of caisson which has been under development as a structure for controlling waves at great water depths (Fig.7). The principle feature of this breakwater is perforated double-cylinder structure. The outer cylinder is pervious with a doughnut-shaped retarding pool in the space between the outer and inner cylinders. Waves arriving at the breakwater enter the retarding pool through windows in the outer cylinder, go around either side of the pool, and collide with each other at the back. The section underneath of the retarding pool and the inner cylinder are filled with material such as sand to provide weight. Features of this caisson are the following:

- -Being of cylindrical structure, savings can be made in members so that wave forces acting can be alleviated, an economical breakwater for wave control in waters of great depth results.
- -The ratios of openings of the outer cylinder wall can be selected as suited for any variation between impervious strucure and pervious structure, while since reflected waves can be made small, this is a breakwater effective for preserving the water quality environment in the harbor and improving navigability of small watercraft in the front sea area of the breakwater.
- -Being of cylindrical shape, the normal line of the breakwater can be curved with consideration given from the point of view of appearance.

Demonstration tests were completed at Sakai Port in Tottori Prefecture in 1989, and it is scheduled for caissons 30m in height to be constructed at Shibayama port in Hyogo Prefecture in 1992.

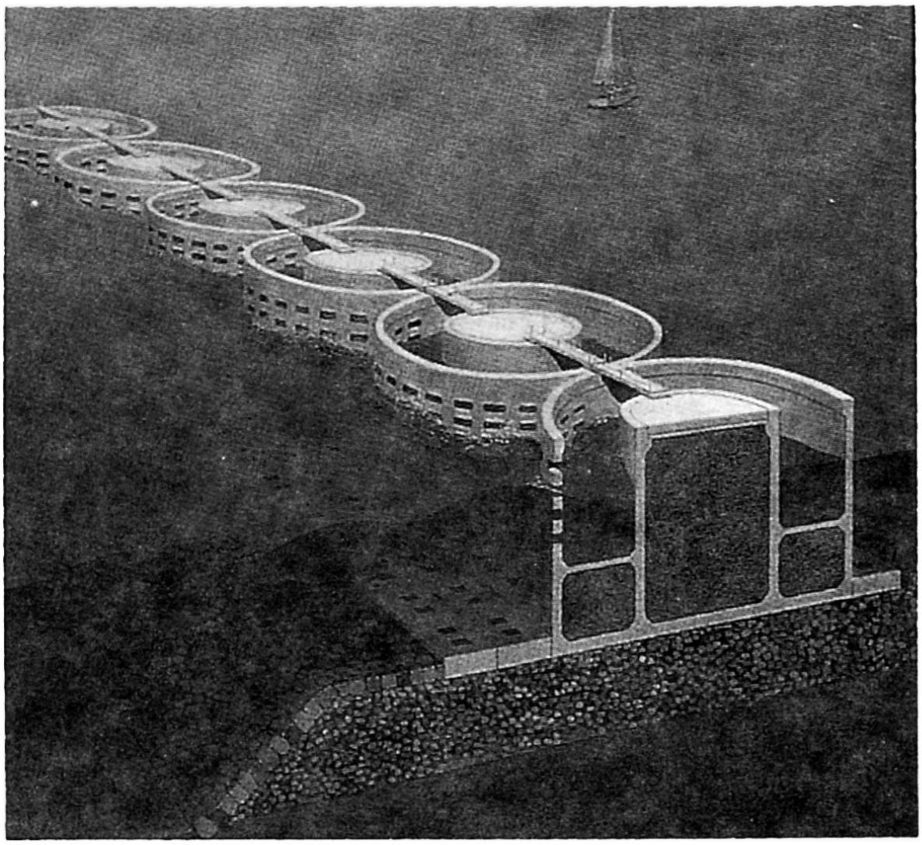


Fig.7 Double-cylinder caisson-type breakwater
(Courtesy of Ministry of Transport)

3. MARINE RANCH SYSTEMS

A marine ranch is a system where the method of putting cattle and horses to pasturage is applied to fishery production, where fish are released into the natural sea and instead of providing fences the range of movement of the released fish is controlled by sound and availability of feed. Since areas available for ocean fishing have shrunk as countries of the world have declared 200-sea-mile exclusive fishery zones, marine ranches which are a form of fisheries made in coastal areas where resources are nurtured, controlled and harvested, have gained attention.

The systematization of marine ranches where synergistic effects are produced through compositing of marine photovoltaic power generating system, plant for effective use of deep sea water, and seaweed cultivation floating tower with marine ranches, is described below.

3.1 Marine Ranch (Acoustic Conditioning Feeding Process Type)

The smallest unit of marine ranch consists of an artificial fish reef and a feeding buoy which supplies feed while emitting sounds several times daily. Figure 8 is a conceptual drawing of the world first marine ranch system introduced in Oita Prefecture. Here, a set of artificial fish reefs and two acoustic feeding buoys are installed, and the movement and quantity of red sea bream are measured by sensors attached to the buoys, with this information, along with sea area environment data, being transmitted by radio waves to an onshore monitoring station.

