TECHNICAL MANUAL FOR RESOURCE ENHANCEMENT

TD/RES/25

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TRAINING DEPARTMENT

SOUTHEAST ASIAN FISHERIES DEVELOPMENT CENTER

Technical Manual for Resource Enhancement

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Training Department
Southeast Asian Fisheries Development Center

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Preface

In the last two decades, many countries throughout the world have declared their own Exclusive Economic Zones (EEZ), of which there are now two hundred. However, in the case of neighbouring countries, many of them have not yet reached agreement on the extent of their territorial waters. On the other hand, on a more general level, the situation with regard to fishing gear and fishing technology has improved considerably. Nevertheless, this modernization has, in turn, brought about a rapid decline in marine resources, due to both the increase and the greater efficiency in fishing activities. As a result, the demand for more advanced technology in order to enhance marine resources has grown rapidly in those regions where the EEZ situation is still unresolved.

As a contribution to this resource enhancement, therefore, SEAFDEC is issuing a technical manual which is concerned with artificial reefs, in particular. The author, who has been working with SEAFDEC for two years, feels that there is still a lack of knowledge of tropical marine ecology. For instance, major additions to the marine forest in the Southeast Asian region are recommended, as part of the new technology. At first, it was considered whether it would be better to reconstruct coral reefs, instead of introducing more marine forest; and, given the importance of the vegetable kingdom in the environment, it was decided that the latter should be recommended. Both artificial reefs and additions to the marine forest are, therefore, recommendations made in the manual.

It is hoped, first of all, that this manual will be made available to the many officers, who are in charge of artificial reef projects in the SEAFDEC member-countries, and that it will reinforce the work which is being carried out.

ACKNOWLEDGEMENTS

The author wishes to express his gratitude to Emeritus Professor Dr. Nobuo Taga, a JICA expert attached to Srinakarinvirot University, and to Professor Dr. Khanjanapaj Lewmanomont of Kasetsart University, both of whom checked the contents of the manual, (except for chapter 6).

The author would also like to express his appreciation to the staff of the SEAFDEC Aquaculture Department (AQD), Iloilo, the Philippines, and to Miss S. Suvapepun of the Marine Fisheries Division, Thailand, for contributing the record sheets of the life histories which are contained in Appendix I.

Finally, the author is indebted to the former Secretary General Dr. Veravat Hongskul, who approved the original proposal to compile the manual, and to the present Secretary General, Dr. Thiraphan Bhukaswan, who agreed to its publication.

CONTENTS

APPENDICES

1. Objectives

(i) The main objectives of this manual are to establish the requirements that should help to ensure the success of existing and future Resource Enhancement Projects.

(ii) More concretely, (in order to ensure) the purpose of the manual is to assist in the smooth and efficient operation of Artificial Reef Projects, with regard to the setting up and organization of such projects, which are a major part of marine resource enhancement in the Southeast Asian region.

2. Background Literature

The manual is based on "Structural Design Guidelines for Coastal Fishing-Ground Improvement and Development Projects" and "Planning Guidelines for Artificial Reef Work for Coastal Fishing-Ground Improvement and Development Projects", and it is specifically concerned with the situation in the Southeast Asian region. (These guidelines were published by the Fisheries Agency of Japan).

3. Definitions

The term "artificial reef" has been widely used in the field of fisheries technology, without being clearly defined. In the manual, it is used to mean a "fish aggregate device" which may be easily constructed. There are two types of artificial reef, namely, the seabed device and the floating device, the latter being mostly constructed out of either coconut-palm leaves (Unjan) or bamboo (Payao). This manual, however, is concerned with seabed devices only.

The device or module is placed on the seabed, and it is intended to be no bigger than 10 cubic metres.

Devices larger than 10 M^3 are discussed in the chapter on new technology (chapter 8).

In addition, the target areas (where the devices are placed) are at a depth of less than 40 M at each site.

4. Flow-chart

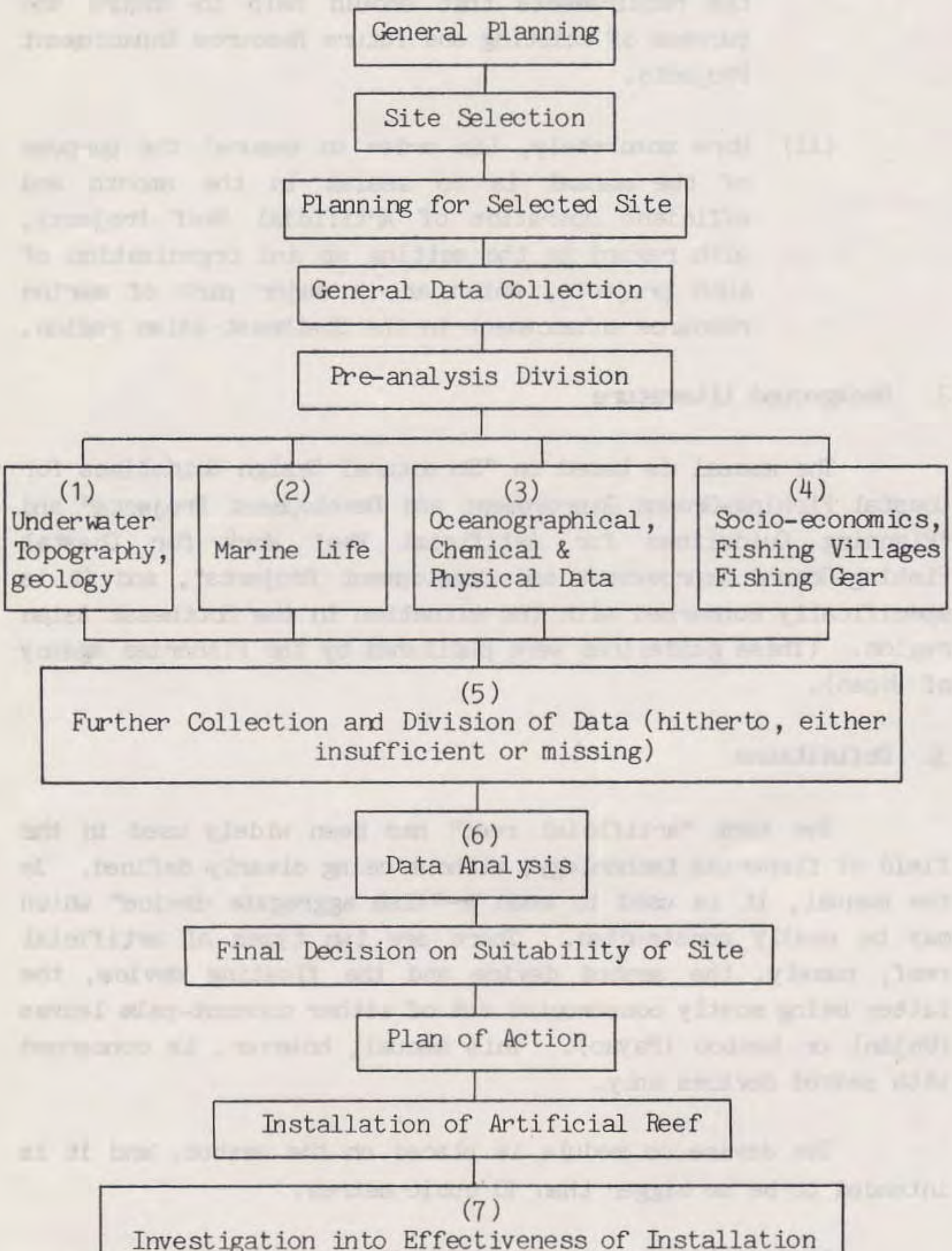


Fig. 1. Flow chart of the planning, site selection, data collection and analysis, and installation of an artificial reef (first phase).

The flow chart (Fig. 1) shows the procedure for the installation of an artificial reef. The details of each block from (1) to (7) are as follows:

(1) Underwater Topography and Geography

The site should be selected depending on the features of the underwater topography, which are shown by the contour lines, as in Fig. 2 (chapter 4). More specifically, the suitability of each site should depend on the seabed gradient, as depicted by the contour lines-in other words, an artificial reef can be installed where the seabed flattens out, (refer to Figs. 2 & 3 in chapter 4).

With regard to natural reefs, their position and shape should be accurately charted, after which the scale of each reef should be measured using an echo-sounder. The bottom quality should be analyzed after sampling.

(2) Marine life

The target species should be chosen from those species which are commercially more highly-priced. The target species should be observed throughout their phasic development. (These features are noted and arranged in Table 1, chapter 5). Then, their feeding habits and predator-prey interaction should be observed. After that, the ecological characteristics of the target species should also be studied, (by means of diving observations and/or through the use of bio-telemeters). Finally, a resources estimation should be made to evaluate the possible size of catch-in other words, by statistical analysis, tagging and making a sample catch.

(3) Oceanography

Oceanographical data, especially relating to currents and waves, should be collected for two reasons, namely, in order to calculate the external pressure exerted on modules and, secondly, to assess the enviromental conditions at the site.

Current velocity and direction should be measured throughout the year, and the period of each measurement should last for at least fifteen days, which should be the fixed period for an oceanological measurement. Data on waves, on the other hand, should be collected over a longer period, and this can also be predicted from data gathered on wind. (Calculations on wind data will be discussed in Appendix IV). Temperature and salinity levels should be measured at the same time as the current measure ments are being made. With regard to the chemical data required, nutrient salts (e.g.; phosphate-P, ammonium-N, nitrite-N and nitrite-N) in seawater and the chlorphyll-a contents of suspended particles should also be analyzed. Additionally, nutrient salts are an important chemical factor for maintaining primary production at the site. The contents of chlorophyll-a are also an indicator of phytoplankton biomass and of potential primary production. This data is directly relevant to marine forest construction- (refer to chapter 8).

(4) Socio-economics

In order to clarify the situation at the site, data on the following items should be collected:

* the number of fishermen using the site

* the cost of the fishing operation

* the kinds of fishing gear used

* the quantity and value of the fish which is processed

* the different types of fishing gear used at the fishing-ground

* the number of fishing villages near the site and the existence (or not) of fishing cooperatives

* illegal fishing that is carried out

In order to ensure the success of each operation, fishing ground management should be considered at the planning stage.

(5) Further collection and division of data

If any of the above-mentioned data required either proves impossible to collect or is insufficient-for instance, the data on currents-further surveying should be carried out. The data which is available should be collated and analyzed. Fishermen using the site should be interviewed and the information collated so as to understand better the effectiveness and validity of the methodology.

(6) Data analysis

All the data collected relating to items (1) to (5) should be analyzed section by section, after which the characteristics of the site should be more comprehensible. This, in turn, should enable decisions to be made as to whether to proceed with the project, or not. Depending on this, the level of investment required can be projected.

(7) Follow-up

At least one year after the installation of the artificial reef, the surveys should be repeated for items (1) to (4). Depending on these results, a re-evaluation should be made to see whether the operation can be improved upon and, if so, where and how.

Anyway, from the planning stage onwards, the local fishermen should be consulted in that their experience and knowledge of the proposed site should be a valuable contribution towards the development of the project. Most fishermen in a particular area should be aware of the topography and marine life at the proposed site.

In addition, the effectiveness of the project should be cross-checked with similar sites in the region, which ought to increase the overall effectiveness of each individual project.

5. Site selection

5-1 Site selection

Site selection criteria for the installation of an artificial reef are as follows:

(1) There should be a satisfactory concentration of fish at the site, and the fishermen living near the site should be able to use the reef effectively.

(2) From the point of view of the marine life, the area should be a suitable breeding ground and habitat for the target species and, furthermore, the area should be on the route along which the species migrate.

Fish change their environment according to the various stages of their development. For instance, at the fry stage, especially immediately after hatching, they float on the surface of the sea. At the juvenile stage, when their mouths remain open and until they start feeding, they are mostly concentrated along shallow, coastal nursery areas which are sometimes areas of marine forest. From the beginning of the juvenile stage until they become adults, fish continue to migrate until they return to their original starting point. This migration is controlled by the environment, the most important factors being temperature, salinity and depth.

Based on the relationship between the environment and phasic development, the target species may be chosen and their life history analyzed. An example of this relationship is shown in Table 1 and Appendix I.

(3) From an environmental point of view, the physical and chemical conditions around the site have to be suitable.

The physical conditions that should be considered are temperature, salinity, current direction, current velocity, underwater topography and the type and quality of the seabed. (Details of temperature and salinity are not described here, as they are laid out in the life history in Table 1).

Current direction and velocity should be worked out by mapping counter-currents, eddies and upwellings. The type and quality of the seabed depend on the current velocity. If a current exists, the seabed will consist of sand and/or gravel. The underwater topography needs to be worked out by mapping as well - in this case, variations in the seabed, such as banks, caldrons and depressions. Those sites which fulfil the above-mentioned conditions should be very similar, topographically, to those indicated by the contour lines in Fig. 2.

Where there are extensive, sandy areas (Fig. 2.2), the flat area between a steep slope and the continental shelf should be selected for the site, as shown in a modified cross-section in Figs. 3.1-2. The two sites, which are shown in Figs. 2 & 3, are suitable from both a horizontal and a vertical view-point.

In order to select a suitable site, data of all kinds (as mentioned above) should be collected and a site chosen after close analysis of the data. This kind of survey is very time-consuming and requires considerable financial investment. In order to save time and money, interviews with local fishermen have proved to be beneficial, as they are familar with local conditions.

Table 1. Record sheet of life history of target species

			1	2	3	4	5	6	7
	Stage		Egg	Fry (up to 50 mm in length)	Juvenile	Adult			
						Feeding period	Pre-spawning period	Spawning period	Post-spawning period
A	Season of appearance								
B	Distribution area								
C	Conditions of Distribution	Depth							
D		Sea-bottom quality							
E		Sea-water temperature							
F	Relationship between prey & predator								
G	Growth								
H	Propagation								
I	Migration								
	Reaction to against stimulation								