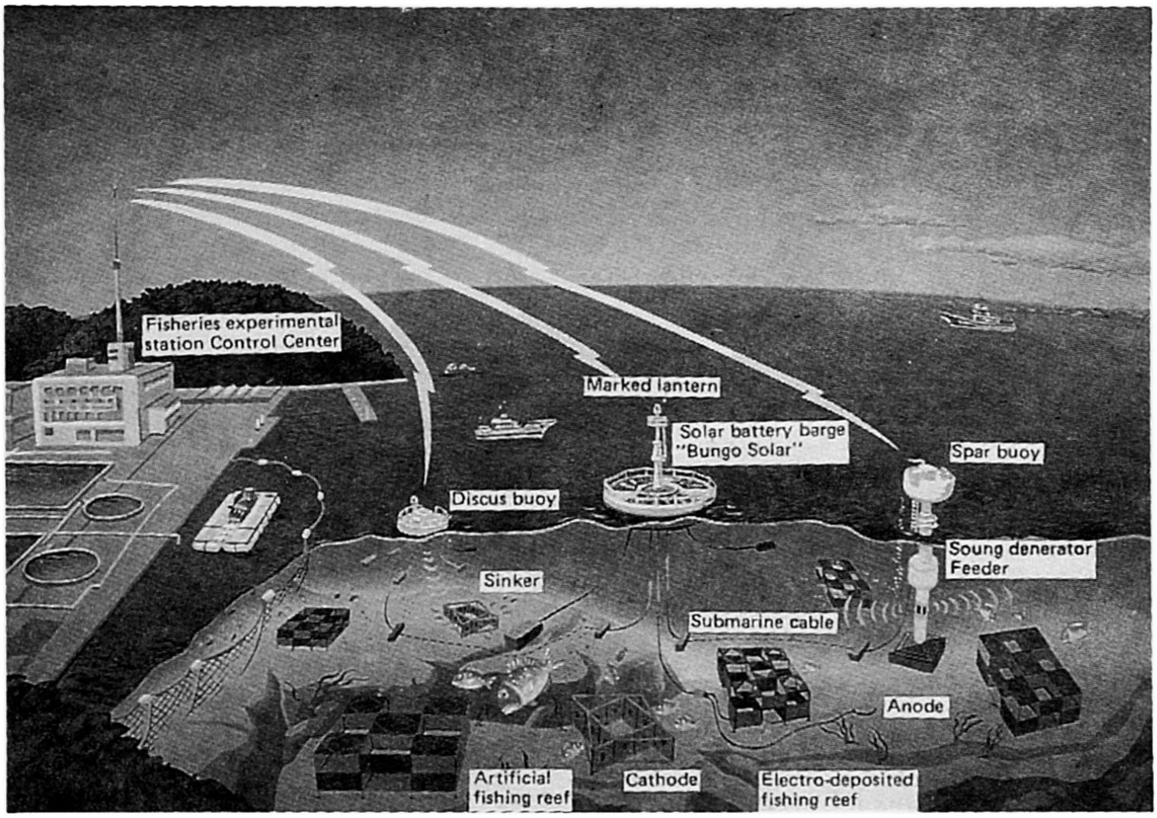


Fig.8 General view of marine ranch

The marine photovoltaic power generating system shown in Fig.9 was developed as the power supply source for this marine ranch. This system consists of 264 photovoltaic cell modules mounted on a barge of diameter 16m and height 3.8m, with this barge moored by three chains at a place of water depth 25m to generate electric power. This barge is a floating structure of concrete with thin walls (25cm) to secure draft while still being sufficiently watertight. For construction of this barge, the knowhow gained with the Arctic Ocean drilling platform, "Super CIDS", was applied adopting a structure with prestress induced in a high-strength, lightweight concrete (σ_{ck} = 3920 N/cm^2, γ_c = 1.85 kgf/cm^3).

Since this marine ranch utilizes the productive capabilities of nature, the amount of feed supply suffices to be one-half of the requirement, and there is the merit that water pollution due to excessive feed considered to be a problem in conventional fish breeding is reduced. There is much expectation of the increased provision of marine ranches as a means of overcoming the trend of decline in catches in coastal fishing seen in recent years

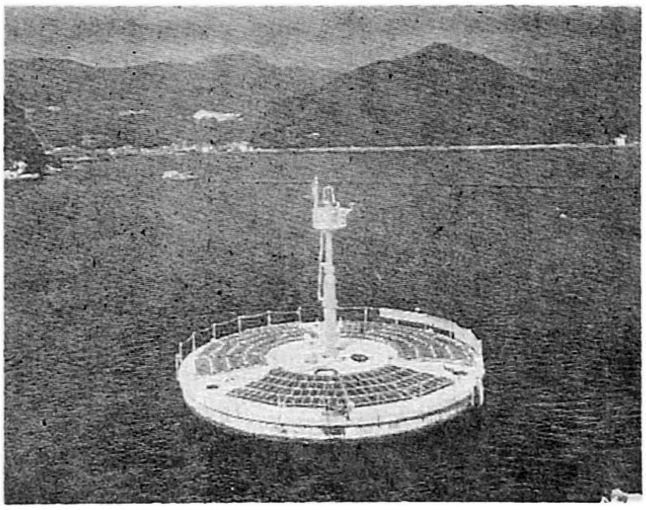
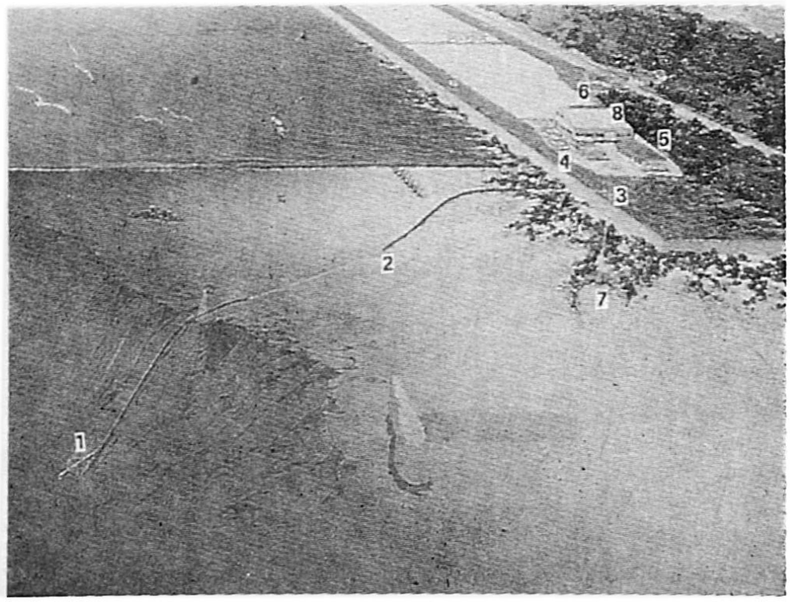


Fig. 9 Marine photovoltaic power generating system

3.2 Plant for Effective Use of Deep Sea Water

Deep sea water is sea water at depth exceeding 200m and has three features of being highly nutrient, very pure, and constant low temperature throughout the year. An experimentation plant for effective use of deep sea water taking advantage of these features was built in Kochi Prefecture in 1989. This plant, as shown in Fig.10 is composed of a deep sea water intake pipe (the high-density polyethlene pipe reinforced by steel wire), surface water intake pipe, pumping facilities, and onshore facilities, and is capable of supplying deep sea water from a depth of 320m and surface layer water from the sea surface in quantities of 460m^3/day and 500m^3/day, respectively, to the onshore experimentation facilities. Especially, the intake facilities of the deep sea water intake pipe (length 2650m, water depth 320m) takes advantage of the knowhow gained with an ocean thermal energy conversion plant constructed in the Republic of Nauru. It is possible for deep sea water and the surface water taken in to be freely mixed together at this research facility to create a breeding environment optimum for the object organisms.

Studies are being made for these characteristics of deep sea water to be taken advantage of for breeding of fishes and shellfishes and as a heat source focusing on the low-temperature properties of the water, cultivation of microscopic algae and refining of anticancer drugs using the algae for a broad scope of applications. Studies are also being made for use in storing of carbon dioxide, cleaning of sea areas, and sea water therapy. In Hawaii, where there are similar facilities, favorable results are already being attained in breeding of fishes and shellfishes, with the stage of commercial application drawing near.