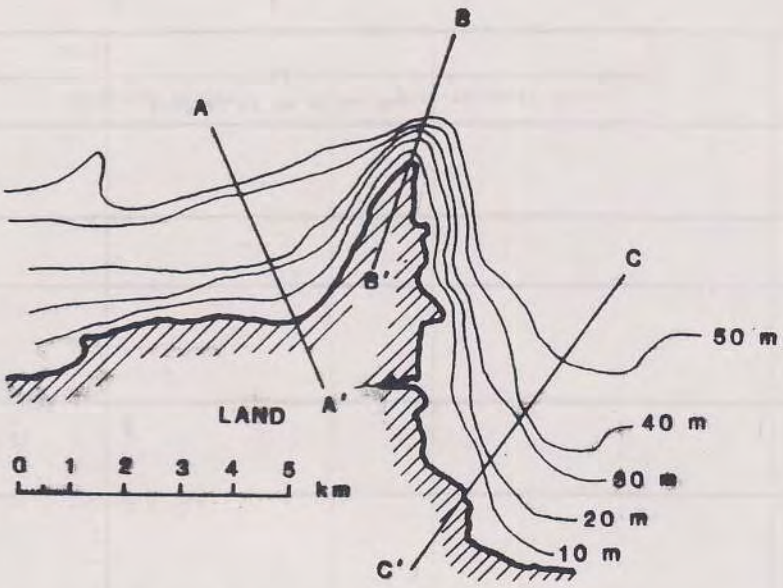


Fig. 2.1 Underwater topography

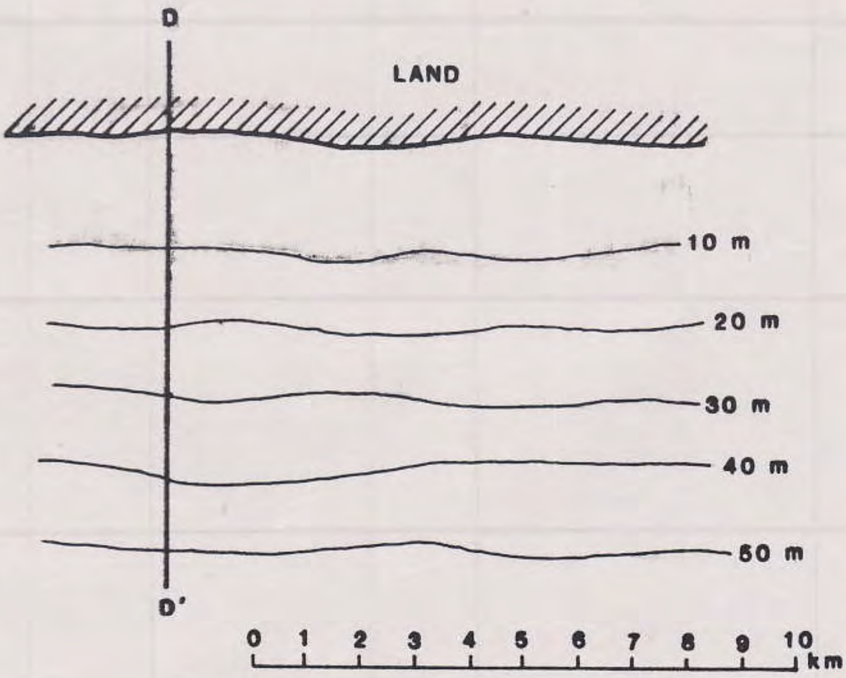


Fig. 2.2 Underwater topography

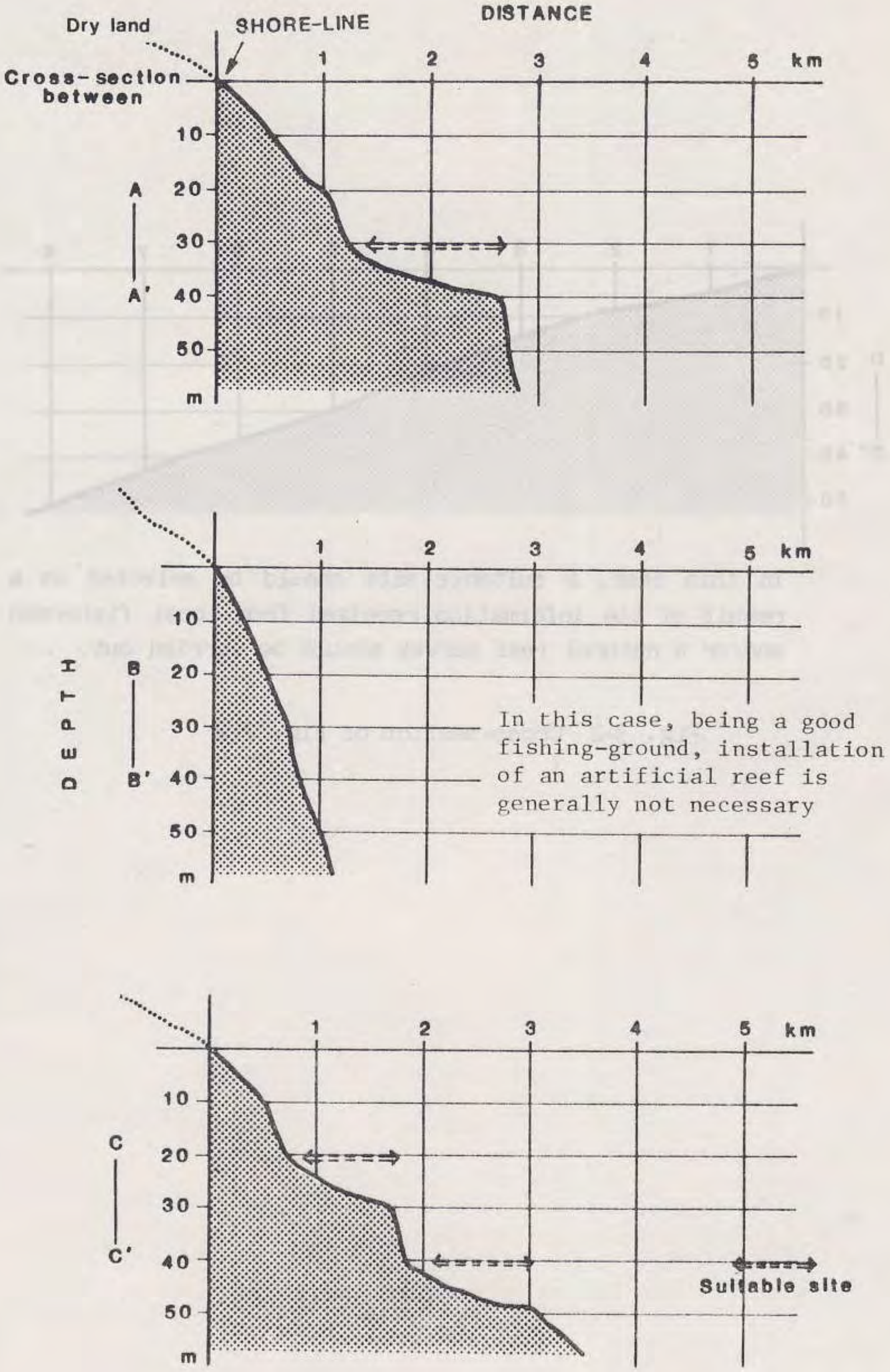
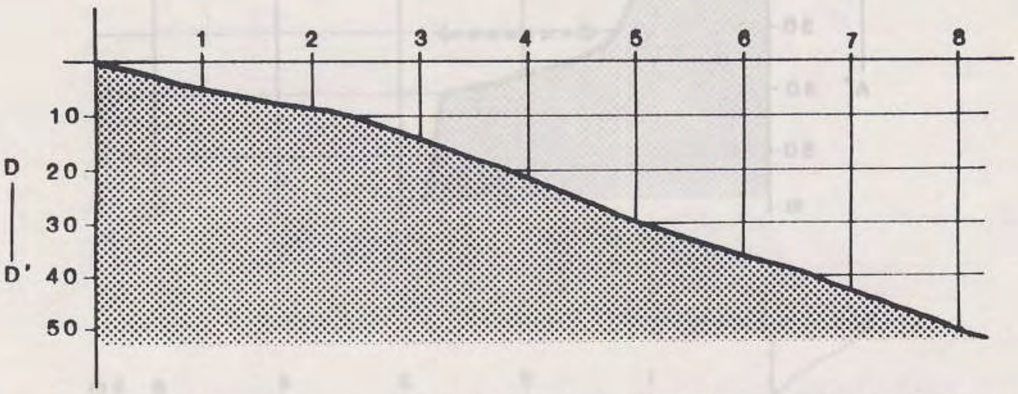


Fig. 3-1 Cross-section of Fig. 2.1



In this case, a suitable site should be selected as a result of the information received from local fishermen and/or a natural reef survey should be carried out.

Fig. 3-2 Cross-section of Fig. 2.2

5-2 Case study

The flow-chart makes clear that very varied data is needed to proceed with a project efficiently. More concretely, using data on the underwater topography, biology, temperature and current, selection of a site can be made.

(1) Underwater topography

Isobaths are presented as in Fig. 5 from charts which have been scaled down 1/250,000. From Fig. 5., the following may be understood.

* Between Osaka and Awaji Island (from East to West), even zones exist at depths of 15-25 m and 35-50 m.

* Between Kobe and the Tomogashima Channel (from North to South), there are three even zones at depths of 60-70 m, 35-50 m and 60-70 m.

* There are two caldrons, one of which is in the Akashi Strait, the other being in the Tomogashima Channel at the mouth of Osaka Bay. For reference purposes, with regard to the size of each caldron, the former is 12 km from east to west, 2.5 km from north to south, and 148 m at its deepest. The latter consists of five small caldrons, of which the biggest is 2 km from east to west, 10 km from north to south, and 197 m at its deepest.

The reasons why these even zones and caldrons exist may be easily explained by studying the geography.

During the glacial period, from about 17,000 to 18,000 years ago, much of the Northern Hemisphere was covered with great sheets of ice (the Würm to Günz Glacial Period) and the sea-level dropped by about 130 - 140 m (Daly: 1934, Minato: 1980). During the following inter-glacial period, the sea-level rose to nearly its present level. (This phenomenon, the rising and falling of the sea-level, has occurred several times since the glacial period up to the present day). In particular, in the period when the sea-level dropped, most of Northern Hemisphere became land and was eroded by river currents. During the following period when the sea-level rose again, the eroded areas were covered again by the sea. It has been estimated that the caldrons were formed during the period when the sea-level dropped. In that period, between what are now called Osaka Bay (formerly Osaka Tide Pond) and the Kii Channel (formerly Kii Channel Bay), there was a tidal current which resulted in the formation of these caldrons.

(2) Biology

In this case, red sea bream were chosen as the target species. The phasic development of the red sea bream in the area is shown in Table 2 and, based on this data, their distribution in the areas is shown in Fig. 6.

(3) Temperature

The variations in the surface temperature, when the red sea bream were at the fry stage, is shown in Fig. 7.

(4) Current

The average current velocity and direction during springtides are shown in Figs. 8 & 9.

(5) Analysis/site selection

The actual site for the work/project had to be chosen in accordance with Figs. 5-9. Initially, only Figs. 5 & 6 were used; these two were copied onto transparent film individually and superimposed, as shown in Fig. 10, to study the relationship between red sea bream and the underwater topography. As a result, it was possible to make the deductions required.

From the fry to the juvenile stage, the main concentration of red sea bream was along the shallow coastal area where the depth is less than 30 m. Then, the proposed site for the resource enhancement work or project had to be carried out in the southeastern area of Osaka Bay along the coast, at depths of less than 30 m. Additionally, a nursery ground had to be constructed in order to carry out the project.

Secondly, Figs. 7-9, had to be copied onto transparent film, as mentioned above, in order to obtain confirmation.

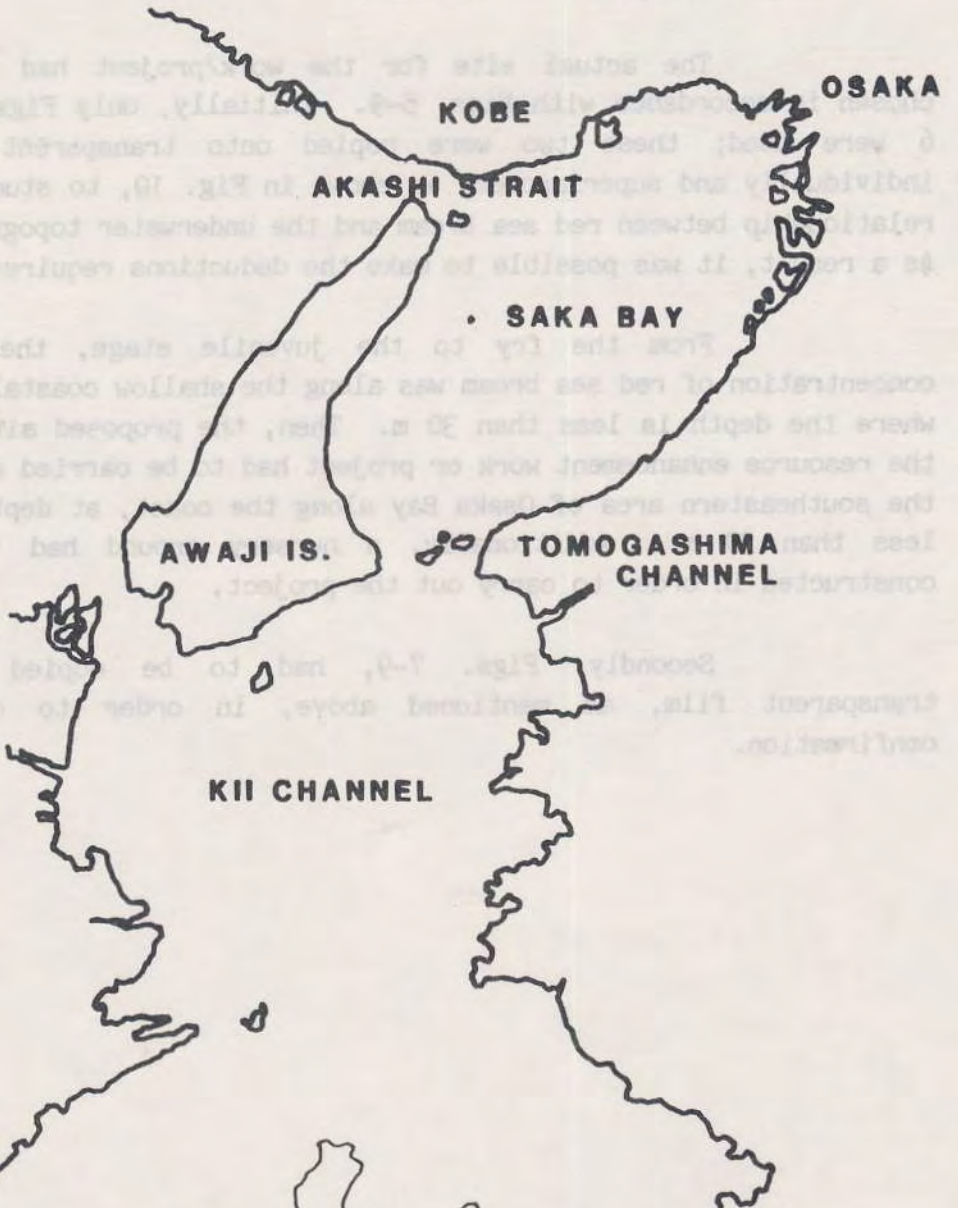


Fig. 4. The target area

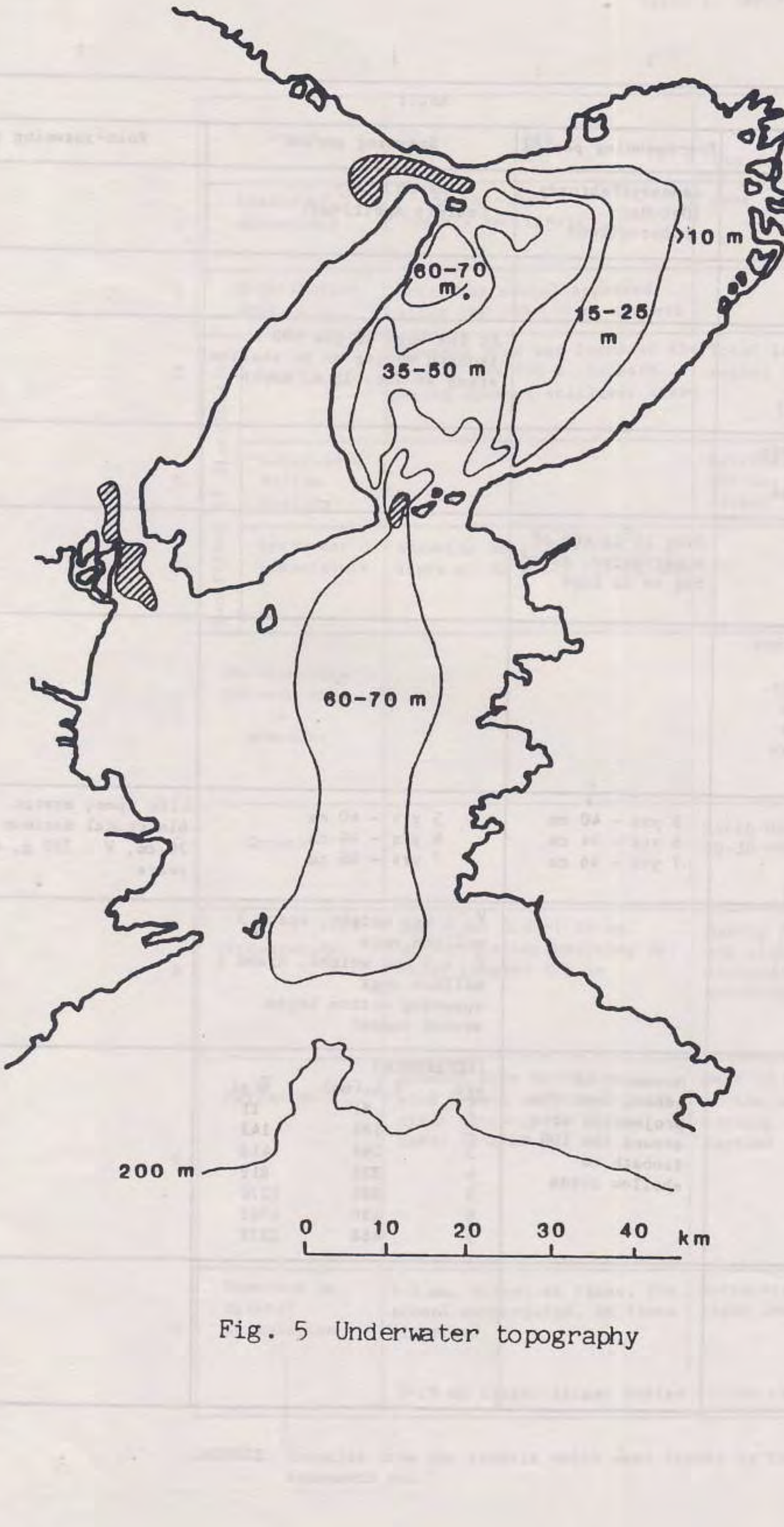


Fig. 5 Underwater topography

Table 2. Record sheet of life history of RED SEA BREAM, *Pagrus major* (TEMMINK and SCHLEGEL)

		1	2	3	4	5	6	7
					Adult			
	Stage	Egg	Fry (up to 50 mm, in length)	Juvenile	Feeding period	Pre-spawning period	Spawning period	Post-spawning period
A	Season of appearance	March - May (mainly April/May)	June - August	September - November		January/February (Dec-Mar: hibernation)	March - May (mainly April/May)	
B	Distribution area	March May school appeared along the 100-150 m. isobath						
C	Conditions of distribution: Depth	Spawning area was found at the edge of the 100 m. isobath moving towards shallower area	Total length: 10-30 mm.; depth: 20 m	Total length: 30-80 mm. - depth: less than 30 m; 70-160 mm. - depth 20-50 m.	At 110-170 mm. stage: hibernation at a depth of over 60 m. (until following spring)		At the edge of the 100 m. isobath moving on to shallow areas at abt. 25 m. depth	
D	Conditions of distribution: Location & Bottom quality		Extremely shallow areas; bottom: sand & underwater forest	Where shrimp live, moving onto rocky areas	Effective fishing grounds are S.CS. & S.Sh.SM.M. C.R bottom quality areas			
E	Conditions of distribution: Sea-water temperature	Spawning area; 14-19°C at a depth of 50 m. cl. 19-19.30%			Over 18°C; prey well below 12°C; end of preying & hibernation	Over 15°C; end of hibernation, gonads beg on to ripe		
F	Relationship between prey & predator			Caprella (ghost shrimp) pantopoda (sea-spiders) echinoidea (sea-urchins) asteroida (sea-stars) etc.	Mostly, a with temperature drops in Nov, moved to rocky areas to hibernate. At the end of Nov, when water temperature falls they moved to deep rocky areas & hibernated			
G	Growth		March-May (0 year stage); 10-30 mm	Length: 30-80 mm (June-Aug) 70-160 mm (Sept-Nov) 110-170 mm (Dec-Mar)	Northern Kyushu area: 2 yrs - 23 cm. 3 yrs - 30 cm. 4 yrs - 36 cm.	5 yrs - 40 cm 6 yrs - 44 cm 7 yrs - 46 cm	5 yrs - 40 cm 6 yrs - 44 cm 7 yrs - 46 cm	Life span; approx. 30 years biological minimum size; T.L.: 36 cm, W : 750 g, age : 3 years
H	Propagation	Egg size: 0.83-1.03 mm. directly after hatching up; total length: 2.5 mm	Nearly 3 mm; Mouths open and without yolksack (which disappears 3 days after hatch-up)				♀; 1 kg. weight, spawn 3 million eggs ♀ 1.5 kg. weight, apawn 4 million eggs spawning action began around sunset	
I	Migration	Spawned eggs moved by wind & wave action directly after hatch-up to 30 mm.; total length: 2.5 mm	Over 10 mm; school stayed at the surface in the morning & evening, in the daytime at the bottom	School move along isobath		Movement of school from the projection area around the 100 m isobath to shallow areas	(REFERENCE) age F.L.(mm) W̄(g) 1 81 11 2 186 143 3 266 418 4 332 812 5 385 1270 6 430 1767 7 468 2278	
G	Reaction to against stimulation	4-5 mm. stage; at times, the school congregated, at times dispersed	Horizontal movement into a light zone, at night					
		8-10 mm stage; larger bodies stayed on the bottom, smaller bodies on the surface						

(SOURCE: Compiled from the reports which were issued by the Fisheries Experimental Station in Kyushu District i.e. hagasaki,

Fig. 6 Migration route of RED SEA BREAM SNAPPER

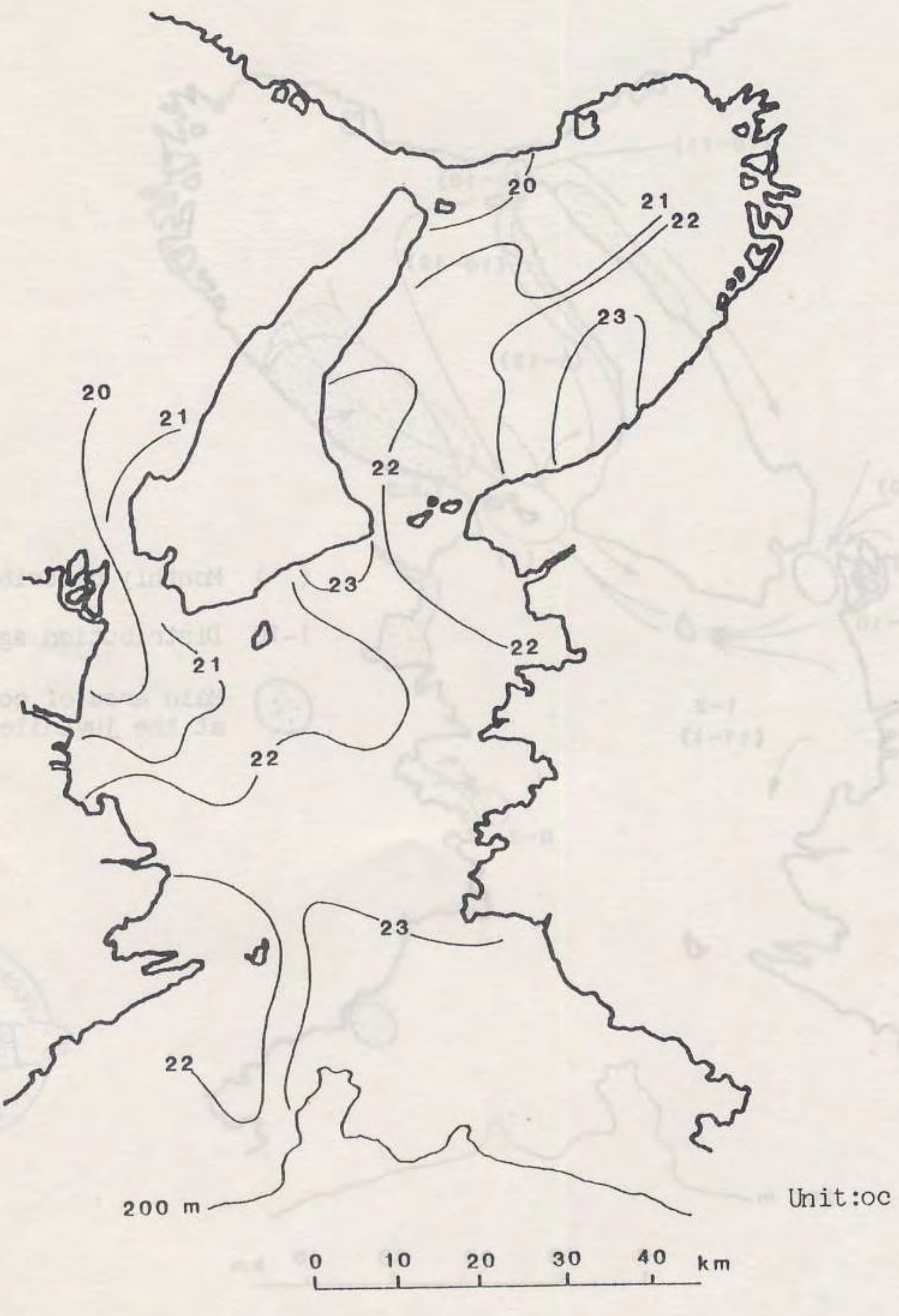


Fig. 7 Surface temperature (1950 June 13-16)

Fig. 8 Surface currents (1) Average springtide current velocity and direction (strongest current towards West)

Fig. 9 Surface currents (2) Average springtide current speed and direction (strongest current towards East)

Fig. 10 Superimposed figures of the migration route of RED SEA BREAM SNAPPER and the underwater topography

6. Implementation

6-1 Shape of the module

When surveying natural reefs, their size and shape should be measured by using an echo-sounder, although it is difficult to determine the exact shape of natural reefs by relying on only low-range beams. However, if high-range beams are used, the level of distortion is reduced and it is possible to obtain the outline of a reef close to its actual shape. Generally, only the height, width and/or length of a natural reef can be recorded by using an echo-sounder. The choice of the overall shape of the module, therefore, ought to be based on a modified or arranged shape-that is, a sphere, cube, cylinder, prism, cone or pyramid.

Based on this data and selection, the next consideration should be how to construct the module as simply and as economically as possible. At this stage, not only the method of construction but also the installation procedure should be considered, bearing in mind the equipment available at the site. In particular, since the placing of a module is very difficult with regard to the current, its shape and position are very important factors. In this manual, the recommended shape is a triangular pyramid which offers least resistance to the current and whose orientation, therefore, is largely unimportant.

Finally, when all the above factors have been taken into account, it is usually preferable to make the final decisions in conjunction with the architects and civil engineers to avoid any misunderstandings.

6-2 Materials for the construction of the module

The materials used in the construction of modules need to be durable and cheap; and, world-wide, reinforced concrete, used tyres, wood, bamboo, stone and steel are generally used. However, the extensive Japanese experience in marine construction, including artificial reefs, has revealed that steel and, particularly, reinforced concrete are the most suitable materials currently available, with a life-span of thirty years. (At the moment, these projects are funded by the Japanese Government).

In the case of steel reinforced concrete, in order to avoid weakening of the module as a result of the steel rusting in the seawater, the regulation in the Japan is that the concrete surrounding the steel should be at least 5 cm thick.

Steel has been introduced as a suitable material for modules in the last ten years. And again, to avoid rapid corrosion, it is stipulated that the thickness of the steel should be greater, depending on the annual rate of corrosion.

Corrosion rate of steel (mm/year)

(1) Above high-water level (H.W.L.)	0.3
(2) H.W.L. to the seabed	0.1
(3) Under the seabed	0.03

Corrosion rate depending on depth and temperature

Water depth	Water temperature	Rate (mm)
50 m or less	10° C or more	3.6
50 m or less	10° C or less	2.7
50 m or more	10° C or more	2.7
50 m or more	10° C or less	2.1

Used tyres have been widely put into use, but rubber is not a suitable or recommended material, because of the many kinds of chemical substances used when the tyres are manufactured - for example, vulcanization accelerators, stabilizers, and age resistors. These substances are pollutants, and until just a few years ago, they included DPT (a mixture of N, N-Diaryl p-Phenylene diamine, phenyl-Naphthy-lamine (D) and Acetone condensation product (DA)), AW (6-Ethyoxy-2:2:4-Trimethyl 1-1, 2-D:hydroquinoline), H;P;D; P (N,N'-Diphenyl-p-Phenylenediamine), and 3C; 810-Na (N-Phenyl-N'-Isopropyl-p-Phenylene). Nowadays, most of them are prohibited, due to conservation efforts, both in the USA and Japan. However, similar substances are still used. These substances are physically, and not chemically, combined with rubber, and they dissolve easily in sea-water. (Also, the ratio of the substances used is always an industrial secret).

From the environmental viewpoint, therefore, tyres should be used as little as possible and, because of the above-mentioned risks, should only be disposed of on land. (Incidentally, since the first oil crisis in 1973, used tyres have been used in Japan as auxiliary fuel in the drying process in the manufacturing of cement).

Wood, bamboo and stone are not only natural materials but also cheap and, therefore, should be used more widely. Clearly, wood and bamboo are not as durable as concrete but, in the Central Visaya Regional Project (CVRP) carried out in the Philippines, the local fishermen themselves constructed bamboo modules which remained in position for four years after installation, without being damaged by typhoons. And, during that period, the local fishermen benefited considerably.

In conclusion, reinforced concrete is the most suitable material for the construction of modules. However, if bamboo or wood is readily available, it may also be used quite satisfactorily.

6.3 The stability of the module

Modules require sufficient strength to resist external pressures (mostly waves, and currents) and have to be able to withstand the strain of being lowered. And, in order to understand better the required strength at each stage, a multidiscipli nary study is required. For instance, a knowledge of structural mechanics is required at the construction stage; and a knowledge of hydrodynamics and soil mechanics is required for the installation and for the period following the installation, respectively.

To assist in this, basic information, concerning the installation of a module, is presented in the Appendix and was compiled by Mr. Akira Nagano, the Deputy Chief of the Construction Division, Fishing Port Department, Government of Japan's Fisheries Agency. When using this information as reference material, it is recommended that experts in each field should be consulted.

The modules should be stable after installation, by which it is meant that the installed modules should be able to maintain their original position, without sliding or overturning as a result of wave motion and the dynamic pressure caused by currents. A prototype is, therefore, required in order to check the stability of the module against such hydrodynamic forces.

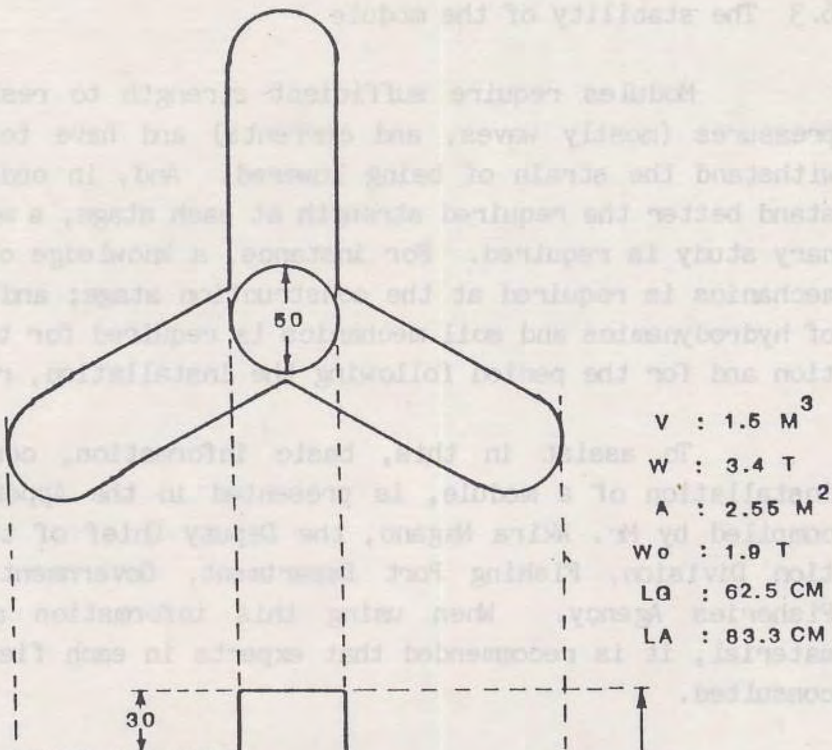
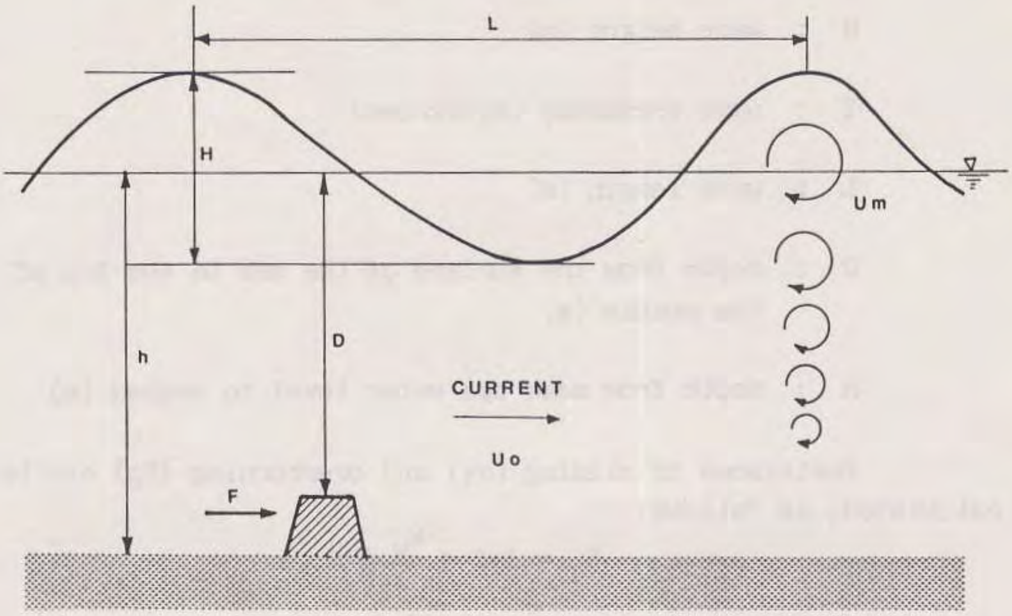


Fig. 11. Prototype concrete module

The pressure caused by waves and currents



The pressure (external force) on a module can be calculated as follows:

$$F = C_D . A . Wo . \frac{(Uo + Um)^2}{2g}$$

$$U_m = \frac{\pi H}{T} . \frac{\cosh \frac{2\pi D}{L}}{\sinh \frac{2\pi h}{L}}$$

where C_D : drag co-efficient (1.0, refer to Appendix 3)

A : total shadow area of vertical surfaces perpendicular to the direction of waves (m^2)

Wo : unit of volume weight of sea-water (1.03 t/m^3)

g : gravitational acceleration (9.8 m/sec^2)

Uo : current velocity (m/sec)

Um : velocity of water particles due to wave motion

H : wave height (m)

T : wave frequency (cycle/sec)

L : wave length (m)

D : depth from the surface of the sea to the top of the module (m)

h : depth from mean sea-water level to seabed (m)

Resistance to sliding (s_1) and overturning (S_2) can be calculated, as follows:

$$S_1 = 1.2 < \frac{W_W \cdot \mu}{F}$$

$$S_2 = 1.2 < \frac{W_W \cdot 1A}{F \cdot 1G}$$

where S_1 : optimum slide resistance co-efficient, and the figure 1.2 is based on the Fisheries Agency's guidelines

Ww : submerged weight of module (Ww = W-Fo) (Fo: buoyancy, W: weight of module)

μ : co-efficient of friction between module and seabed (0.6, supposition number)

S_2 : optimum overturn resistance co-efficient, and the figure 1.2 is the same as for S_1

1G : distance from seabed to centre of gravity

1A : distance from the sides of the module to its centre

The results of the calculations are shown in Table 3:

Table 3. The stability of the module

	Wave height : H(m)	3			4			5		
	Cycle : T(sec)	6.7			7.7			8.6		
	Wave length : L(m)	70			93			116		
	Uo : m/sec	0.5	1.0	1.5	0.5	1.0	1.5	0.5	1.0	1.5
Depth of installed module (m)	10: (S_1/S_2)	1.8/3.9	1.2/2.6	0.8/1.9	0.9/2.1	0.7/1.5	0.5/1.2	0.5/1.2	0.4/0.9	0.3/0.8
	20: (S_1/S_2)	0	0	1.2/2.6	1.9/4.3	1.3/2.8	0.7/1.6	1.3/2.8	0.9/2.0	0.5/1.2
	30: (S_1/S_2)	0	0	0	0	0	1.0/2.1	0	1.1/2.5	0.8/1.8
	40: (S_1/S_2)	0	0	0	0	0	1.0/2.3	0	1.2/2.7	0.9/1.9

Remarks 1. The relationship between wave height (H) and wave cycle (T) and between wave height and wave length (L) can be calculated as follows:

$T = 3.86\sqrt{H}$, $L = 1.56T^2$

2. 0 : stable

3. Safety factor : 1.2

In Table 3, a wave height of 3 M is predicted as the maximum wave height in the north-east part of the Gulf of Thailand, over a fifty-year return period. Based on this figure, two other heights, 4 m. and 5 m., are shown in Table 3 to represent more severe conditions. With regard to currents, the maximum velocity in the same part of the Gulf of Thailand, during springtides, was measured at approximately 50 CM/sec. (one knot).

In the other two cases, 1.0 and 1.5 M./sec. have been predicted. At any rate, the required conditions for ensuring the stability of a module can be under-stood from this table. With regard to wave height, long-term collection of data is recommended. Nevertheless, this is often difficult to obtain. Such data can be obtained from any hydrographic office in any country (e.g. in Thailand, the Hydrographic Department of the Royal Thai Navy).

Table 3 shows that, if the modules are installed at a depth of more than half a wave's length, the modules are almost stable. In marine work, the greatest wave height recorded over a period of many years is the standard. In countries where there is limited or no data, this figure has to be predicted. As far as the durability of a module is concerned, it might be possible to install the module in an area that is shallower than half a wave's length. Furthermore, if the safety factor is reduced by 20 percent, from 1.2 to 1.0, it is possible to scale down the size of the module. The reduction in the safety factor can be decided on, depending on the data gathered from actual projects.

6.4 Transportation and installation of modules

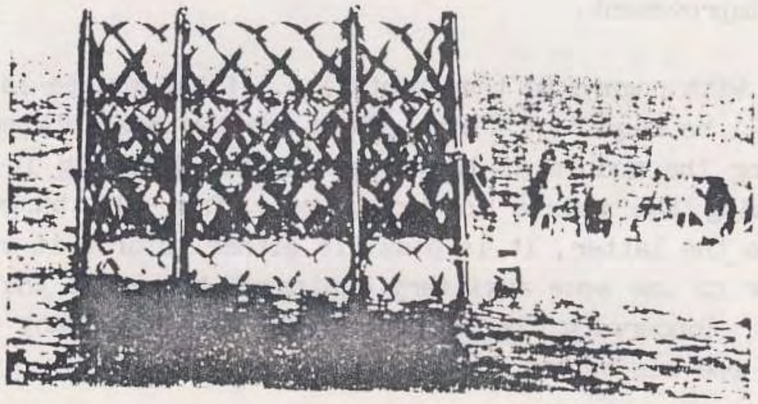
Based on experiments and calculations, this section deals with the transportation and installation of the module. To carry out effective artificial reef work, some suitable equipment should be designed and, on that score, there is scope for general improvement.

With regard to transportation, if the module is heavy, a barge will be required. Then, there are two possible methods of installing the module at the target point: lowering it by crane or allowing the module to drop freely from the barge. With regard to the latter, it is possible either to drop it completely freely or to use some auxiliary equipment to reduce the speed of descent. Concerning the latter, there have been many theories, but only one has become popular (refer to Fig. 12).

In Japan, which has most experience in this field, the lowering method using a crane is favoured, up until the point when the module touches the seabed. In this case, a barge with a crane for the transportation and installation work is used. However, cranes can only be used suitably in calm and shallow sea areas, such as port construction sites, but not at off-shore sites because, when installing modules at greater depths (usually over approximately 20 m), the length of the wire required is too great. This is because the wire then has to be coiled around an additional drum.

Anyway, in this manual, the depth under consideration is limited to less than 40 M (refer to page 1), and so the process of installing a module using a barge with a crane is described here. Generally, the barge, as shown in Fig. 2, is suitable for the work; however, in Thailand, the actual equipment which has been used (Fig. 14) is often second-hand and, in addition, requires a tug-boat. With regard to construction costs and suitability, therefore, the gantry crane (Fig. 14) is cheaper than the rotary crane (Fig. 13). However, when operating at sea, the latter is much safer - and, incidentally, it is motorized - and, therefore, it is recommended in this manual.

Anyway, this equipment is required for the transportation and installation of modules. However, economic efficiency should be considered.



10-cylinder FRP unit being placed with a reusable airbag system (eliminating the need for a barge and crane) off the coast of Florida. Units are anchored on site and sunk by degassing air bags.