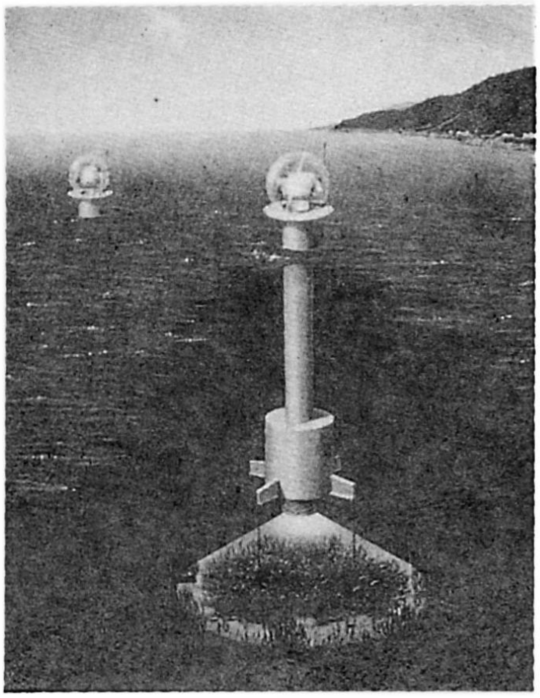


1 Inlet of deep sea water
2 Suction pipe of deep sea water
3 Pump pit
4 Filter tank
5 Research laboratory
6 Experiment building
7 Inlet of surface sea water
8 Machine building

Fig.10 Experimentation plant for effective use of deep sea water

3.3 Seaweed Cultivation Floating Tower

Seaweed cultivation floating tower shown in Fig. 11, is a system for promoting breeding of fishes and shellfishes by stimulating growth of seaweed and phytoplanktons by casting sunlight on the sea bed where light does not easily reach. A demonstration test was conducted in Yamaguchi Prefecture in 1987 with brown algae as the object, while in 1992, proving tests for large water depths are being planned to be carried out in Oita Prefecture. The feature of this system is that the reflecting mirror of the light collector automatically rotates to follow the sun by means of a light sensor, with sunlight passing down through the cylinder of the buoy and being dispersed at the bottom by a concave lens to be cast on seaweed. This is a highly efficient system with little attenuation of sunlight.



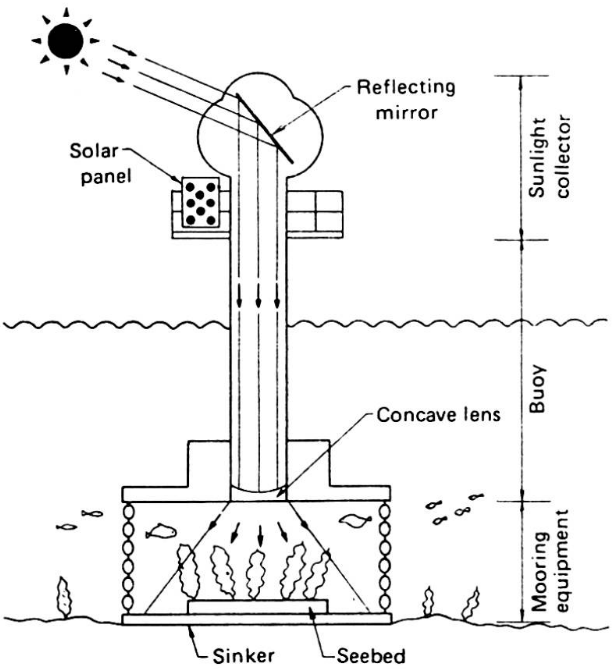


Fig.11 Image perspective of seaweed cultivation floating tower

4. COASTAL WATER CLEAN-UP SYSTEM

With the increase in waterfront development projects it has become necessary for positive measures to be taken for water quality improvement and preservation of sea areas, especially, large sea areas of enclosed nature. For this purpose, technology development is being done for sea water clean-up facilities and simulation of water quality variation prediction. Examples are given below.

4.1 Hybrid Clean-up Breakwater

A hybrid clean-up breakwater is a system consisting of a breakwater which also has the function of cleaning sea water. As shown in Fig.12, a wave arriving from the outer sea runs up the inclined wall of the breakwater and the sea water drops down on a gravel layer filling the interior of the breakwater, passes through the gravel layer, and flows out to the calm inner sea area. Dissolved oxygen in the sea water is increased during this process, while at the same time, organisms adhered to the gravel surfaces clean the water. This clean-up breakwater has low resistance to the passage of water so that water can get through by means of natural energy (tides, waves) or small-scale motive power, for low running cost. This is still at the experiment stage, but it has been clearly shown that substantial improvements in suspended solids (SS) levels, and improvement in chemical oxygen demand (COD) of approximately 30 percent can be achieved.

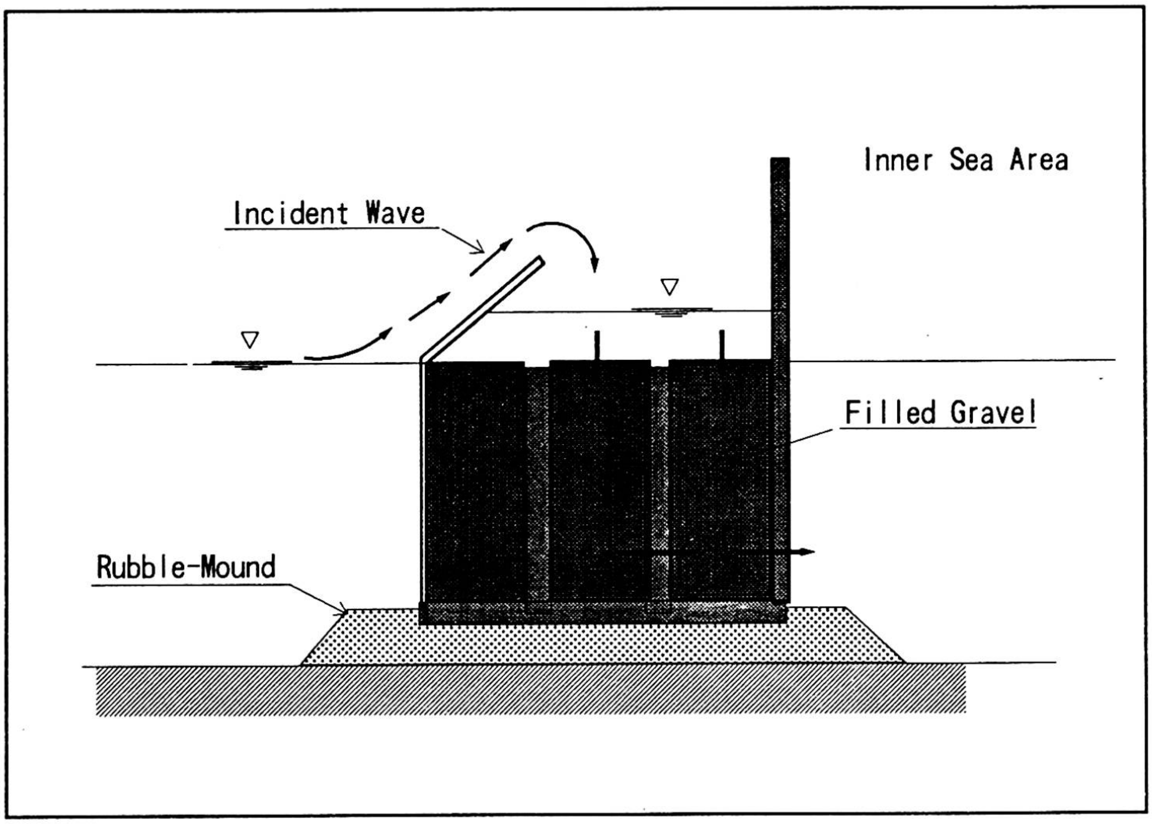


Fig. 12 Conceptual drawing of hybrid clean-up breakwater structure

4.2 Marine Environment Assessment Technology

By marine environment assessment technology is meant a system for grasping current states of water quality, beaches, etc., predicting future changes, or evaluating maintenance and control. This system is still in the process of development, but Fig.13 gives an example of an assessment made of the possibility of water quality preservation in case of a large-scale marine resort development in Nagasaki Prefecture, where a simulation was made of sea water exchange and distribution through tides in artificial channels. Such water quality prediction and techniques for simulation of seashore changes will become increasingly needed at the planning stage of marine development.

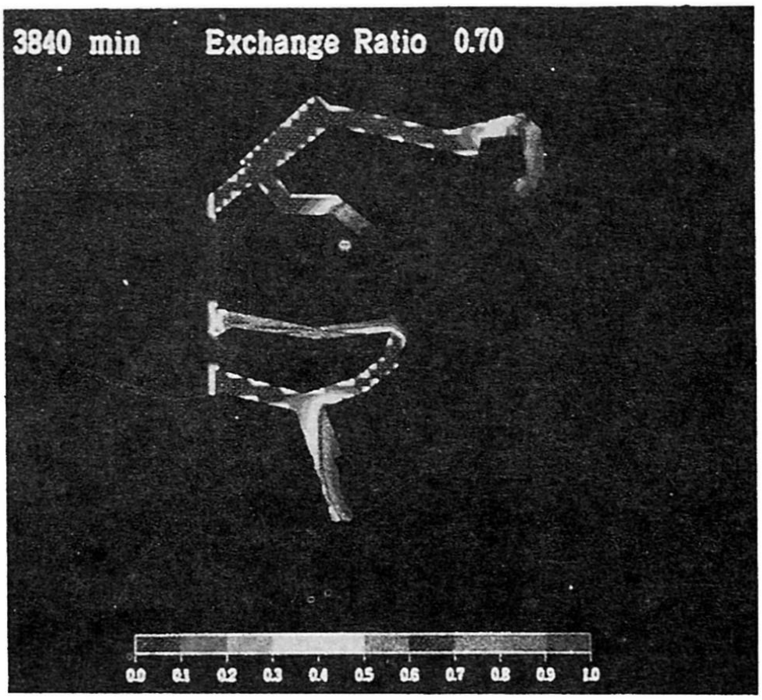


Fig.13 Simulation of sea water exchange distribution in artificial channels

5. CONCLUSIONS

The examples which have been given here are all of technologies or facilities with specific purposes or functions. However, the respective basic conceptions are not for only functional properties, or economic natures to be given first priority; they have the features of "creating an environment compatible even the least bit with the lives of people and ecology." From a technical standpoint, the principal aim is to overcome severe natural conditions such as great water depths, high waves, and very soft ground, but considerations are also given to ecological systems of sea areas. However, these measures are very inadequate as yet, and the technologies now available are still insufficient. For example, these short-comings must be met through introduction of advanced technologies such as biotechnology and new base materials, with these ingeniously combined to fit regional needs.

As a backup for this, it is indispensable for there to be R&D through cooperation between industry, government, and academe of civilian leadership type and cooperation between different fields of business. Lastly, at this time when the topic of the global environment has become a matter of international concern, the author wishes to state that it is his desire to deal with marine development carrying from the point of view of creative engineering friendly to the marine environment." It would be gratifying if this paper were to provide some kind of hint in contemplating marine development of the future.

REFERENCE

[1] Y. Yoshimoto, Recent Port and Harbor Construction Technology in Japan, Seminar on Engineering for Coastal Development, pp. s1-s-10, 1991.

[2] M. Tanaka, T. Ohyama, T. Kiyokawa, T. Ueda, A. Omata, Wave control By Flexible Underwater Mound, Proceeding of Offshore Technology Conference, 1990.

[3] J. McNary, T. Nakajima, M. Iguro, S. Ono, K. Inoue, Control of Themal Cracking in the construction of offshore concrete structure, ACI, 1984 Fall Convention, ACI Committee 357.

[4] Y. Ono, T. Suzuki, M. Niwa, K. Kuroki, M. Iguro, T. Ota, Construction of Arctic Concrete Island Drilling System, Civil Engineering in Japan '85 Japan Civil Engineering, 1985.

[5] T. Toyota, T. Nakashima, S. Ishi, K. Hagiwara, Installation of a deep-sea water supply system for Maricultur, Techno Ocean '88, 1988.

[6] Y. Yamada, M. Ishibashi, T. Ota, K. Shimizu, Development of a pipe line for land-type OTEC Plant, Seventh International Conference on Offshorel Mechanics and Arctic Engineering, ASME, 1986.

[7] M. Ogata, K. Ezoe, M. Niyagawa, Filed test for seweed cultivation floating tower, Techno Ocean '88, 1988.

[8] T. Ota, M. Kaneshima, T. Hori, Marine Photovoltaic buoy system, Techno Ocean '88, 1988

Submerged Tunnels, Examples of Marine Structures

Tunnels immergés, exemples de structures maritimes

Absenktunnel, Beispiele von Offshore-Bauwerken

Charles J. VOS
Prof. in Constr. of Techn.
Delft Univ. of Technology
Delft, The Netherlands

Charles, J. Vos was trained in civil engineering at the Universities of Delft (The Netherlands) and Leeds (UK). Since 1963 he has been active in the design of heavy civil engineering structures such as immersed tunnels and concrete offshore structures. Since 1982 he also teaches construction technology of concrete structures at Delft University of Technology.

SUMMARY

Submerged tunnels have been constructed since the beginning of this century. They represent the wide range of engineering practice required for offshore structures, such as: deep water dredging and seabed preparation, marine transport and installation operations, large scale fabrication in drydocks and waterproofing. The paper explains these different items including the most up-to-date solutions.

RÉSUMÉ

Les tunnels immergés sont construits depuis le début de ce siècle. Ils mettent en oeuvre une grande partie des techniques de construction en mer par exemple: dragage en eaux profondes, préparation des fonds marins, transport maritime et opérations d'immersion, fabrication à grande échelle en cale sèche et imperméabilisation. Cet article expose ces différents problèmes et les solutions les plus récentes qui leur sont apportées.

ZUSAMMENFASSUNG

Absenktunnel werden seit Beginn dieses Jahrhunderts gebaut. Ihre Realisierung verkörpert einen breiten Umfang an Bauweisen und Technologien, die zur Herstellung von Offshore – Bauwerken erforderlich sind. Dazu zählen Nassbaggern in tiefen Gewässern und Unterwassergründungen, Überseetransporte und Absenkoperationen, sowie grossformatige Vorfertigung in Trockendocks und Bauwerksabdichtung. Der Beitrag verdeutlicht die einzelnen Bauabschnitte und beinhaltet deren neueste Lösungen.

1. INTRODUCTION AND HISTORICAL BACKGROUND

On request of the chairman of the scientific committee this paper has been introduced in the session on offshore structures of unconventional nature. It serves the purpose of demonstrating that many techniques required for such structures are not only proven art, but are also up to date controllable procedures. It further shows to many engineers present, not being familiar with these techniques, that submersed tunnels can be a solution to many communication problems.