Fig. 12. Auxiliary equipment to reduce the speed of descent

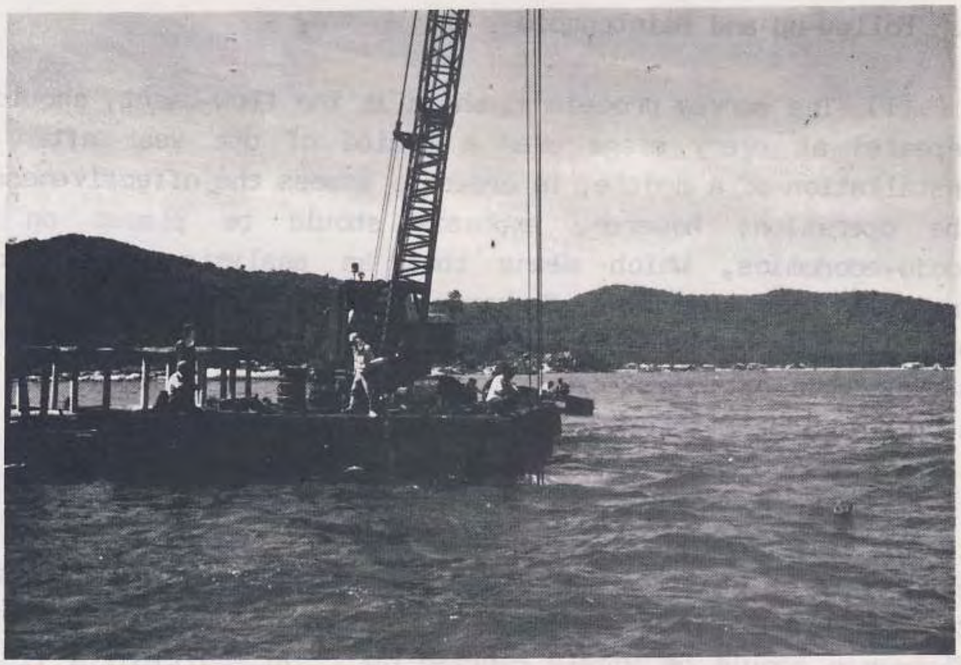


Fig. 13. An example of installation equipment

Fig. 14. Actual equipment used in Ranong Thailand

7. Follow-up and Maintenance

(1) The survey procedure, shown in the flow-chart, should be repeated at every stage over a period of one year after the installation of a module, in order to assess the effectiveness of the operation; however, emphasis should be placed on the socio-economics, which means that an analysis of the data gathered from the local fishermen should be carefully carried out. This is because, by comparison with the data from the field survey, the data provided by the fishermen is more useful and more revealing with regard to overall site conditions.

In particular, from their first-hand experience, the local fishermen have a good understanding of what kinds of fish congregate at the site, when this happens, and where. Therefore, to make use of their knowledge, interviews of experienced local fishermen should be widely carried out. In addition, a fishing diary should be kept to record the types and volume of fish caught and where they were caught.

(2) The local fishermen should be involved in the project from the planning stage onwards and, also, it ought to be impressed upon them that their contribution will benefit them in the end. As a result, if they have faith in the operation, this should lead to a reduction in the level of illegal fishing i.e. catching fish by using dynamite or poison. (An example of where this has happened is the Central Visaya Region Project (CVRP) in the Philippines). At any rate, the project-planners should attempt, from the outset, to win the trust of the local fishermen as quickly as possible, and this trust should not depend on the size of the project. Purely for reference purposes, the Japanese experience, indicates that 400 M^3 projects are regarded as the most suitable by local fishermen.

(3) In order to gain the trust of the local fishermen, the work should be carried out clearly making use of their advice and opinions. However, conflict over the use of the fishing-ground where modules have been installed is predictable, given that other sites will have been rejected. This conflict ought to be resolved by establishing fishing rights and, with this in mind, artificial reef work should involve not only the installation of modules but also consideration of the overall situation, including use of the fishing-ground.

8. New technology (recommendations)

In this chapter, the following three recommendations are made.

(1) The size of the module

It was suggested earlier that the ideal size for a module is less than 10 M^3. However, there are a large number of big natural reefs which are over 10 M^3, in depths of less than 40 M. Also, it is known that the larger the module is the better the fishing, according to the local fishermen.

This fact is borne out by the way in which warships and transport ships sunk in World War II have become focal points for fish to congregate; and, to illustrate this further, it has been reported that scuttled ships (made of steel or wood) and disused oil rigs also make effective artificial reefs. The former have been emplaced in many regions (Japan, Korea, Malaysia) as part of large-scale government programmes, while the use of scuttled ships and disused rigs as artificial reefs is still being researched into in the United States. More time, therefore, is needed to produce more concrete results.

With regard to size, before a suitable module can be chosen for an artificial reef project, it must, naturally, be considered in terms of economic efficiency. However, clearly, it also makes good sense to consider first the option of using sunken ships.

(2) Marine forest construction

Another important consideration with regard to the selection of a site for an artificial reef is whether it is an area which attracts predators because it is a rich source of food for them. Its contents fish, barnacles, tube worms, ghost shrimp etc. -congregate on the surface and periphery of the reefs. Big fish are also said to congregate around reefs seeking smaller prey. Here, seagrass and/or algae are important factors. This situation is comparable to a terrestrial forest, which is richer in life than, for example, a desert, both in terms of quantity and quality. The abundance of life is, in large part, due to the existence of a plant community, especially trees. Similarly, this phenomenon may also be said to be true of the sea. It is, therefore, proposed that an environment in the sea similar to that of a forest on land-in other words, a marine forest-should be constructed.

It should also be noted that, during the evaluation survey conducted in 1988 by a joint team consisting of SEAFDEC and Marine Fisheries Division of Thailand personnel, local fishermen in Rayong Province were interviewed, and it became clear that many understood the need for marine forests. They also reported that, for some unknown reason, there had recently been a dimunition in the marine forest (i.e. sea grass).

Marine forests, with regard to their composition, fall into two categories: sea grass distributed over a sandy area, and marine algae distributed over a rocky area. In this manual, artificial reef modules function similarly to rocks. Thus, different species of marine algae were chosen as the target species for the marine forest construction. Naturally, therefore, the life-cycle (i.e. the types of marine algae and the season of propagation) of the target species has to be studied. Initially, certain kinds of Sargassum, which are classified into perennial plants, proved to be suitable after observation of their propagation-period and the form that the propagation takes. Anyway, transplantation or seeding of the target species would probably be needed on the modules. Therefore, from all points of view, when constructing a marine forest, a clear understanding of bearing the features of the species is required.

(3) The use of mineral-electrodeposition in sea-water in line construction of artificial reefs.

This technology has been experimented with in the United States and Japan for nearly a decade, and significant progress has been reported. There follows a short account.

Sea-water contains nine major elements: sodium, magnesium, calcium, potassium, strontium, chlorine, sulphur, bromine and carbon. These elements comprise more than 99.9 percent of all dissolved salts in the ocean. The constancy of the ratios of the major elements in the oceans has long been well-known. Furthermore, by establishing a direct electrical current between electrodes in an electrolyte like sea-water, calcium carbonates, magnesium hydroxides and hydrogen are precipitated at the cathode, while the anode produces oxygen and chlorine (Fig. 15). These cathodic building materials protect the framework of the artificial reef. However, it first needs cleaning by means of a direct electrical current, after which electrodeposition can proceed. During the cleaning process, a coating is also formed cathodically, consisting of magnesium and calcium salts. If this coating is hard and unbroken, it affords the enclosed metal a considerable degree of protection from corrosion (Table 4). In the food-chain, lower marine organisms utilize the minerals in solution surrounding them to build structural formations. Molluscs and shells, for instance, are generally composed of calcium carbonate crystals enclosed in an organic matrix. A significant proportion of the soluble protein of the matrix is composed of a repeating sequence of aspartic acid, separated by either glycine or serine.

This sequence, comprising regular repeating negative charges, can bind Ca^{+} ion and, thus, performs an important function in the mineralization of the template. Preliminary investigations indicate that the mineral accretion process produces a very suitable substrate for marine growth and a strong primary building material. Accreted wire mesh components also present a reduced profile, compared to solid components, which reduces resistance to water currents— thus, increasing stability, while offering open volumes and entrances for shelter to marine organisms.

Placement of steel mats or wire mesh as an artificial substrate in areas of predominantly soft, fine-grained sediments has been suggested. Accordingly, the use of accreted wire mesh may be particularly well-suited for these areas.

The technology has been experimented with at over twelves sites not only in Japan but also in the United States and, as a result, a great deal of effective data has been collected, both on artificial reefs and on bases for marine forest.

Table 4 Characteristics of Electrodeposited Compounds

Item		Electrodeposition	Concrete
True gravity		2.5	2.8
Virtual gravity		2.1	2.4
Vickers hardness		100 - 200	-
Compression strength	(kg/cm3)	60 - 200	200 - 500
Bending strength	(kg/cm3)	50 - 70	30 - 60
Heat conductivity	(Kcal/mh C)	1.18	1.3
Young ratio	(Kg/cm3)	2 x 105	3 x 105

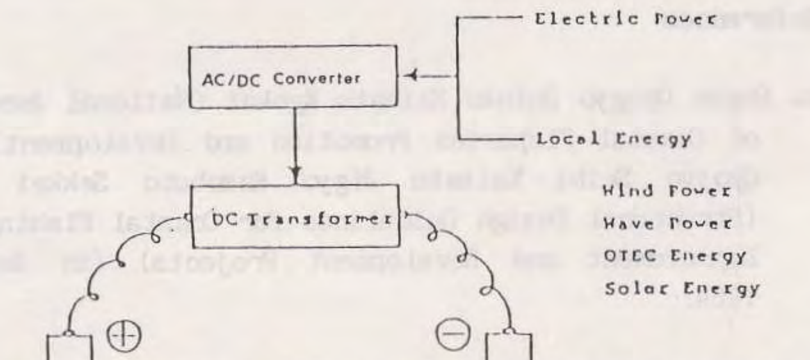


Fig. 15 Principle of Electrodeposition

9. Conclusion

The recommended modular shape, the triangular pyramid, is the result of a detailed study of the marine environment in Thailand's coastal waters. And, triangular pyramid modules could undoubtedly be installed to good effect elsewhere in the region. However, the data on some of the other marine environments in the region is not sufficient enough to be able to make the same recommendation without reservation. Nevertheless, this should not discourage marine officers from experimenting with triangular pyramid modules for trial periods. If the trial period is a success, then, naturally, this type of module may be installed; but if not, it is strongly recommended that a detailed survey of the particular marine environment should be carried out, following which it should be possible to select an alternative, based on experiments with modules of different shapes.

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Appendix I

1. RECORD SHEET OF LIFE HISTORY OF *Lutjanus Lineolatus*

	EGG	FRY	JUVENILE	ADULT			
				Feeding Per	Pre-Spng	Spng	Post
Season of Appearance							
Distribution			carnivorous/greedy food fish are abundant on rocky shores but sometimes venture into bodies of freshwater				
depth bottom temp							
Predator-Prey relationship			feed at the bottom or intermediate depths, subsisting principally on small fish and crustaceans				
Growth				size range:175-325 mm SL			
Propagation				F:M: 1.8:1			
Migration							
Reaction				form schools			

(Source: compiled from the attached list of reports by the Aquaculture Department of SEAFDEC, Philippines)

2. RECORD SHEET OF LIFE HISTORY OF *Lutjanus Vitta*

	EGG	FRY	JUVENILE	ADULT			
				Feeding Per	Pre-Spng	Spng	Post
Season of Appearance	August		late Aug to early Sept	Aug - Jul - Sept ripe females only		Jan - Feb - Oct Oct - Nov - Dec peaks of spng	
Distribution	open sea			bottom/reef edges/ledges			
depth bottom temp	26.5°C			"warm seas"			
Rel'n Prey-Predator				being a large group of active carnivorous fish, they feed on small fish and crustaceans			
Growth				size range: 100->300 mm SL maximum length: M = 312 mm SL; F = 264			
Propagation				at first maturity: M = 128 mm SL; F = 138 ratio of mature fish::F:M::1:1.1			
Migration		< 7 mm larvae in open sea; 7-16 mm migrate to bay in shallow waters; 16 mm larvae enter seagrass beds on southern side/pelagic at 24 mm become memi-benthic; at 32 mm is fully demersal					
Reaction				periodically come up in open waters and display their reddish/bright yellow froms move in small schools or as individuals and take shelter in the reef by day but move elsewhere to feed at night			

(- ditto -)

3. RECORD SHEET OF LIFE HISTORY OF *Nemipterus Hexodon*

	EGG	FRY	JUVENILE	ADULT			
				Feeding Per	Pre-Spng	Spng	Post
Season of Appearance				July and Oct - Mar			
Distribution							
depth				seasonality in abundance affected by monsoon winds during lean months, tradewinds prevail and weather is variable; abundant 20-50 m. down			
bottom temp							
Rel'n Prey-Predator				feed on small fish and bottom invertebrates			
Growth		for range 7.6-21.3 cm, 22-239 g $W = 0.0433\ L^{2.78}$		small to moderately sized fish marketable at 20 cm			
Propagation							
Migration							
Reaction				"common", solitary fish			

(- ditto -)

4. RECORD SHEET OF LIFE HISTORY OF *Leiognathidae*

	EGG	FRY	JUVENILE		ADULT		
				Feeding Per	Pre-Spng	Spng	Post
Season of Appearance							
Distribution	outside Manila Bay		carried into the Bay where they grow in shallower waters		migrate to deeper waters as they grow older and leave bay to breed		
depth bottom temp							
Rel'n Prey-Predator	feed on zooplankton and phytoplankton						
Growth	5 cm/yr						
Propagation							
Migration							
Reaction							

(- ditto -)

5. **RECORD SHEET OF LIFE HISTORY OF** *Pomadasyidae*

	EGG	FRY	JUVENILE	ADULT			
				Feeding Per	Pre-Spng	Spng	Post
Season of Appearance							
Distribution							
depth bottom temp							
Rel'n Prey-Predator		littoral, carnivorous fishes					
Growth		marketable size 30-40 cm in length					
Propagation							
Migration							
Reaction							

(- ditto -)

6. RECORD SHEET OF LIFE HISTORY OF *Sciaenidae*

	EGG	FRY	JUVENILE	ADULT			
				Feeding Per	Pre-Spng	Spng	Post
Season of Appearance							
Distribution	abound in sandy shores, staying at the bottom or at intermediate depths. None are known to inhabit rocky places or to ascend to greater depths						
depth bottom temp							
Rel'n Prey-Predator		carnivorous					
Growth		marine fish of small to moderate size, but mostly small, ranging from 15 cm to less than 40 cm in length					
Propagation							
Migration							
Reaction							

(- ditto -)

7. RECORD SHEET OF LIFE HISTORY OF *Lethrinidae*

	EGG	FRY	JUVENILE	ADULT			
				Feeding Per	Pre-Spng	Spng	Post
Season of Appearance							
Distribution			species found predominantly in reef environments, including associated sand, rubble, rocky areas; from 0-60 m with all individuals caught no further than 20 m from the reef				
depth bottom temp							
Rel'n Prey-Predator							
Growth							
Propagation							
Migration							
Reaction							

(- ditto -)

8. RECORD SHEET OF LIFE HISTORY OF *Cephalopholis Pachycentron*

	EGG	FRY	JUVENILE	ADULT			
				Feeding Per	Pre-Spng	Spng	Post
Season of Appearance							
Distribution				outer reef drop-offs or rocky areas	seagrass beds and lagoonal reef slopes	seaward portion of outer reef slope near channel through fringing reef or barrier reef	
depth bottom temp							
Rel'n Prey-Predator			"moderate to large" predatory fish, usually seen resting on their pectorals with their heads emerging from a protective hole waiting to snap at any passing fish of suitable size feed on living invertebrates and fish				
Growth			11-14.2 cm in a year				
Propagation							
Migration							
Reaction			highly territorial bottom dwellers				

(- ditto -)

9. RECORD SHEET OF LIFE HISTORY OF *Labridae*

	EGG	FRY	JUVENILE	ADULT			
				Feeding Per	Pre-Spng	Spng	Post
Season of Appearance							
Distribution			species found predominantly in reef environments, including associated sand, rubble, rocky areas; from 0-60 m with all individuals caught no further than 20 m from the reef				
depth bottom temp							
Rel'n Prey-Predator							
Growth							
Propagation							
Migration							
Reaction							
(- ditto -)							

10. RECORD SHEET OF LIFE HISTORY OF *Siganus Oramin*

	EGG	FRY	JUVENILE	ADULT			
				Feeding Per	Pre-Spng	Spng	Post
Season of Appearance			May-June or 2 days after new moon			4-7 days after new moon around midnight/early AM	
Distribution	demersal/fertilized before they settle on substrate	fry pelagic	grass flats or mangroves	shallow weedy areas/mainly grass flats/ reef flats/mangroves			
depth							
bottom	made up of grass (*Enhalus* sp)						
temp	23-36°C/17-37 ppt						
Rel'n Prey Predator			mainly herbivorous and feeds on sea-grasses/ benthic algae also on copepods/crustacean larvae				
Growth		at hatching: 1.5-2.1 mm SL yolk resorbed/feeds after 48 hrs/metamorphose in 21 days (20-24 mm SL) at 28-32°C	at 2 mos. = 80 mm 4 1/2 mos = 100 mm with egg/sperm dev'lng maturation size = 10.6 cm SL (males); 11.6 cm (females)				
Propagation	eggs transparent demersal/adhesive measures 0.42-.65 mm; hatches 30-62 hours at 22-29°C spawned eggs = 300-400,000			fish come in large schools to shallow tidal areas as tide begins to rise, and spawning begins after midnight, when the tide recedes, and lasts to dawn/may occur in large *Enhalus* flats accessible to open sea spawning behavior: captive female nudges abdomen of male to encourage release of milt; as soon as male responds, female releases eggs fecundity: 166-650,000 in 11.1-11.5 cm females			
Migration			enormous groups of juveniles come to coral areas during flood tides in the 6th lunar month and form dense schools among seagrasses	school of fish gradually loosens and spreads over wider area but still localized in seagrass community			
Reaction	newly hatched larvae orient themselves head down in water column; frequently wriggling downward in short bursts	gregarious/swims feeds in schools but when a conditions become unfavourable they become territorial and each individual defends a specific area; also capable of rapid colour changes; show camouflage ability; attracted to diffuse light, particularly the juveniles, but adults immobilized by strong lights					

- ditto -

11. RECORD SHEET OF LIFE HISTORY OF *Siganus Guttatus*

	EGG	FRY	JUVENILE	ADULT
				Feeding Per Pre-Spng Spng Post
Season of Appearance				Spawning all year round: 2-3 days after 1st lunar qtr days bet. new moon at full moon or 5-2 days before full moon; maximum around 1st qtr at 2200-1000 hr. or 1400-1800 hr.
Distribution	attached to bottom	in waters beyond the outer reef (pelagic)	in mangrove areas/roots; in shaded areas/shallow bays/river mouths	coastal but enter and leave rivers with the tides estuaries
depth bottom temp	 26-28°C/3-71 ppt		1-15 meters	
Rel'n Prey-Predator				nibble at vegetation with their heads pointed downwards feed on vascular plants/filamentous/thalloid/periphytic algae
Growth		at hatching: 1.5-1.98 mm SL resorbs yolk in 40-50 hrs; feeds in 48-72 hrs. metamorphose to adults beginning 8th to 45th day at 26-30°C	Day 17-21 metamorphose to juvenile Day 29 juvenile become brownish, form schools and keep to deeper portions Day 35 dive to bottom when disturbed (18.3-21.9 mm SL) Day 45 juveniles heavily pigmented and develop spots characteristic of adults Mature adult: F=190 mm SL; M=215 (age = 10 and 12 mos. respectively)	
Propagation	spawned eggs average 570,000 rate of fertilization = 84.2% at 26-32 ppt and 26-28°C 0.467-.593 mm in diameter; hatched after 18-31 hours			Spawning behavior: male chases female, nudging its abdomen; male continues swimming close to female, now and then nudging operculum, anal reg. caudal peduncle in sequence; female releases egg and male its milt Fecundity: 400 g fish= 0.8 M eggs; GSI=13.8 520 g fish=1.2 M; GSI=12.6 Spawning is at midnight/dawn to early AM
Migration		running distance of larvae (lab. con'd) averaged 58.2 cm/min (Day 2 1/2) and 70.6 (Day 6 1/2)		
Reaction		Day 12 larvae: nibble at algae growing at tank sides Day 15: show aggressive behav. (chasing/biting) Day 18: stay deeper in water column Day 23: start schools and swim continuously in search of food		move in schools while browsing on algae; aggression leading to cannibalistic attitude