Since the construction of the Michigan Central Railroad Tunnel in Detroit, completed in 1909, almost 100 submersed tunnels have been built. The idea to construct structures like bridgepiers, quaywalls and tunnels in a sheltered dock instead of in an exposed pit, being an obstacle to shiptraffic as well, at location, is even far older. It dates back to the end of the 18th century [1].
It is remarkable to notice that the way the Michigan tunnel was built, still represents the "American" way of constructing tunnels. This is characterized mainly by the way the construction takes place. The "american" or "Steel" immersed tunnels are constructed on a shipyard as a single or usually double steel hull, with some concrete for stability as a keel. This structure is than immersed, towed to location, and locally filled with usually non structural concrete, to obtain the required weight and soundness for immersion and in situ functions (Fig. 2).
The "European" tunnel dates back to 1936, when the Maastunnel under the shipping lane to Rotterdam was constructed. The authorities selected, amongst others, two 2-lane American type tunnels, leaving pedestrians and bicycles, temporarily on one or two of the four lanes available. A contractors alternative, involving just one huge reinforced concrete cross section, containing 2 x 2 lanes plus a double deck pedestrian and bicycle channel, was offered for a lower price and accepted. In this way the "European" or "Concrete" immersed tunnel was born. It was completed 50 years ago, in 1942 (Fig. 1).

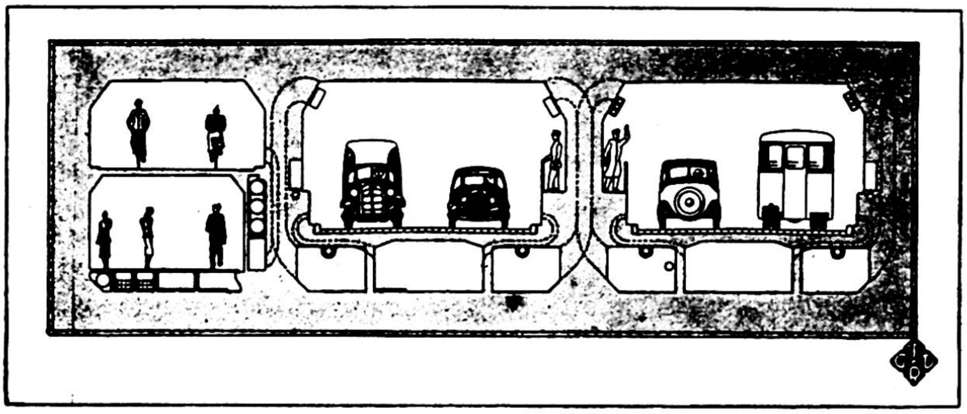


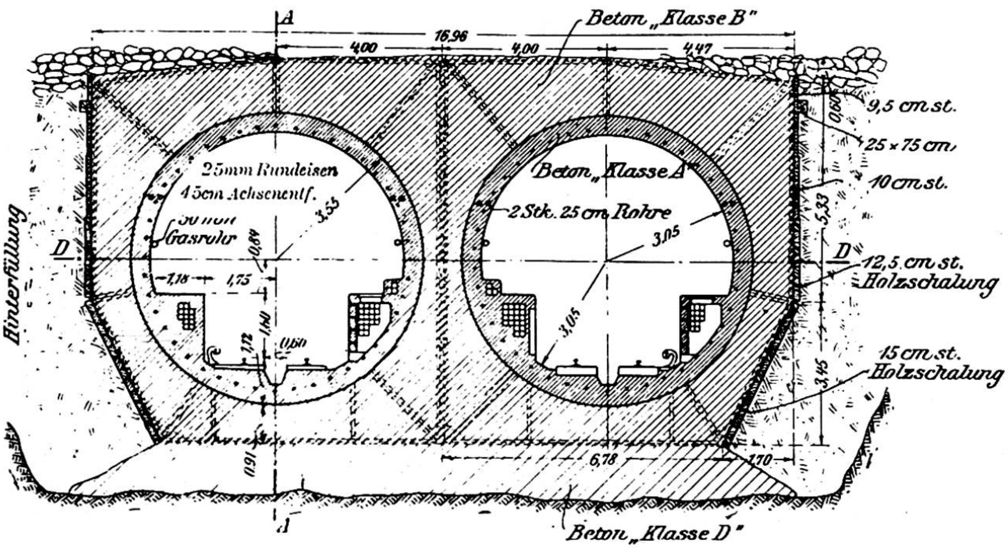
Fig.1 The Rorterdam maastunnel as constructed

At present 42 reinforced "concrete" tunnels and 34 "steel" tunnels have been constructed. 14 of them are constructed in Japan, where both systems are used.[2] Many more submersed tunnels are planned, such as in Greece, Ireland, Hong-Kong, USA, Uk and Holland.

2. BRIDGING, BORING AND IMMERSING

There are of course, like in every engineering discipline, rules of thumb to decide on methods to solve a problem; in this case, how to cross a channel. These rules are however, changing by the development of technology and new public requirements and values. The rules further provide a large area, where all three methods, to cross, have to be considered and evaluated on the basis of costs and quality.
Bridges have been replaced by tunnels because of the impact on shiptraffic. The height of the bridge above the waterline governs the allowable shiptraffic. Today, allowing offshore equipment or large sea going ships to pass, free heights are required of 60 meters and over.
The introduction of an opening span reduces the traffic capacity of the bridge not just during the time of being up, but also before and after the actual opening time. As traffic usually increases, an opening span bridge is no sound solution that will last for long, downstream of cities with a harbour.
The introduction of bridgepiers in shipping channels is a potential danger to shiptraffic that can be quantified quite well with modern simulation techniques.

Last but not least bridge approaches consume scarce space in usually dense industrious areas. All of this makes bridges comparatively less attractive compared to tunnels in a large range of circumstances (Fig. 3).
Bored tunnels need substantial cover underneath the mudline, which usually dictates an overlength of tunnel, especially when the slopes are of limited steepness. They further require suitable soil for drilling to reduce substantial construction risks. As more techniques become available, the feasibility of drilling tunnels increases. Bored tunnels further require substantial length compared to immersed tunnels, in order to depreciate the investment in the shield over sufficient length, to arrive at a competitive price per unit length.



<u>Fig.2</u> Cross section: Michigan Central Railroad tunnel in Detroit

Immersed tunnels are quite flexible in cross section, they only require a dredged trench to be installed and a simple drydock, sometimes located in the future approaches, to be constructed.
All of this explains that immersed tunnels are of increasingly interest for the solution of traffic communication within and around cities. From the number of

tunnels, mentioned in chapter 1, 10 have been completed during the last 5 years. Although no real offshore immersed tunnels have been constructed yet, many plans are under consideration. The Channel tunnel was just not built as an immersed tunnel as the limited width in cross section, being a raillink only and the favourable soilconditions for boring, just ruled out an immersed tunnel. For the Great Belt Link in Denmark, things were different. Although an immersed tube tunnel was offered as more expensive and initiated the potential risk of dredging contaminated soil, it presented less risks compared with a bored tunnel through the geologically complex soilstructure.
The bored tunnel was selected, but presents actually major escalations in time and costs. This may influence the decision process in future offshore tunnelling jobs.

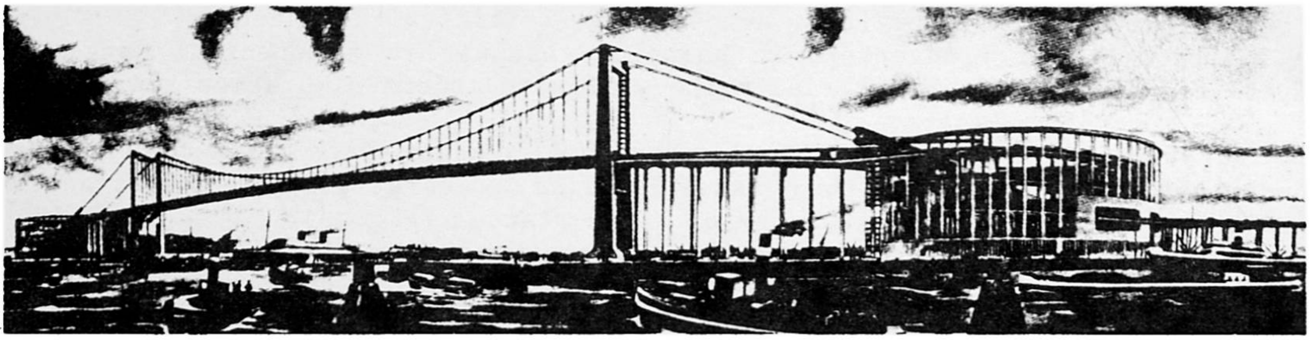


Fig.3 A bridge with spiraltype access structures as proposed for the Maastunnel in Rotterdam.

3. FOUNDATION

Although immersed tunnels, like most offshore structures, float temporarily, they are to be installed on a proper foundation.
It is here where all kind of techniques are used. Tunnels are founded on piles, on a pre-installed gravel or rock beds and on provisional foundations, to be replaced by undergrouting or underbase sand jetting.
This variety of engineering solutions to provide a sound foundation for the immersed tunnel is not only a consequence of geotechnical circumstances at the tunnel location, but also addresses the structural system of the tunnel in longitudinal direction.
The "American" tunnels are usually founded on a gravel or rock bed, being layed on top of a usually quite stiff bottom of a dredged trench. Such a bed, having a minimum depth, provides obviously sufficient elasticity, to safeguard acceptable foundation reactions for tunnelelements of lengths and size as installed in the USA. There is only little information on tolerances being measurable and consequentially tolerable using this method. The record is good and does not show any major problem. The method has been used in Europe as well in a limited scale, especially for service tunnels where uneven subsidence did not raise major problems.
Far more popular in Europe is the method of providing a temporary foundation by means of concrete tiles, on the bed of the dredged trench, on which the tunnel is temporarily founded and geometrically positioned up to quite fine tolerances by means of jacks. The remaining space in between the tunnelbottom and the bed of the trench is than filled with sand. This was originally done by jetting a mix of sand and water from the side of the tunnel through a system of pipes, from which two served the supply of sand and one caused suction in order to

drain the superfluous water (Fig. 4).
At present, the method of just injecting a sandflow through the bottom of the tunnel became more popular, as it avoids any disturbance of shiptraffic and can be applied fast after immersion. This has the advantage, that silt has none or anyhow quite reduced changes to settle in the trench before the final foundation is realized. The sand flow method is based on the principle that velocities in and around a cone of sand being built up underneath a hole in the tunnelslab on the bottom of the trench are such, that the sand settles in a proper way on the outside of the cone. With a centre to centre distance of around 10 m for a 1 m thick void, a sufficient foundation can be realized (Fig. 4) [4].

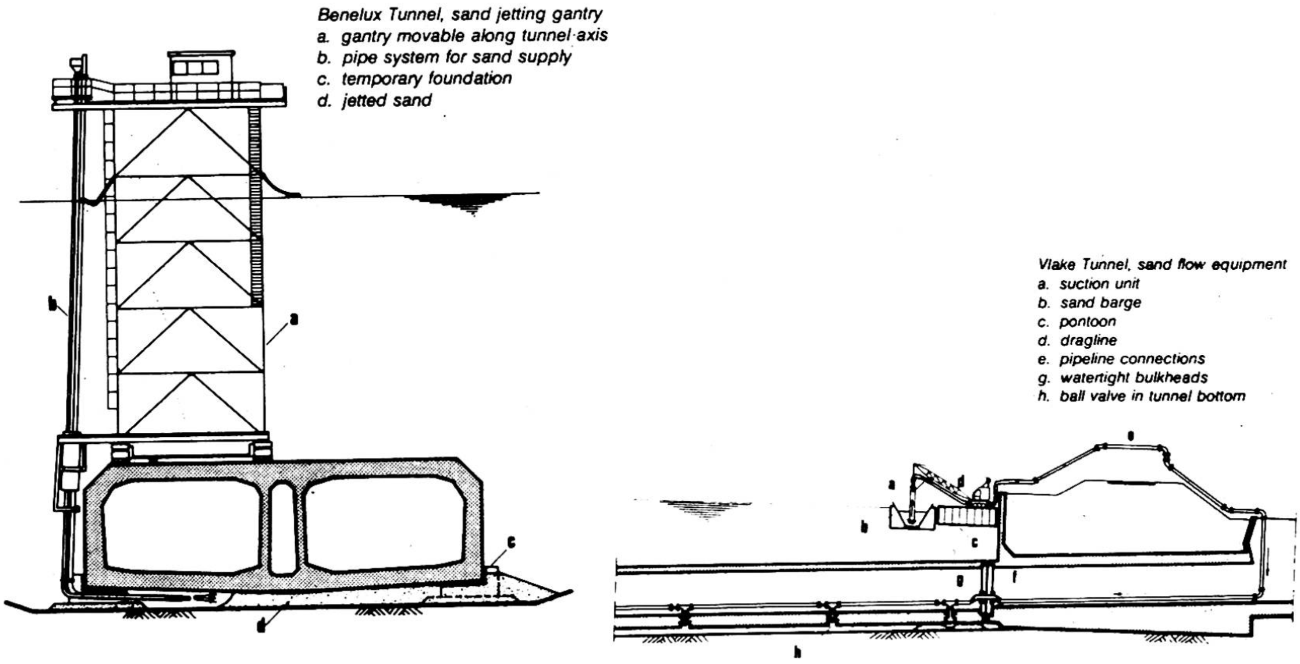
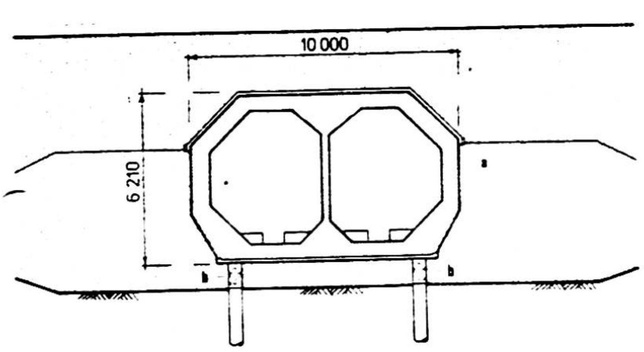
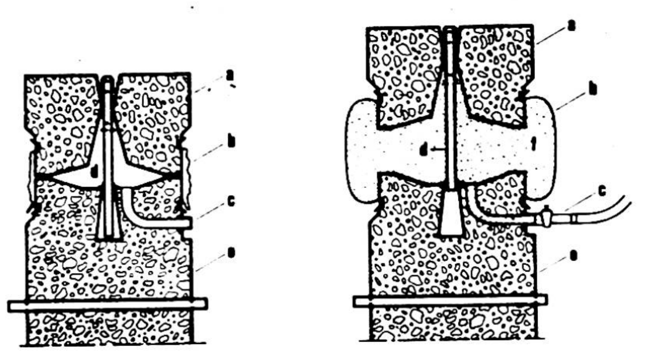