(- ditto -)

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12. RECORD SHEET OF LIFE HISTORY OF *Saurida Undosquamis*

	EGG	FRY	JUVENILE	ADULT			
				Feeding Per	Pre-Spng	Spng	Post
Season of Appearance		Throughout the year, peak Feb - March, July - Sept			spawn throughout the year; two major periods: Jan - March and July - Setp		
Distribution							
depth bottom temp				31-50 m	spawn in deeper water at depth 51-55 m salinity 33.17 - 33.24‰.		
Rel'n Prey-Predator			feed on small fish, squid, shrimp and other crustaceans				
Growth			first recruitment was at length of 13.5 cm, growth rate 2 cm/month. Fish population consist of more than one year class; mean length in catch range from 14.5 - 21.5 cm.		mean length ♂ 27.34 cm, ♀ 32.82 cm		
Propagation					first spawn female was at length 16.25 cm, females were on the average about 4.25 cm longer than males; sex ratio male to female 1.508		
Migration							
Reaction							

(Source: Compiled from the attached list of reports by Miss S. Suvapepun, Fisheries Biologist in Marine Fisheries Laboratory, Thailand)

13. RECORD SHEET OF LIFE HISTORY OF *Priacanthus Tayenus*

	EGG	FRY / JUVENILE	ADULT: Feeding Per / Pre-Spng	ADULT: Spng / Post
Season of Appearance	May-June	July-Sept (West coast) March (Inner Gulf)	throughout the year, peaking in winter	Oct - April (Andaman Sea); spawn throughout the year (Gulf of Thailand), peaking Jan - March, and consisting of at least 4 different batches
Distribution		all over the Gulf 15-40 mile from shore	all over the Gulf	
depth bottom temp		25-50 m muddy sand	10 - > 50 m, abundant at depth 40 - > 50 m	
Rel'n Prey-Predator			predators - feed on squid and small fish, shrimp, crabs, worms, snails; major food item crustaceans	
Growth	growth of small fish is 0.2 mm/day, of large fish 0.024 mm/day; male is 10.64 mm longer than female.		mean length in catch 11.9 cm (Log W = -3.3815 + 2.4607 Log L) weight range 9-80 g	
Propagation			number of males greater than females; sex ratio 1:072	fecundity 23000-26000 eggs, ready to spawn at age 8-9 months, length 15 cm.
Migration			do not make extensive migration	
Reaction			active day feeder, in habit deeper off shore water	
- ditto -				

14. RECORD SHEET OF LIFE HISTORY OF *Nemipterus Peronii*

	EGG	FRY	JUVENILE	ADULT			
				Feeding Per	Pre-Spng	Spng	Post
Season of Appearance		throughout the year, most abundant in Feb, May-Sept		throughout the year, most abundant June-Sept		Feb-April	
Distribution	larvae were found 1-40 miles from shore			all over the Gulf			
depth bottom temp				most abundant at depth 21-30 m.			
Rel'n Prey-Predator				feed on small fish and invertebrates			
Growth				males are approximately 0.8 cm longer than females; mean length for males is 21.11 cm, for females 20.32 cm; marketable size 14.5-27.5 cm.			
Propagation				females were predominant in Feb, July, Oct, Nov; Sex ratio about 1:1			
Migration				Feb-May, they occur at all depths between 10-50 m; June-Sept they were most abundant at 21-40 m depth; Oct-Jan abundant at 21-30 m depth			
Reaction							

- ditto -

15. RECORD SHEET OF LIFE HISTORY OF *Nemipterus Mesoprion*

	EGG	FRY	JUVENILE	ADULT Feeding Per	Pre-Spng	Spng Post
Season of Appearance	throughout the year	throughout the year		throughout the year, peaking June-Sept		all the year round- Upper West coast Jan-April, Lower West coast Jan-April, East coast Oct-Nov
Distribution	all over the Gulf	all over the Gulf				
depth				abundant at depth 41-50 m		30-50 m depth
bottom				muddy sand		salinity 32.51-32.94‰
temp						
Rel'n Prey-Predator				feed on shrimps, polychaeate, fish and other crustaceans		
Growth				maturity ♀ 9.9-12.5 cm ♂11.2-16 cm ♂longer than ♀ length in catch 7.2-19.2 cm		
Propagation	mean egg size 163 microns			sex ratio 1:1		fecundity 15812-61140 eggs of fish size 8.8-14.0 cm
Migration						
Reaction						fecundity increases in correlation with the total length

- ditto -

16. RECORD SHEET OF LIFE HISTORY OF *Hemipterus Hexodon*

	EGG	FRY	JUVENILE	ADULT			
				Feeding Per	Pre-Spng	Spng	Post
Season of Appearance	throughout the year	through-out the year	most abundant in May	Aug-Oct	throughout the year	June - August Feb - April	
				seasonal abundance were not so different at significant level; most abundant during rainy season			
Distribution	coastal area 1-40 miles from shore		near shore	off-shore in deep-water, abundant on east coast and south-west coast			
depth bottom temp			shallow water muddy sand	at all depths 10 - 70 m.; the density of commercial size was highest at depths 20-40 m.			
Rel'n Prey-Predator		plankton feeder (shrimp larvae, copepods ostracods)		carnivorous - polychaeate, small shrimp, squid, mollusc, young fish and benthic animals (bottom feeder)			
Growth			growth rate 1 cm/month	size at 14-19 cm, growth-rate about 0.5 cm/month		spawn when they attain a size of about 18 cm or longer. Fish of fourth year class are 26-28 cm. long, third year class 23-26 cm. long, second year class are 17-23 cm long, first year class are 14-17 cm long	
			males are longer than females, size-range 13-29 cm; there were 4 different size groups entering into fisheries in June, August, September and November; sex ratio 1:1				
Propagation							
Migration		small fish live in shallow water	adult fish move to deeper water, at 60 m. tagging study of this species found one specimen travelled about 50 miles in 48 days but some fish were recovered at the place of release after 37 days of freedom.				
Reaction							

- ditto -

17. RECORD SHEET OF LIFE HISTORY OF *Scolopsis Taeniopterus*

	EGG	FRY	JUVENILE	ADULT			
				Feeding Per	Pre-Spng	Spng	Post
Season of Appearance		November		at least three recruitments enter the fisning-ground annually, in July, November and February		throughout the year major periods were found Dec-Jan, April, August.	
Distribution				Eastern coast of the Gulf and Upper West Coast, appear in all			
depth bottom temp				depth zones 6-43 m muddy bottom		ripe ♀ were found at 25 m depth	
Rel'n Prey-Predator				feed on small benthos shrimp, polychaeate, copepods, fish			
Growth				male fish is much bigger than female and distributed in deeper water; there is no male fish under 10 cm long and no female over 25 cm. ♂ size 7-25 cm, ♀ size 10-27 cm.			
Propagation		males and females differ markedly in number; the sex ratio of male to female is 1:10; a sexual dimorphism in growth exists in this fish population; percentage of males increases as the size increases; at 21 cm long, the ratio of males to females is almost 1:1; a higher percentage of males found in Dec-Jan				estimated fecundity is about 55,189 eggs in one ovary; diameter of ripened eggs 550-815 microns; ripe female range from 16 to 20 cm long; dominant group of males 18-25 cm. long	
Migration							
Reaction							
- ditto -							

18. **RECORD SHEET OF LIFE HISTORY OF** *Nemipterus Nematophorus*

	EGG	FRY	JUVENILE	ADULT			
				Feeding Per	Pre-Spng	Spng	Post
Season of Appearance		most abundant in Feb, least abundant in May		throughout the year, abundant in rainy season (June-September)	fish with mature stage of gonad were found all over the Gulf	November and March (East coast) Jan-March and Aug (Upper West coast) Jan, April, Aug, Nov (Lower West Coast)	
Distribution				all over the Gulf	most abundant along the West Coast		
depth bottom temp				41- > 50m depth muddy sand	water depth 48-50 m salinity 32.24-33.49%		
Rel'n Prey-Predator				feed on small animals - small shrimp, fish, polychaeate			
Growth				when first mature, they are 11.7 cm long, total length mean length of fish at each stage of maturity is greater for females than for males, mature female size 10.2-13.8 cm long, male 11.2-20 cm.			
Propagation							
Migration							
Reaction							

- ditto -

19. RECORD SHEET OF LIFE HISTORY OF *Leiognathus Brevirostris*

	EGG	FRY	JUVENILE	ADULT			
				Feeding Per	Pre-Spng	Spng	Post
Season of Appearance		throughout the year, peaking April-May and July		many recruitments enter into the fishing-ground, most abundantly in October and less abundantly in April		spawn all year long	
Distribution		all over the Gulf larvae were found most abundantly within 10 miles of the shore		all over the Gulf at all depth zones abundant in 21-30 m			
depth bottom temp						spawn at depth < 20 m	
Rel'n Prey-Predator				feed on zooplankton - copepods, amphipods, ostracods, mysids, polychaeate, fish larvae, macruran larvae			
Growth				length of females 8-13.5 cm, male 8-12 cm			
Propagation				when first mature female 8.6-13.5 cm long mean length of male was 0.49 cm smaller than female sex ratio 1:1			
Migration							
Reaction							

- ditto -

20. RECORD SHEET OF LIFE HISTORY OF *Epinephelus Tauvina*

	EGG	FRY	JUVENILE	ADULT			
				Feeding Per	Pre-Spng	Spng	Post
Season of Appearance		throughout the year, peaking in January and September				November-April	
Distribution		river-mouth and up to 2800 m. (Songkhla, Chantaburi)		river-mouth all over the Gulf	rocky shores & river-mouth staying at the bottom		
depth		3-4 m.			deep water, rocky bottom clear water		
bottom		muddy, muddy sand		muddy, muddy sand	rocky, muddy sand		
temp salinity		27.5-33°C 1-30 ppt, pH 7-8.10					
Rel'n Prey-Predator		plankton feeder	predator feed on small fish	predator	predaton	Predator	
Growth	egg size 200-300 microns	growth rate 2.3-2.6 gm/ day		mean length in catch 14.9 cm (Log w = -4.3022+2.8983 Log L)		size 4-8 kg. 14.7-77 cm	
Propagation		3 days = 2.4 mm 10 day = 4.1 mm 15 days = 5.5 mm 25 days =10.4 mm	4 months = 11.5 cm	8 months = 31.8 cm		fecundity 10000-5,000,000	
Migration		larvae occur at river-mouth, when larger migrate to deeper water of rocky bottom, feed at the bottom and migrate to spawn near shore					
Reaction							

- ditto -

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Appendix II

The required strength of the components of the module

Suspending the module, the force of its impact on the surface of the water, and then placing it on the seabed have an effect on the components of the module. Thus, the capacity of the components to withstand external pressures is an essential factor, if the module is to retain its shape and position, and if it is not to sustain any damage. In fact, the strength of the components has to be greater than that of the external pressures. The following are of prime importance.

1) TENSILE STRESS OR TENSION is the internal total stress, S, exerted by the material fibres to resist the action of an external force, P (Fig. 1), tending to separate the material into two parts along the line, mn. For equilibrium conditions to exist, the tensile stress at any cross-section will be equal and opposite in direction to the external force, P. If the internal total stress, S, is distributed uniformly over the area, the stress can be considered as unit tensile stress, $\sigma = S/A$.

2) COMPRESSIVE STRESS OR COMPRESSION is the internal total stress, S, exerted by the fibres to resist the action of an external force, P (Fig. 2) tending to decrease the length of the material. For equilibrium conditions to exist, the compressive stress at any cross-section will be equal and opposite in direction to the external force, P. If the internal total stress, S, is distributed uniformly over the area, the unit compressive stress $\sigma = S/A$.

3) SHEAR STRESS is the internal total stress, S, exerted by the material fibres along the plane, mn (Fig. 3) to resist the action of the external forces, tending to slide the adjacent parts in opposite directions. For equilibrium conditions to exist, the shear stress at any cross-section will be equal and opposite in

direction to the external force, P. If the internal total stress, S, is uniformly distributed over the area, the unit shear stress = S/A.

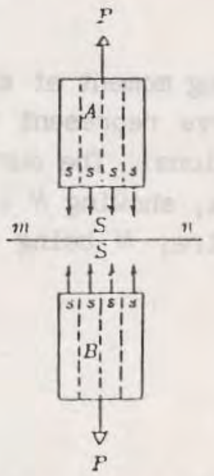


Fig. 1 Tensile stress

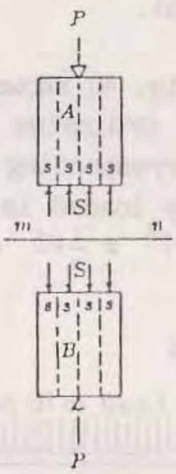


Fig. 2 Compressive stress

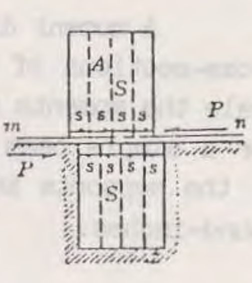


Fig. 3 Shear stress

4) Bending moment, at any cross-section of a beam, is the algebraic sum of the moments of the external forces acting on either side of the section. It is positive when it causes the beam to bend convex downward, hence causing compression in the upper fibres and tension in the lower fibres of the beam. When the bending moment is determined from the forces that lie to the left of the section, it is positive if it acts in a clockwise direction; if determined from forces on the right side, it is positive if it acts in a counter-clockwise direction. If the moments of upward forces are given positive signs, and the moments of downward forces negative signs, the bending moment will always have the correct sign, whether determined from the right or left side. The bending moment should be determined for the side for which the calculation will be simplest.

In Fig. 4 let M be the bending moment, pound-inches, at a section, mn, of a simple beam at a distance, x inches, from the left support; w = weight of beam per 1 in. of length; l = length of the beam, in inches. Then the reactions are $\frac{1}{2}wl$, and $= \frac{1}{2}wlx$ -- $\frac{1}{2}xwx$. For the sections at the supports, $x = 0$ or l and $M = 0$. For the section at the centre of the span, $x = \frac{1}{2}l$ and $M = \frac{1}{8}wl^2$ $= \frac{1}{8}wl$, where W = total weight.

A moment diagram (Fig. 4) shows the bending moment at all cross-sections of a beam. Ordinates to the curve represent to scale the moments at the corresponding cross-sections. The curve for a simple beam uniformly loaded is a parabola, showing $M = 0$ at the supports and $M = \frac{1}{8}wl^2 = \frac{1}{8}Wl$ at the centre, M being in pound-inches.

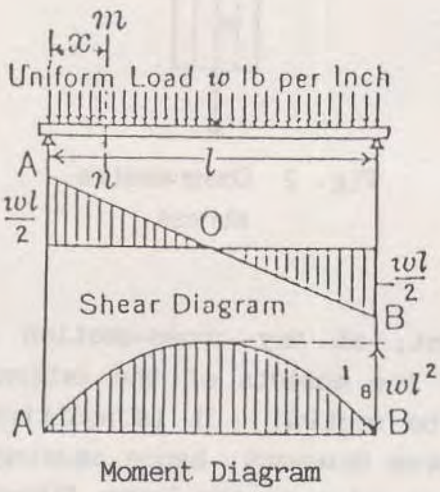


Fig. 4 Shear and moment diagrams, simple beam.

All four strengths should enable the components to withstand the external pressures that act on the module. And, in order to find out the breaking strength of the components, it is possible to test them by causing compression, tension, shearing and bending damage.

On the other hand, the stress limit can be calculated by mathematical means, which is done by dividing the total breaking strength by the safety factor (the safety factor usually ranges from 1.5 to 3.5). If the stress limit is greater than the external pressures, the components of the module can be used.

Appendix III

Simulated external forces

External forces to be taken into consideration, when designing a prototype, are gravity, the force of the impact on the surface of the sea, hydraulic force and bed reaction; and they should be tested in all conditions that can occur, during construction, transportation, installation and after the module has been installed.

(1) The gravity is, when the unit volume weight of the component member is represented by σ_c,

$$\begin{cases} \text{Total weight} \quad W = \sigma_G . V \text{ (ton, kg - - -)} \\ \text{Component unit load } q = \sigma_G a \text{ (ton/m, kg/cm)} \end{cases}$$

where V: actual volume of fish shelter; and a: cross-sectional area of the components of the prototype.

(2) The impact force may be considered a static load, with the force due to acceleration at the time of collision given in the form of an equivalent static weight, σ_G and the unit volume weight assumed to be σ_G (= $k\sigma_G$).*

(3) The hydrodynamic forces are due to the pressure of the waves, currents and buoyancy.

(4) The bed reaction should have the dynamic characteris tics of rock, gravel, sand and soft mud taken into consideration. They include the bearing force, shear strength, modulus of elasticity, the co-efficients of stress concentration and of subgrade reaction.

* The unit volume weight, σ_G, is the gravity acting on the mass, σ, per unit volume. It is expressed as

$$\sigma_G = g\sigma \qquad \text{---- (1)}$$

and is generally measured in kilograms (kg weight) or simply σ_G (kg).

2. Impact Load when submerging the module

The impact force at the time of placing the module on the seabed is obtained by calculating the equivalent static weight, $\sigma_G = k.\sigma_G$, assuming that the force of inertia, when placing it on the seabed, is k times the gravity.

(1) The impact load, in the case of directly setting it on the sea bottom, is $\hat{\sigma}_G$

The bed reaction, R, is expressed by $R = K\varepsilon^2$, assuming that the seabed has a maximum displacement, ε , at the time of setting the module down, and is obtained by formula (2)

$$\left.\begin{array}{l} \hat{\sigma}_G = \frac{R}{V} = \frac{K}{V}\varepsilon^2 \\ \hat{\sigma}_G/\sigma_G = k \end{array}\right\} \text{----} \quad (2)$$

In the case of a module composed of composite members different in unit weight, the unit volume weight, σ_G, of the respective members should be multiplied k times to obtain the setting impact load. In the case of ferroconcrete, the value of σ_G is assumed to be 2.4 - 2.45t/m^3.

ε is the solution to the following:

$$\left.\begin{array}{l} L\varepsilon^3 - M\varepsilon - N = 0 \\ L = \frac{gk}{3WoV},\ M = g(\frac{\sigma G}{Wo} - 1) - \frac{C_D A}{4V} V^2 \\ N = (\frac{\sigma G}{Wo} + C_{MA}) \frac{V^2}{2} \end{array}\right\} \text{---} \ (3)$$

and, using the asymptotic method, the n-th approximation of ε are

$$\left.\begin{array}{l} \varepsilon_1 = \sqrt[3]{\frac{N}{L}} \\ \varepsilon_{n+1} = \varepsilon_n - \frac{L\varepsilon_n^3 - M\varepsilon_n - H}{3L\varepsilon_n^2 - M} \end{array}\right\} \text{----} \ (4)$$

obtaining an approximate value for ε, with the desired level of accuracy, the values of $\hat{\sigma}_G$ and k are obtained from formula (2).