Fig.4 Sand jetting equipment and sand flow equipment in action.

On locations where poor soilconditions would cause unacceptable uneven settlement in the tunnel, or above the tunnel at covered parts outside the actual river, foundations on piles have been provided. This was for instance the case for the Rotterdam subway line (Fig. 5). To meet tolerances, a system was developed with jacks on top of the pre-driven piles.
It should be realized, that for most offshore structures, these methods will not provide a valid solution, as the ratio of horizontal reaction over vertical reaction is basically larger, because of wave forces acting on the structure. Therefore either foundations directly on the seabed or on a prepared seabed are used. In case this is not possible for technical reasons, a skirt is provided around the perimeter and across the bottom of the structure is provided. This skirt penetrates into the seabed. The remaining space is filled by injection of materials that can be mixed with seawater, such as cement and silicate, giving smooth flow characteristics.



Rotterdam Metro Tunnel, cross-section
a. concrete tunnel structure
b. foundation piles with adjustable head



Rotterdam Metro Tunnel, adjustable pile head
a. pile head
b. nylon sleeve
c. grout pipe connection
d. guide rod
e. prefab pile section
f. grout injection

Fig.5 Cross section of Rotterdam subway tunnel and piling system

4. WATERPROOFING AND DURABILITY

A most important aspects of marine structures is the waterproofing and durability. Here again immersed tunnels offer a large record of satisfactory behaviour. There seem to be quite some different approaches towards waterproofing, but most of them just exist, based on historical background.
In the first place the "American" type tunnel had a steel lining. This was not essentially for watertightness or durability, but was there as a consequence of the fabrication method and the structural system. But being there, it was taken for a waterproof hull as well. Many tunnels and other marine structures, including the above mentioned Maastunnel were consequentially provided with a steel or carbohydrants based skin, to provide watertightness.
The construction of tunnels and parts of tunnels by means of pneumatic excavated caissons raised some concern about the resistance of waterproof layers on the outside walls against the soilfriction during placing. It was decided for that reason, to omit the waterproof layer in some cases in Holland and Germany. This decision was further supported by the fact that existing tunnels with watertight coatings were leaking anyhow, because of failing details in joints and details of penetrations. Such leaks were usually quite difficult to trace at their source and to stop.
Since about twenty years now, tunnels in the Netherlands are constructed without an extra watertight layer. The performance is extremely well and can be an example worldwide, provided that a few things are noticed. This concerns concreting including treatment, detailing of joints and penetrations and the provision of back up measures where relevant.
When the concrete has to be the only and consequentially reliable way of defense against leakage, the whole process of concreting with all its aspects has to be controllable in order to provide the required reliability. This has been improved in several ways during the last decade, especially by the ability to study all aspects influencing the hardening process of concrete in one computer model [5]. These aspects concern mix-design, hardening parameters like cooling and heating, environmental aspects like temperature and wind and construction parameters like formwork and time of stripping.
Working with such a model, stresses during the hardening process of concrete can be predicted and controlled, enabling us to select an effective way of construction in view of costs and durability (fig. 6).

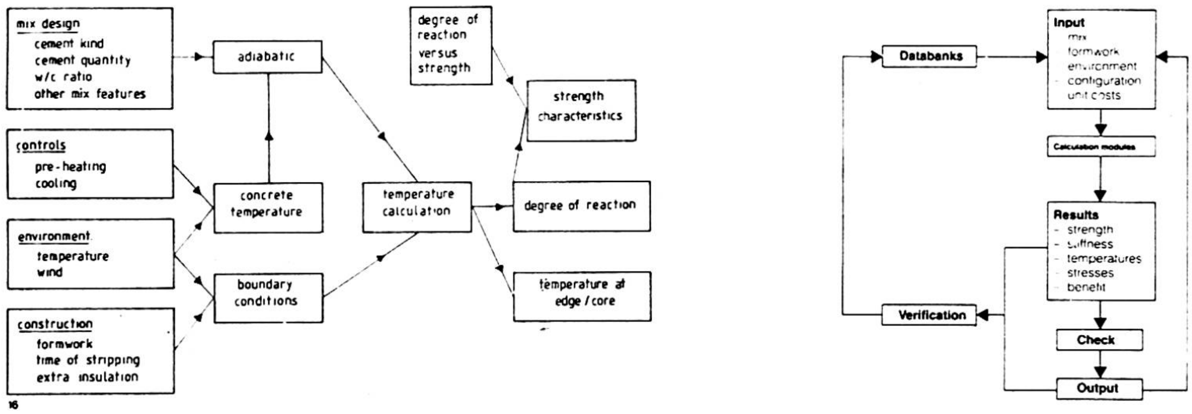


Fig.6 Relation in between construction parameters and concrete characteristics. Flowsheet of a computerprogram analyzing this.

With concrete being sufficiently impermeable by good design, practice and control, only the details, such as construction joints, joints to be provided for expansion and rotation and joints to link independently immersed units together are left for attention.

For construction joints good practice, such as jetting fresh stripped surfaces, is quite common and satisfactory. Joints in between independently immersed elements are usually carried out with double waterstops. Most remaining trouble in the past has been caused by joints to provide expansion and rotation freedom within one tunnel element. It is common practice today, to take special measures during pouring of concrete around such joints, to avoid honeycombing and air entrainment, in the vicinity of the waterstop in the joint. On top of that, means are provided to inject possible leaks in between the concrete and the waterstop anyhow, with some back up for injection after final installation (see fig. 7).

Elastic strip for reinjection

Injection tube

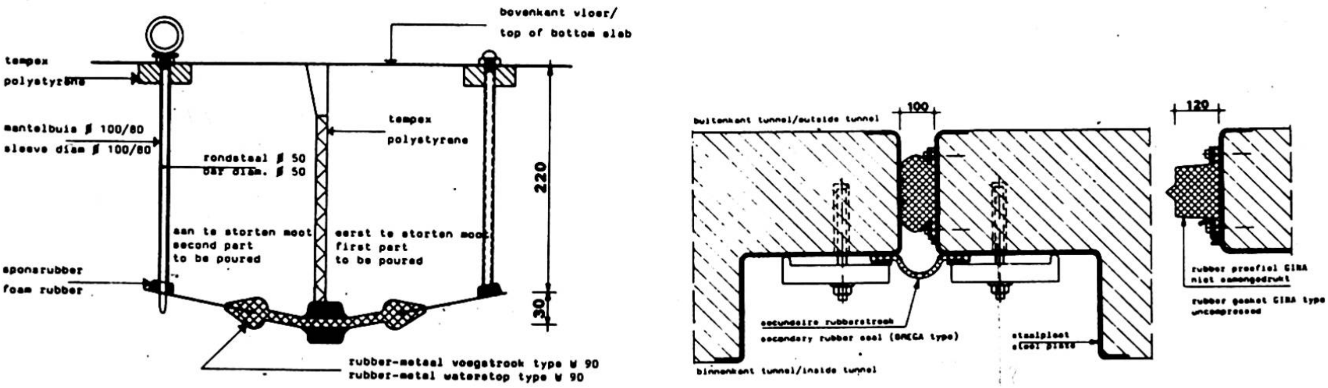


Fig.7 Joint details for joints within and at ends of submersed units.

It can be concluded that watertightness for concrete marine structures is no problem anymore, provided that sufficient know-how is being made available and sufficient quality control is being applied to the job. As durability of the structure requires more or less the same effort, it can be concluded that this can be assured in the same way.

5. STRUCTURAL SYSTEM

The American type tunnels have always been solid structures in longitudinal way for the length of one immersed unit. Connections in between units have also been designed quite stiff, not allowing rotations.
In Europe, where tunnels have been constructed on soils of less stiff nature, the concept of hinges within the units at distances interfering with the casting joints came up and is commonly used. The elements are made stiff by prestressing from bulkhead to bulk-head during float up, tow and immersion. After installation the prestressing cables are removed and the element can follow the differential settlement of the riverbed without forces being introduced in longitudinal direction of the tunnel element. A secondary benefit of this system is the fact, that less than minimum reinforcement in longitudinal direction can be applied in the tunnelelement as no mechanism to cause brittle failure in longitudinal direction is present. In some cases, the temporary prestress is only provided in the area of the joint. In such a case the longitudinal reinforcement should of course have a minimum value as required for membrame tensile stresses in the cross section.
An other aspect of the structural system for reinforced concrete tunnels is the internal force distribution in transverse direction. As shear usually governs the design of the cross section, several systems are available to decide on dimensions of the cross section. In case of low waterdepth, say less than 15 m, or small spans as in case of railtunnels or two lane tunnels, just normal reinforced concrete plate type structures can form roof, bottom and sides of the tunnel. In case of larger depths and wider tunnels, with 3 lanes, sizing roof and bottom will not result anymore in tunnels of minimum cross section still being able to float. In such cases a selection has to be made in between a larger cross section, requiring more concrete, dredging and tunnellength, or solutions with transverse prestressing, providing stirrup reinforcement in roof and bottom or bent up bars in roof and bottom. It may be clear, that an approach for an effective solution now requires more partners in the construction process than just the designers.
Such choices, to be obtain the most effective structure, in a discussion in between designers and constructors, are quite common and even required during the design of offshore structures.

6. CONSTRUCTION FACILITY

Large offshore structures as well as immersed tunnels have been constructed in both existing shipyards and dedicated "polder" type drydocks. Availability, soilconditions, local law, and an increasing impact of environmental aspects govern the choice of a construction facility for a specific job. It is quite possible in certain cases where more tunnels have to be built in a small area, that the same facility will be used several times. In Holland, the Hijnenoord dock, in the vicinity of Rotterdam, was used for seven immersed tunnels, since its construction in 1966.
Sometimes tunneldocks are provided temporarily in the future approaches to the tunnel. This reduces extra dredging work in case of small projects and low draft access to the tunnel trench.
Just as for offshore structures, parts of ship repairdocks, or abandoned drydocks, are sometimes made available for the construction of immersed tunnels. Fast construction becomes quite important in that case.

7. IMMERSION SYSTEMS

Whereas the construction of the elements for an immersed tube tunnel is still of a comparatively conventional character, the marine operations, containing float up (will it float ?, etc.), tow (can it be towed regarding draft, tide, waves and current, etc.) and immersion (will stability be sufficient in all stages; is the time frame sufficient, etc.) are not.
Recent practice has shown, that it is quite useful to consider the skills required for the immersion procedures as an integral required experience in the design and construction of an immersed tunnel job. This means that immersion and the preparation of immersion has so many effects on the total construction of an immersed tunnel, that it can not be considered as a subcontract in the whole procedure.
Apart from design and integration of embedded items for float, tow and immersion, of the elements, unconventional disciplines like weight control, required strength for operations and possible impacts during operations are to be considered.
Beyond this, two basic design philosofies are valuable for the selection of the main parameter of the immersion system. The tunnel elements may have sufficient buoyancy for float and tow and will have to be ballasted for immersion and provisional installation. This method requires quite light immersion equipment, but involves substantial work in the elements before, during and after installation.
The other method, as quite frequently used in the USA involves floating up, towing and immersing tunnel elements without any floating capability. The equipment is consequentially more expensive, but savings are made by having no ballast equipment for storage and pumping within the elements and having no need for the installation of ballastconcrete after installation.

8. CONCLUDING REMARKS

It is clear from the few aspects being touched in this paper, that there is not a thing like an ideal design for a submerged tunnel. Project parameters, like draft, type of traffic, length and depth will provide different challenges to the designers. The design parameters, like structural system, waterproofing and foundation still offer a wide variety of solutions. Both project and design are having an impact on the construction method.
Quality control, especially where information technology plays a role, provides means of simulating construction processes, like marine operations for towing and immersion, like concrete hardening for strength and stress development and like surveying for weight control. This will reduce risks and provide new technologies for faster construction of cheaper and more durable structures.
This is the case in the offshore industry as well. The present record of immersed tunnels in the world proofs it.

<u>References</u>

1. PICON A.,YVON M., L'Ingénieur Artiste. Presses de l'Ecole Nationale des Ponts et Chaussées. Paris 1989. ISBN 2-85978-128-5
2. Immersed tunnel techniques. Proceedings of the conference organized by the Institution of Civil Engineers and held in Manchester on 11 - 13 April 1989. Thomas Telford, London, 1990. ISBN 0-7277-1512-7
3. STIKSMA K., Tunnels in The Netherlands, underground transport connections. Illustra, The Netherlands 1987. ISBN 90 6618 535 X
4. Immersed Tunnels 1. Proceedings of the Delta Tunnelling Symposium Amsterdam 16-17th November 1987. VNC 's-Hertogenbosch 1978; reprint 1987.
5. Immersed Tunnels 2. Proceedings of the Delta Tunnelling Symposium II, Amsterdam 12-13 November 1987. VNC 's-Hertogenbosch 1987.