W_O, σ_G : unit weights of sea water and module components

v : setting velocity to sea bottom [value of formula (6)]

V : actual volume of module

C_V, C_{MA} : co-efficients of drag and added mass

A : total area of shadowing of the module when hitting the current

K : co-efficient of subgrade reaction of sea-bottom, relating to the hardness of subgrade in the case of gravel and taking a value of K = 3,000 - 5,000 ton/m^2

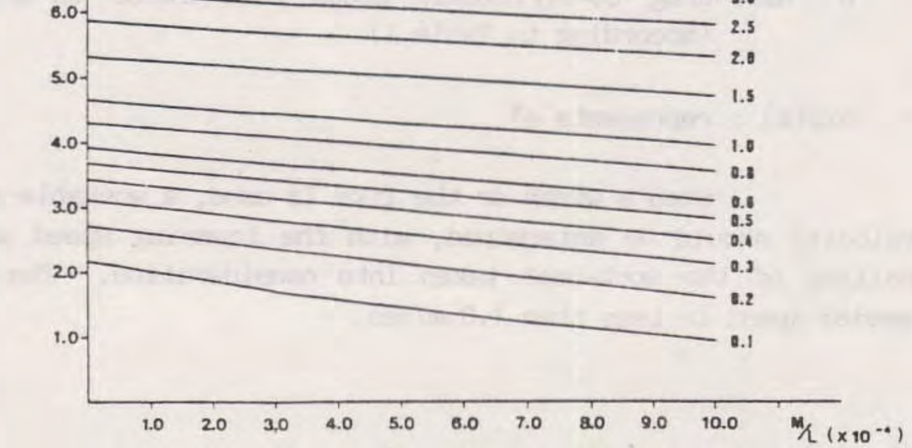


Fig. 1 Subgrade displacement versus M/L and N/L

Of calculating formula (3) with M/L and N/L. The results are shown in Figure 1.

(2) Setting velocity

The setting velocity, v, when the module is allowed to drop freely on to the surface of the sea, is obtained by the formulas

$$v_C = \sqrt{\frac{2gV}{C_D A}\left(\frac{\sigma G}{Wo} - 1\right)} \qquad \text{---- (5)}$$

$$V = V_c\left[1 - \exp\left\{-\frac{2gh\ (\sigma G/Wo - 1)}{(\sigma G/Wo + C_{MA})V_c^2}\right\}\right]^{\frac{1}{2}} \qquad \text{---- (6)}$$

In the case of a water depth of 10 m or more, formula (5) may be used for calculation of the setting velocity. In the formula,

V_C : end velocity

h : water depth

A : total area of shadowing in relation to horizontal plane when the module is dropped (sum of the components)

C_D, C_{MA} : drag co-efficient, added mass force co-efficient (according to Table 1)

exp(x) : represents e^x

When a winch or the like is used, a workable setting velocity should be determined, with the lowering speed and the rolling of the work-boat taken into consideration. The recommended speed is less than 1.0 m/sec.

3. Hydraulic Force

The hydraulic force is comprised of drag and mass forces as a result of waves and currents.

(1) Simulated Waves

Parameters of wave used for calculating a module's stability after installation and for safeguarding the module should be determined according to reliable data or by means of prediction.

1.1 When wave-measurements for a considerable period of time are available for the area concerned, the parameters of deepwater waves are estimated from the measurements shown in appendix IV.

1.2 Where port or fishing port projects are being carried out in the area, the deepwater wave simulation used in such projects should be applied with due alternation of details.

1.3 When 1.1 and 1.2 are not applicable because of the underwater topography, meteorological data (wind direction, velocity and duration) should be used for analysis, as in appendix IV.

(2) Current Velocity

The simulated current velocity should be obtained, as shown in appendix IV.

(3) Calculation of Wave Pressure

Where the water depth, h, of the installed module is greater than 1/2L (L, wavelength), the wave pressure may not be taken into consideration.

i) Non-breaking area

The maximum wave pressure, F, (by wave) is obtainable, as below.

$$\left.\begin{aligned} U &= Um \sin\theta \\ Um &= \frac{\pi H}{T}\frac{\cos h\ 2\pi D/L}{\sin h\ 2\pi h/L} \end{aligned}\right\} \text{---- (7)}$$

$$\left.\begin{aligned} F_D &= C_D A \frac{Wo}{2g} U^2 m \\ F_M &= C_M V \frac{Wo}{g} \frac{2\pi}{T} Um \end{aligned}\right\} \text{---- (8)}$$

$$\left.\begin{aligned} &\text{When } 2F_D < F_M, \\ &\quad F = F_M \\ &\text{When } 2F_D > F_M, \\ &\quad F = F_D + \frac{F^2 M}{4F_D} \end{aligned}\right\} \text{---- (9)}$$

where C_M, C_D : virtual mass co-efficient and drag co-efficient, according to the values shown in Table 1

A : total shadow area of vertical surfaces perpendicular to the direction of the waves (the sum of the respective members)

W_O : unit volume weight of sea water

h : water depth

D : height of module; and

H, L, T : wave height, length and cycle at the site

In the case of a large assembled module or any other module with a complicated shape, if it is assumed that the same current velocity as that at the upstream end acts on each component, an excessive value is likely to be given. The maximum wave pressure may be determined by means of a reliable hydraulic model experiment. In such cases, it is desirable to obtain the drag co-efficient, C_D, and virtual mass co-efficient, C_M (= C_{MA} + 1), by carrying out a model experiment under wave motion conditions (i.e. under unsteady flow). However, if the drag co-efficient can be obtained by means of a model experiment under steady flow conditions, the virtual mass co-efficient, C_M, may be calculated, as set forth below. With C_D obtained through an experiment for the total shadow area, At, of all surfaces in the direction of flow under steady flow conditions, the ratio of C_D, as obtained in the experiment, to the weighted average, $\bar{C}_D$, of each component may be taken as

$$C_D/\bar{C}_D = 1/r_D$$

Then, the virtual mass co-efficient, C_M, may be given as

$$C_M = \frac{\overline{CM}}{\gamma M} = \frac{1 + \sqrt{(n-1)\ (n/\gamma D - 1)}}{n}\ \overline{CM} \qquad \text{---- (10)}$$

where $\bar{C}_M$ represents the weighted C_M of each component.

ii) Breaking area

The total wave force on a submerged fish shelter in a breaking area is calculated by using the formula

$$F = 0.31 C_D A w_0 H \qquad \text{---- (11)}$$

where F is assumed to act on the centroid of A, with

H, h : height and depth of the waves breaking above the module; and

C_D : drag co-efficient (value according to Table 1).

the factor "0.31" was obtained, treating the flow velocity after breaking as that of sarging wave. The flow velocity confirmed through experiment was used.

(4) Pressure exerted by currents

Here, the current speed, u_z, at the upper end of the module is used to. For slow-changing currents, such as tidal currents, the pressure may be calculated by using the formula

$$F = C_D A W_o \frac{U^2 Z}{2g} \qquad \text{---- (12)}$$

(5) Co-present currents and waves

Where currents and waves are co-present, a phase θ, giving a maximum F value in

$$F = F_D \ (\sin\theta + u_z/u_m)^2 - F_M \cos\theta \qquad \text{---- (13)}$$

is obtained, and it is substituted in the formula (13). To obtain the maximum value of formula (13) with $F\ /(2F\ ) = \beta$, $u_z/u_m = \alpha$, $\sin\theta = S$ and $\cos\theta = C$, S and C should be obtained, representing a real root of

$$S^4 + 2\alpha S^3 + (\alpha^2 + \beta^2 - 1)\ S^2 - 2\alpha S^2 - \alpha^2 = 10 \qquad \text{---- (14)}$$

and satisfying

$$\left.\begin{array}{l} Ci\ (Si + \alpha) + \beta Si = 0 \\ 1 - 2S^2 i - \alpha Si + \beta Ci < 0 \end{array}\right\} \text{---- (15)}$$

Then, substituting $S = \sin\theta$ and $C = \cos\theta$ in formula (13), the maximum acting force, F, is calculated.

The formula (14) is a fourth order equation and is obtainable by analytical solution or by using an approximate solution.

According to the Newtonian method,

$$\left. S_{n+1} = Sn - \frac{Sn^4 + 2\alpha Sn^3 + (\alpha^2+\beta^2-1)Sn^2 - 2\alpha Sn - \alpha^2}{4Sn^3 + 6\alpha Sn^2 + 2(\alpha^2+\beta^2-1)\ Sn - 2\alpha} \right\} \text{---- (16)}$$

should be obtained, as the first approximation, in the two cases of $S_1 = 1$ and $S_1 = 0$. Then, using a convergence value of $S_n + 1 = S_n$, a convergence value satisfying formula (15) is used. It should be noted that $S^2 + C^2 = 1$. If the maximum value, F, according to the foregoing, is considered to be due to drag alone, the values of the equivalent drag co-efficient, $\overline{C}_D$, are as shown in Fig. 2. Using these values, F is obtainable as

$$F = \overline{C}_D A \frac{W_o}{2g} (Uz + Um)^2 \qquad ---- (17)$$

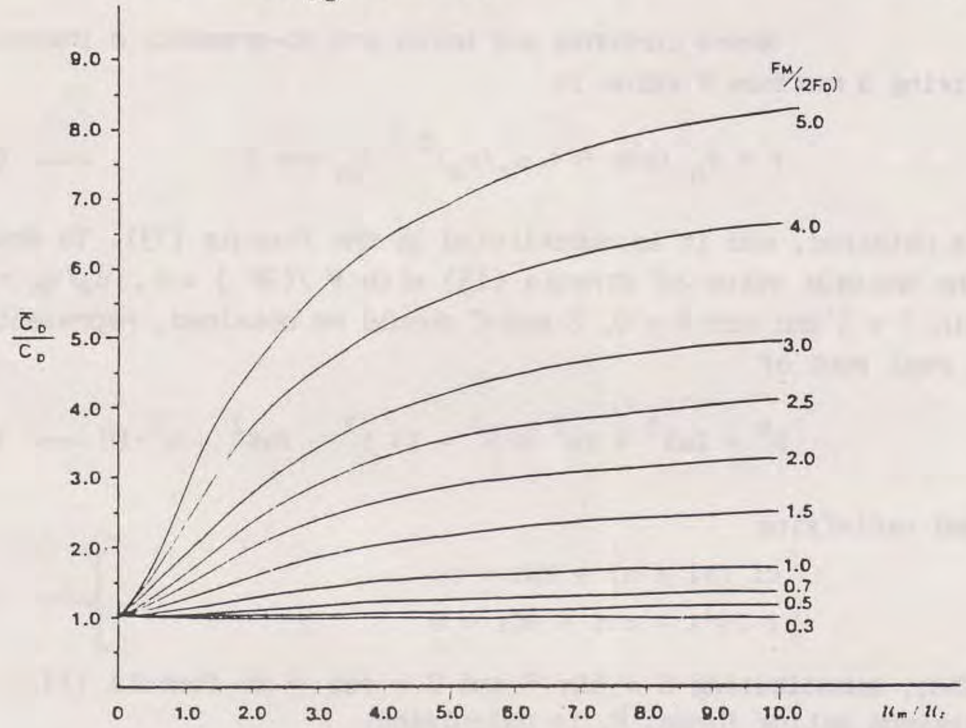


Fig. 2. $\overline{C}_D$ values where waves and currents are co-present

4. Component Strength

The bending moment, axial force and shearing force of the components of the module should be calculated by using simulated external forces in Sections 1.3-1.5; and the accumulated cross-sectional stress must, then, be less than the allowable strength of the material. Calculation of the bending moment, axial force and shearing force should be made for each module. Where stress concentration is likely to occur, such as at the corners, these parts should be reinforced with, for example, a haunches.

Calculation of the components strength, should be made for each module but, in the case of a square module, the calculation should be made by using the values shown in Fig. 3 (plane setting) or Fig. 4 (edge setting).

$$\text{Here, } q = \hat{\sigma}_G \cdot a = k\sigma_G \cdot a \qquad \text{---- (18)}$$

where a: cross-sectional area of the components; and $\hat{\sigma}_G$, σ_G and K: values according to formulas (2) and (19).

$$\left.\begin{aligned} \hat{\sigma}_G &= L + \sqrt{L^2 + M}, \\ L &= (\sigma_G - Wo) - \frac{C_D A Wo V^2}{4gV} \\ M &= \frac{K_L V^2}{gV} (\sigma_G + C_{MA} \cdot Wo) \end{aligned}\right\} \text{---- (19)}$$

In the case of a reinforced concrete module, the calculating procedure is as follows.

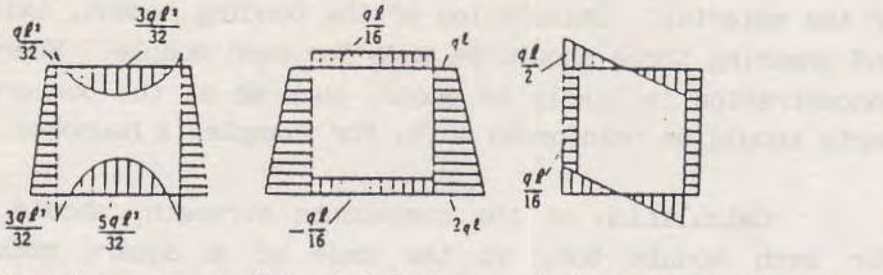
(1) Calculate the main reinforcement required for the bending moment and axial force.

(2) Check the shearing force exerting on the component.

(3) If shearing force is not sufficient, Reinforce with lateral tie.

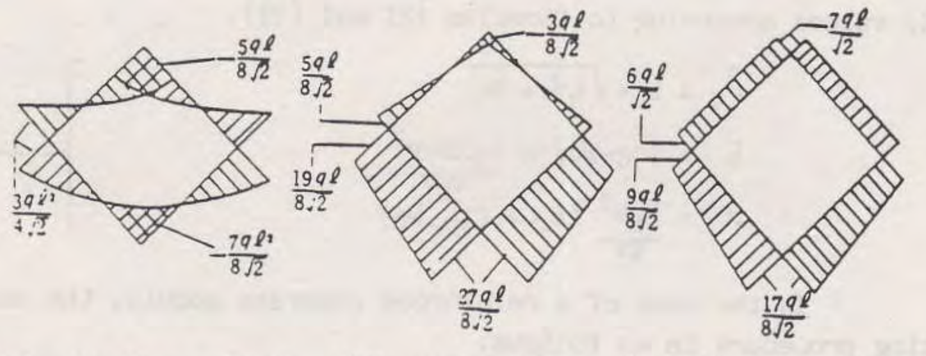
(4) If shearing force sufficient, Built-up reinforcements only.

(5) The load at the time of placing the module on the sea-bottom can be regarded as the tensile strength of concrete ($\sigma_{ct} = 1/10\sigma_{ca}$, σ_{ca}, representing a short-term allowable pressure-resisting strength).



(a) Bending moment diagram (b) Axial force diagram (c) Shearing force diagram

Fig. 3 Plane setting



(a) Bending moment diagram (b) Axial force diagram (c) Shearing force diagram

Fig. 4 Edge setting

5. Stability of the Module

The module should not overturn or slide as a result of wave motion and currents.

The wave force and tidal current force, F, are obtainable by using formulas (9) to (12) or (13) and (17). To be stable against this force, F, the following conditions have to be satisfied.

(1) Conditions for preventing sliding are calculated by

$$S_{FS} = \frac{W\mu\ (1-Wo/\sigma G)}{F} \geqq 1.2$$

where W : weight of the modules out of the waters;

σ_G, w_0 : unit volume weight of module materials and sea-water;

S_{FS} : safety factor against sliding; and

μ : frictional co-efficient between module and seabed, where, in the case of gravel, $\mu = 0.6$

Where the legs are embedded in sandy subgrade, the passive earth pressure of the sand should be taken into account.

(2) Conditions for preventing overturning are calculated by

$$S_{FS} = \frac{W\ (1-Wo/\sigma G)}{F} \quad \frac{\ell v}{\ell A} \geqq 1.2$$

where ℓ_A : height to the centroid of the positive shadow projection of the module to a vertical plane perpendicular to the current; and

ℓ_V : distance from the shadow projection point of the centre of gravity of the module to the bottom to the nearest centre line of the falling.

Appendix IV

On physical conditions with regard to the stability of the module

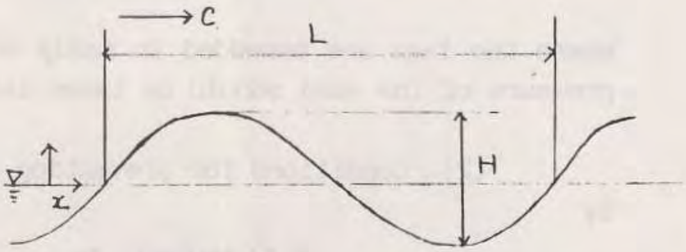
(1) General wave action features

Basically, in the open sea, the intervals between waves are regular and their length unchanging. The wave form, y, is represented by the following equations:

$$y = \frac{H}{2} \sin (kx - \sigma t)$$

$$k = 2\pi/L, \ \sigma = 2\pi/T$$

$$C = \frac{L}{T} = \frac{g}{k} \tan h \ kh$$



where x : the points of rectangular coordinate axis
t : time
H : wave height
L : wave length
T : wave cycle
h : depth of water
C : wave velocity

When wave action is assumed to be an irrational motion, water particle velocity may be calculated, as in the following equations.

$$u = \frac{H\sigma}{2} \frac{\cos h \ k(zth)}{\sin h \ kh} \sin (kx - \sigma t), \quad w = \frac{-H\sigma}{2} \frac{\sin h \ k(zth)}{\sin h \ kh} \cos (kx - \sigma t)$$

where u : particle horizontal velocity
w : particle vertical velocity

The X-axis particle velocity becomes greater as the wave height becomes greater and the intervals between waves shorter. However, the velocity decreases as the water gets deeper. The dynamic water pressure, P, and wave energy, E, are represented by the following equations:

$$P = \frac{W_0 H}{2} \frac{\cos h\ k(z + h)}{\cos h\ kh} \sin (kx - \sigma t)$$

$$E = \frac{W_0 H^2}{8} L$$

E : energy per one wave length

(2) Natural waves

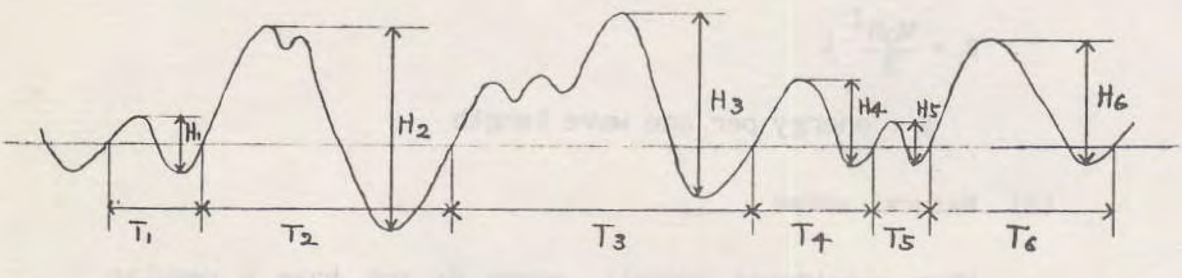
When considered overall, waves do not have a regular sine curve, in fact. Rather, they move in their own direction and in their own manner. They have to be considered as one wave so that they can be analyzed mathematically. We assume significant wave H 1/3 from which H 1/3 can be assumed to be the number of waves that can be analyzed statistically.

Over a suitable time period, the number of waves, the cycle of each wave and the wave height have to be recorded. (About a hundred is a suitable number). Then, a third of them which should be the highest of the total number have to be averaged out. This average is the figure which should be used, when considering the stability of the module with regard to physical conditions.

(3) Wave data to be considered when designing a module

*procedure

Waves transform as they move from deep to shallow water and, naturally, they should also be studied when above the proposed site. There are many features to wave transformation: refraction in relation to water depth, diffraction related to obstructions (e.g. islands), reflection related to obstructions, and shoaling in relation to water depth and waves breaking. The following features of the wave action at the site should be examined.



Time

bigger order

Wave height	H_3	H_2	....
Period	T_3	T_2	....

H 1/3 = average of the highest third of the total number

Missing information relating to waves (especially height)

If there is no reliable data on waves, based on long-term observations at a site, wind data and fishermen's opinions on larger waves should be researched into, in depth.

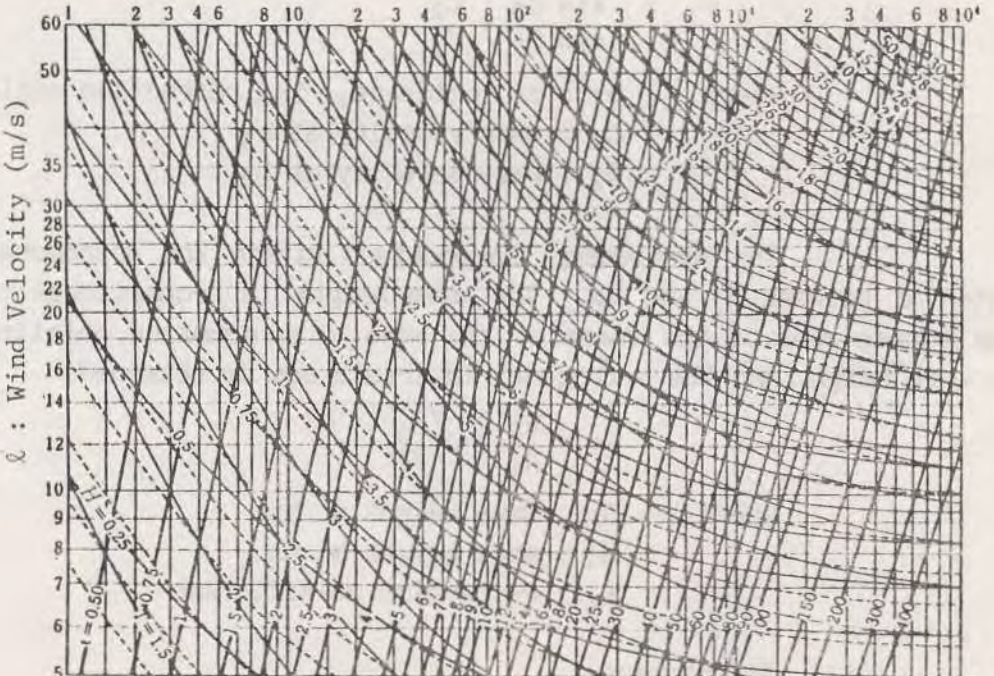
Deep water waves

Deep water waves are studied in order to calculate to what degree they transform as depth changes.

Wave prediction

Gravity waves occur as the result of storms and seasonal winds. The waves become larger as the wind velocity and the duration increase, and as the fetch length changes. The wave prediction diagram is the result of many observations of wave height and cycle in relation to wind velocity, duration and fetch. This is called the S-M-B wave prediction method (Refer to Fig. 1)

Wind data should be established to determine wave data. The wind data should be obtained from a study of storms and weather charts; and in the absence of this data, local fishermen should be consulted.



——— wave height H1/3 (m) - - - - minimum duration (hrs)

——— period T1/3 (sec) -------- Equi-energy line
$(H1/3.T1/3)^2$ = constant

Fig. 1 Wave prediction diagram

(Source : K. Horikawa-1978-Coastal Engineering, p. 77, University of Tokyo, Press)

Wave transformation

(i) Refraction

In shallow water areas where the depth is less than 50 percent of the wave length, changes in wave direction and height caused by refraction need to be taken into consideration.

When a wave moves from water with a depth of h_1 into depths of h_2, with an incidence angle θ_1, its velocity increases from C_1 to C_2, as the water depth changes. According to Snell's law, the following equation applies:

$$\frac{\sin \theta_2}{\sin \theta_1} = \frac{C_2}{C_1}$$

where θ_1 : of incidence, θ_2 : refraction angle
C_1 : wave velocity at h_1
C_2 : wave velocity at h_2

The wave energy is constant within the orthogonal interval between B_1 and B_2. The wave height is proportional to the square root of the force of the wave. An equation relating to wave height and the orthogonal intervals can be obtained.

$$kr = \frac{H_2}{H_1} = \sqrt{\frac{B_2}{B_1}}$$

where H_2 : wave height at h_2
H_1 : wave height at h_1
K_v : refraction co-efficient

(ii) Diffraction

Changes in wave direction and wave height caused by diffraction should be taken into consideration in areas where they may be influenced by diffracted waves because of an obstruction, such as a wave dissipating embankment or island. The diffraction co-efficient, Kd, which represents the change due to diffraction, can be determined from a diffraction diagram (Fig. 2).

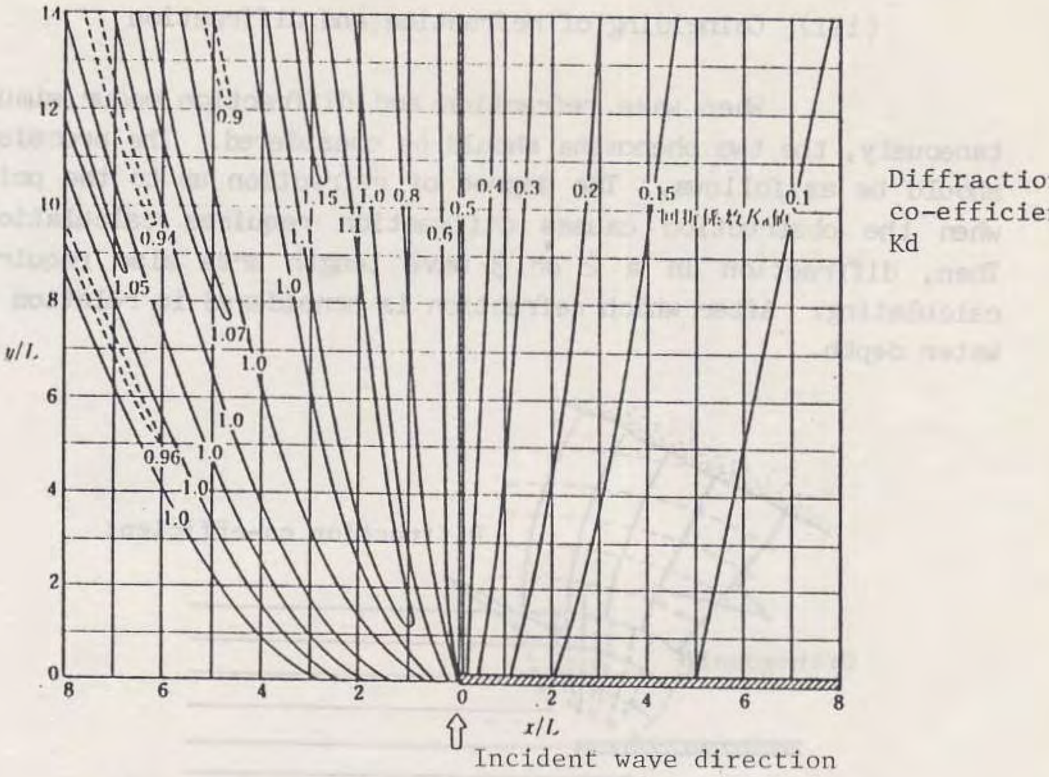


Fig. 2 Wave diffraction co-efficient diagram

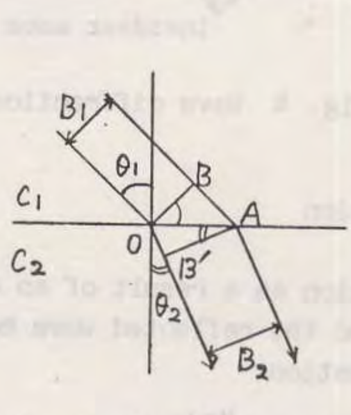


Fig. 3 Wave refraction

(Source : K. Horikawa-1978-Coastal Engineering, p. 46, University of Tokyo, Press)

(iii) Coinciding of refraction and diffraction

When wave refraction and diffraction occur simultaneously, the two phenomena should be considered. The procedure should be as follows. The degree of refraction up to the point when the obstruction causes diffraction requires calculation. Then, diffraction in a 2 or 3 wave length area also requires calculating. After which refraction is considered in relation to water depth.

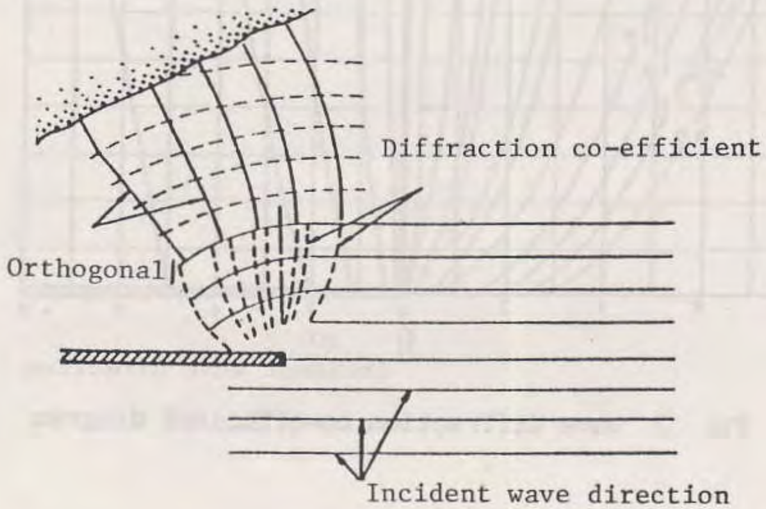


Fig. 4 Wave diffraction

(iv) Reflection

Reflection as a result of an obstruction should be taken into account, and the reflected wave height may be obtained from the following equation.

$$kr = {}^{Hr}/_{Hi}$$

where Hr : reflected wave height

Hi : incident wave height

Kr : reflection co-efficient, depending on the obstruction

Shoaling

*Shoaling with depth

When a deep-water wave moves into an area with a depth of less than 50 percent of its length, wave velocity, length, height and incident direction change. These changes are due to a decrease in depth and refraction. The changes in the wave, due to a decrease in water depth, should be noted here. The wave cycle does not change when the water depth changes. The wave transformation with water depth is represented in Figure 5. As shown in the figure, wave height increases as water depth decreases.

The changes in wave length and wave velocity with water depth are represented in the following equation, figure and table.

$$\frac{L}{Lo} = \frac{C}{C_o} = \tan h \frac{2\pi h}{L}$$

$$Lo = 1.56\ T^2$$

where

- L : wave length depending on water depth (m)
- L_o : wave length in deep water (m)
- C : wave velocity depending on water depth (m/sec)
- C_o : wave velocity in deep water (m/sec)
- T : wave cycle (sec)
- h : water depth

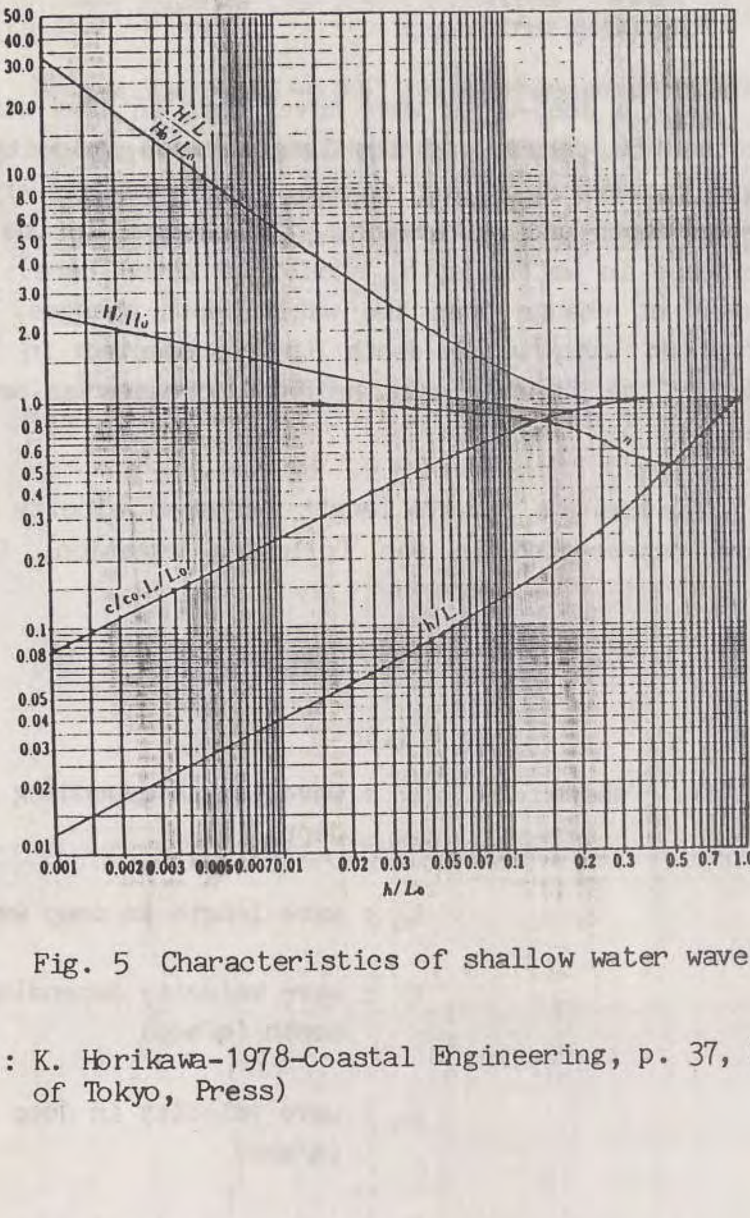


Fig. 5 Characteristics of shallow water waves

(Source : K. Horikawa-1978-Coastal Engineering, p. 37, University of Tokyo, Press)

Table 1. Relationship between wave length and cycle, and water depth

Period (sec.) / Wave length and Wave velocity / Water depth (m)	3		4		5		6		7		8		9		10	
	a (m)	b (m/s)	a (m)	b (m/s)	a (m)	b (m/s)	a (m)	b (m/s)	a (m)	b (m/s)	a (m)	b (m/s)	a (m)	b (m/s)	a (m)	b (m/s)
0.5	6.39	2.13	8.67	2.17	10.92	2.18	13.16	2.19	15.39	2.20	17.62	2.22	19.84	2.20	22.07	2.21
1.0	8.69	2.90	11.99	3.00	15.23	3.05	18.44	3.07	21.62	3.09	24.78	3.10	27.94	3.10	31.10	3.11
1.5	10.22	3.40	14.37	3.59	18.40	3.68	22.37	3.73	26.28	3.75	30.19	3.77	34.08	3.79	37.95	3.79
2.0	11.30	3.76	16.22	4.05	20.94	4.19	25.58	4.26	30.14	4.31	34.70	4.33	39.19	4.35	43.68	4.37
2.5	12.10	4.03	17.71	4.43	23.10	4.62	28.31	4.72	33.46	4.78	38.56	4.82	43.63	4.85	48.67	4.87
3.0	12.68	4.23	18.95	4.74	24.91	4.98	30.71	5.12	36.37	5.20	42.01	5.25	47.58	5.29	53.23	5.31
3.5	13.10	4.37	19.99	4.99	26.52	5.30	32.83	5.47	39.03	5.57	45.13	5.64	51.18	5.69	57.19	5.72
4.0	13.40	4.47	20.84	5.21	27.93	5.59	34.75	5.79	41.42	5.92	47.98	6.00	54.48	6.05	60.92	6.09
4.5	13.61	4.54	21.58	5.39	29.18	5.84	36.49	6.08	43.61	6.23	50.61	6.33	57.53	6.39	64.40	6.44
5.0	13.76	4.59	22.18	5.55	30.29	6.06	38.07	6.34	45.63	6.52	53.05	6.63	60.38	6.79	67.64	6.76
6.0	13.92	4.64	23.12	5.78	32.17	6.43	40.84	6.81	49.24	7.04	57.47	7.18	65.58	7.28	73.58	7.37
7.0			23.76	5.94	33.67	6.73	43.18	7.20	52.38	7.49	61.39	7.67	70.20	7.80	78.91	7.89
8.0			24.19	6.05	34.86	6.97	45.20	7.53	55.15	7.88	64.87	8.11	74.36	8.26	83.77	8.38
9.0			24.47	6.12	35.81	7.16	46.89	7.82	57.60	8.23	68.01	8.50	78.18	8.69	88.24	8.82
10.0			24.65	6.16	36.56	7.31	48.38	8.06	59.80	8.54	70.85	8.86	81.67	9.08	92.33	9.23
12.0			24.84	6.21	37.61	7.52	50.69	8.45	63.46	9.06	75.82	9.48	87.86	9.76	99.63	9.97
14.0					38.22	7.64	52.38	8.73	66.36	9.48	79.96	9.99	93.13	10.35	106.1	10.61
16.0					38.57	7.71	53.57	8.93	68.63	9.81	83.36	10.42	97.75	10.86	111.8	11.17
18.0					38.85	7.75	54.42	9.07	70.49	10.07	86.30	10.79	101.7	11.30	116.7	11.67
20.0							54.99	9.17	71.91	10.27	88.71	11.09	105.1	11.68	121.2	12.11
23.0									73.50	10.50	91.65	11.46	109.5	12.16	126.9	12.70
25.0									74.23	10.61	93.21	11.65	112.0	12.44	130.3	13.03
28.0									75.03	10.72	95.03	11.88	115.0	12.78	134.7	13.47
30.0									75.41	10.77	95.98	12.00	116.7	12.97	137.2	13.72
35.0											97.65	12.20	120.0	12.34	142.4	14.24
40.0													122.3	13.59	146.2	14.63
45.0															149.1	14.91
50.0															151.2	15.12
55.0															152.6	15.26
60.0															153.7	15.37
65.0															154.4	15.44
70.0																
75.0																
80.0																
90.0																
100.0																
120.0																
Deepwater Wave	14.04	4.68	24.96	6.24	38.99	7.80	56.15	9.36	76.43	10.92	99.82	12.78	126.3	14.04	156.0	15.60

Period (sec.) / Wave length and Wave velocity / Water depth (m)	11		12		13		14		15		16		18		20	
	a (m)	b (m/s)	a (m)	b (m/s)	a (m)	b (m/s)	a (m)	b (m/s)	a (m)	b (m/s)	a (m)	b (m/s)	a (m)	b (m/s)	a (m)	b (m/s)
0.5	24.27	2.21	26.53	2.21	28.71	2.21	30.94	2.21	33.13	2.21	35.37	2.21	39.80	2.21	44.22	2.21
1.0	34.23	3.11	37.37	3.12	40.54	3.12	43.65	3.12	46.81	3.12	49.91	3.12	56.24	3.12	62.51	3.13
1.5	41.80	3.80	45.66	3.81	49.53	3.81	53.41	3.82	57.23	3.82	61.09	3.82	68.77	3.82	76.49	3.82
2.0	49.06	4.46	53.63	4.47	57.10	4.39	61.51	4.39	66.00	4.40	70.48	4.41	79.33	4.41	88.22	4.41
2.5	53.69	4.88	58.69	4.89	63.69	4.90	68.72	4.91	73.65	4.91	78.62	4.91	88.63	4.92	98.58	4.93
3.0	58.61	5.33	64.15	5.35	69.62	5.36	75.11	5.37	80.57	5.37	86.05	5.38	96.97	5.39	107.9	5.40
3.5	63.16	5.75	69.11	5.76	75.07	5.78	80.98	5.79	86.88	5.79	92.83	5.80	104.6	5.81	116.4	5.82
4.0	67.33	6.12	73.69	6.14	80.08	6.16	86.42	6.17	92.92	6.20	99.11	6.20	111.7	6.21	124.3	6.22
4.5	71.20	6.47	77.98	6.50	84.72	6.52	91.71	6.55	98.25	6.55	105.1	6.57	118.3	6.57	131.8	6.60
5.0	74.86	6.80	82.05	6.84	89.19	6.85	96.32	6.88	103.4	6.90	110.6	6.91	124.7	6.93	138.9	6.94
6.0	81.55	7.41	89.44	7.45	97.31	7.48	105.1	7.51	113.0	7.53	120.7	7.55	136.3	7.57	151.8	7.59
7.0	87.56	7.96	96.14	8.01	104.6	8.05	113.2	8.08	121.6	8.11	130.1	8.13	146.9	8.17	163.7	8.18
8.0	93.06	8.46	102.3	8.52	111.4	8.57	120.6	8.61	129.6	8.66	138.7	8.67	156.9	8.71	174.7	8.74
9.0	98.13	8.92	108.0	9.00	117.7	9.05	127.4	9.10	138.7	9.14	146.7	9.17	166.0	9.21	185.0	9.25
10.0	102.8	9.35	113.4	9.44	123.6	9.50	133.8	9.56	144.0	9.60	154.2	9.64	174.5	9.69	194.7	9.73
12.0	111.3	10.15	122.8	10.23	134.2	10.37	145.6	10.40	156.8	10.45	168.0	10.50	190.3	10.58	212.6	10.62
14.0	118.8	10.80	131.3	10.94	143.8	11.06	156.1	11.15	168.3	11.22	180.5	11.28	204.8	11.37	228.8	11.44
16.0	125.5	11.41	139.0	11.58	152.4	11.72	165.7	11.83	178.8	11.92	191.9	11.99	217.9	12.11	243.7	12.18
18.0	131.4	11.95	146.0	12.16	160.3	12.33	174.5	12.46	188.5	12.56	202.4	12.65	230.2	12.78	257.6	12.87
20.0	136.8	12.44	152.3	12.69	167.6	12.88	182.5	12.90	197.5	13.15	212.2	13.26	241.5	13.42	270.6	13.53
23.0	144.0	13.09	160.7	13.40	177.3	13.63	193.6	13.83	209.7	13.93	225.7	14.10	257.3	14.29	288.6	14.43
25.0	148.2	13.48	165.9	13.82	183.2	14.11	200.2	14.30	217.2	14.47	233.8	14.62	267.1	14.84	300.0	14.99
28.0	153.9	13.99	172.7	14.40	191.3	14.71	209.5	14.97	227.6	15.17	245.6	15.34	280.8	15.60	315.7	15.78
30.0	157.3	14.29	176.9	14.74	196.3	15.10	215.3	15.38	234.1	15.61	252.7	15.79	289.6	16.08	325.6	16.28
35.0	164.4	14.95	186.0	15.50	207.2	15.94	228.1	16.29	248.8	16.52	269.0	16.81	309.1	17.17	348.6	17.43
40.0	170.1	15.46	193.5	16.12	216.5	16.65	239.2	17.08	261.4	17.43	283.3	17.71	326.7	18.15	369.3	18.46
45.0	174.5	15.86	199.5	16.64	224.4	17.26	248.3	17.77	272.6	18.17	296.2	18.51	342.6	19.03	388.2	19.41
50.0	178.0	16.18	204.7	17.06	231.0	17.77	256.9	18.35	282.5	18.83	307.6	19.23	357.0	19.83	405.4	20.27
55.0	180.7	16.43	208.9	17.40	236.5	18.20	264.1	18.86	291.1	19.41	317.9	19.86	370.1	20.56	421.3	21.06
60.0	182.8	16.61	212.2	17.68	241.4	18.57	270.2	19.31	298.8	19.92	326.9	20.43	382.1	21.22	435.9	21.80
65.0	184.3	16.75	214.8	17.90	245.3	18.87	275.7	19.69	305.6	20.37	335.2	20.95	393.0	21.83	449.3	22.48
70.0	185.5	16.86	216.9	18.08	248.6	19.13	280.3	20.02	311.5	20.77	342.5	21.40	402.8	22.39	462.1	23.11
75.0	186.3	16.94	218.7	18.22	251.5	19.34	284.3	20.30	316.8	21.12	349.1	21.81	412.2	22.91	473.8	23.69
80.0			220.0	18.33	253.8	19.52	287.6	20.55	321.4	21.43	354.8	22.18	420.5	23.36	484.7	24.23
90.0					257.2	19.78	293.1	20.93	329.0	21.94	364.9	22.80	435.4	24.19	504.1	25.20
100.0					259.5	19.96	296.9	21.21	335.0	22.32	372.8	23.30	447.8	24.88	521.0	26.06
120.0					262.0	20.15	301.6	21.54	342.7	22.83	383.9	23.99	467.0	25.94	549.0	27.43
Deepwater Wave	188.7	17.16	224.6	18.72	263.6	20.28	305.7	21.84	350.9	23.40	399.3	24.96	505.3	28.07	623.9	31.19

a = Wave length (m)
b = Wave velocity (m/s)

(Source : K. Horikawa-1978-Coastal Engineering, p. 364-367, University of Tokyo, Press)

Breaking waves

When a wave moves farther into shallow water, then the wave steepness (H/L) is greater, resulting in the wave breaking. The wave is at its highest and the wave force strongest when it breaks. In other words, the breaking wave exerts great pressure on the module. When the slope of the seabed is gentle, there is a relationship between the height at which the wave breaks and the water depth at the breaking point.

$$Hb = (0.73 - 0.78)\ hb$$

where Hb : breaking wave height

hb : water depth at the breaking point

The stages at which the wave height changes are different depending on the slope of the seabed. The figures show the wave changes in relation to the seabed slope.

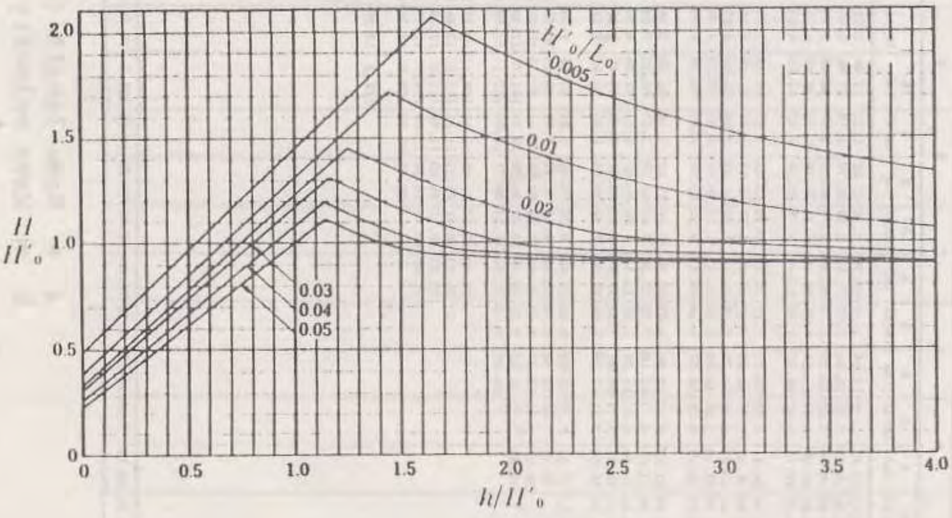
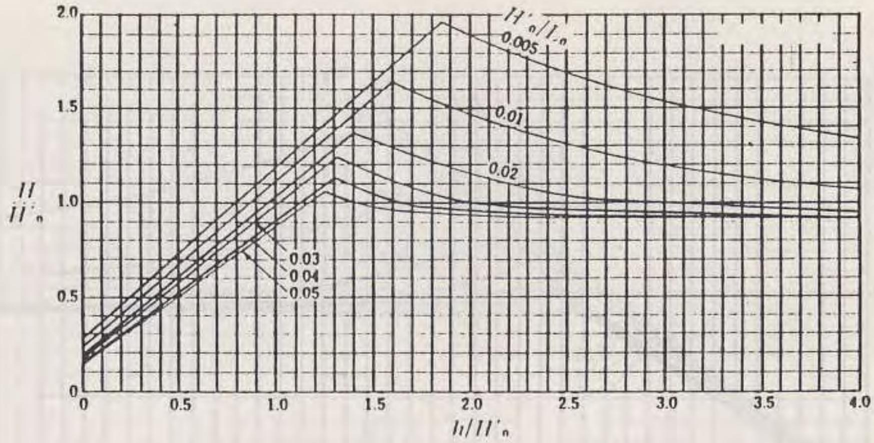
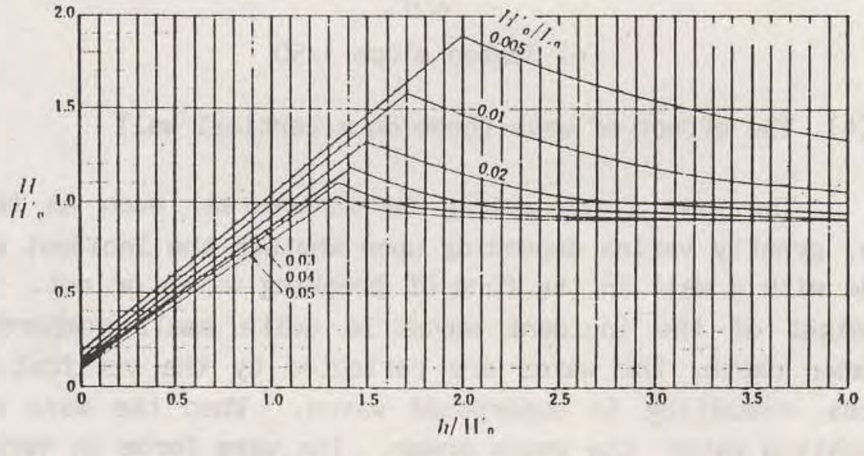


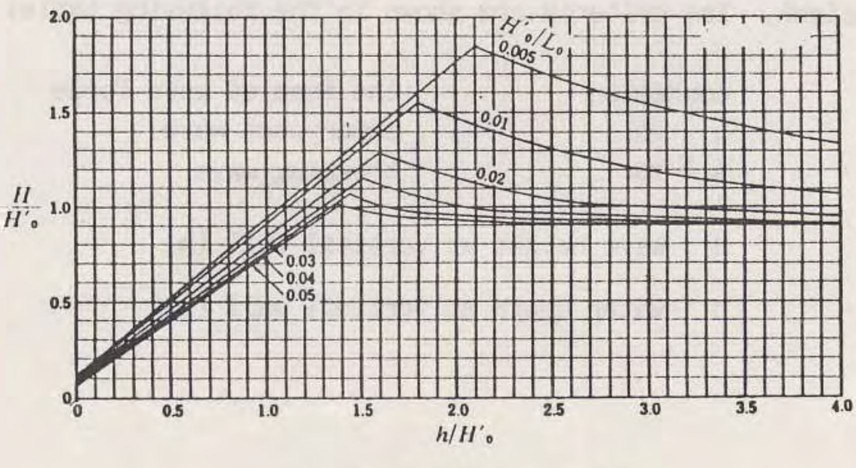
Fig. 6 (a) Seabed slope 1/10



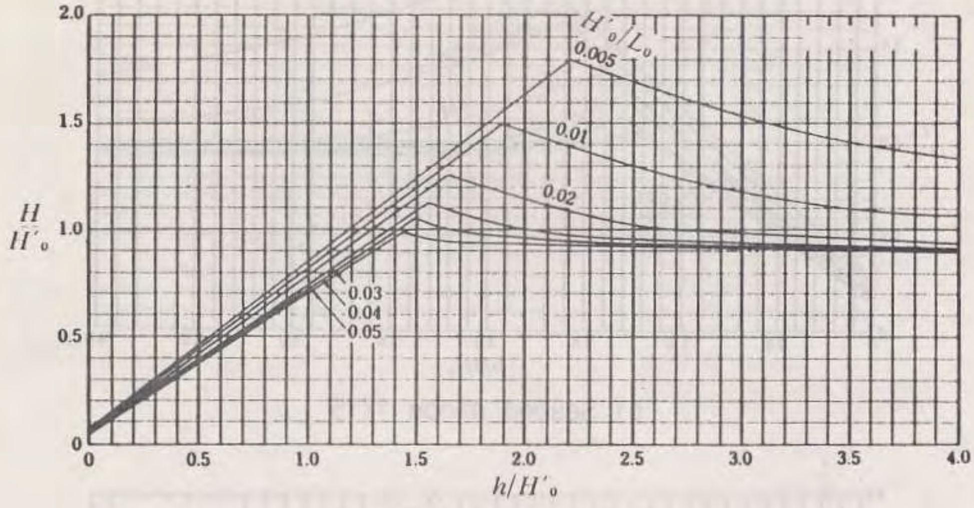
(b) Seabed slope 1/15



(c) Seabed slope 1/20



(d) Seabed slope 1/30



(e) Seabed slope 1/50

(4) The effect of wave force on a vertical wall

The wave force acting on structures, such as breakwaters, greatly varies depending upon whether the incident waves collide with a wall in the form of breaking waves or not. When the height of the incident waves is quite small compared to the water depth, the waves are reflected by the vertical wall surfaces, resulting in superposed waves. When the wave moves into shallow water, the waves break. The wave force on vertical walls differs greatly in each case. The water force, in each case, may be calculated by means of the ratio of water depth to wave height. The criteria are shown in the following table:

condition	the form of wave force
$h > 2H$	superposed wave
$h \leqq 2H$	breaking wave

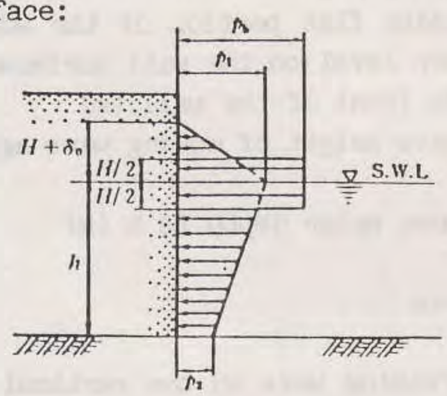
H : wave height at vertical wall (m)

h : water depth at vertical wall (m)

(i) Perfect superposed wave pressure

Generally, when the water-depth in front of a structure is twice the height of the approaching wave or higher, the wave does not break. Also, if there is no wave breaking projection on the front of the structure and it has a vertical wall which completely reflects the wave, then superposed waves will be created. The wave force of the superposed wave can be approximately calculated by means of the simplified Sainflou formulas below.

Where the peak of the wave is against the wall surface:



$$P_1 = (P_2 + \omega h)\left(\frac{H + So}{h + H + So}\right)$$

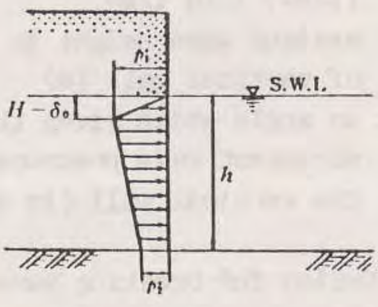
$$P_2 = \frac{\omega H}{\cos h\ 2\pi h/L}$$

$$So = \frac{\pi H^2}{L} \cos h\ \frac{2\pi h}{L}$$

Fig. 7 Wave pressure distribution at the point when the crest reaches the wall

Where the valley of the wave is against the wall surface:

(in this wave force direction against wave progressing direction)



$$P'_1 = \omega\ (H - So)$$

$$P'_2 = \frac{\omega H}{\cos h\ 2\pi h/L}$$

Fig. 8 Wave pressure distribution at the point when the traigh reaches the wall

In the formula shown above,

P_1: intensity of wave pressure at still water level when the peak of the wave is against the wall surface (t/m^2) P_2, P_2': intensity of wave pressure at the bottom of wall (t/m^2)

P_1': intensity of wave pressure below still water level ($H-\sigma o$) when the valley of the wave is against the wall surface (t/m^3)

ω : unit weight of sea water in t/m^3 ($1.03\ t/m^3$)

σo : height of middle flat portion of the wave to the still water level on the wall surface (m)

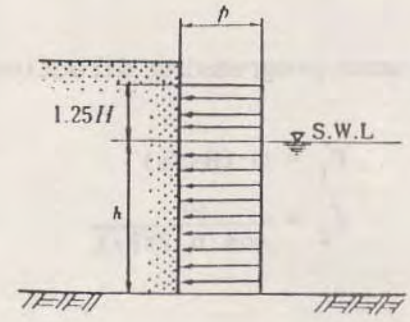
h : water depth in front of the wall (m)

H : significant wave height of moving wave against the wall (m)

L : wave length when water depth is h (m)

(ii) Breaking wave force

The force of a breaking wave on the vertical wall is considered to be distributed uniformly below a height of 1.25 H above the still water level, as shown in the following figure.



In the figure,

$P = 1.5\ W_0 H \cos^2\beta$

Wo : unit weight of sea-water (t/m^3) $1.03\ t/m^3$

H : maximum wave height in front of vertical wall (m)

β : an angle which gives the strongest wave pressure on the vertical wall (in degree)

Fig. 9 Wave pressure distribution for breaking wave

(5) General current features

(a) Types of current

When designing a module the wave current, tidal current, ocean current, the current movement in a bay and density current need to be taken into consideration. These currents greatly contribute to littoral drift and to the drag acting on the module. The features to be considered are the velocity and direction, their vertical distribution and periodicity.

Ocean, tidal, wind-driven and near-shore currents, all need to be observed and considered, when deciding on the design and direction of the module.

(b) Decisions on the stability of the module with regard to currents

The values for current velocity to be used when designing the module should be as follows.

For currents, such as ocean and tidal currents, measurements should be made for 15 or more days at the depth of the module. With the data, the maximum expected combined current velocity should be determined through harmonic analysis and by measuring the highest average movement over a 12-hour period, and then the greater of the above two current velocity values is multiplied by K (ordinary K = 1.2 to 1.6) to give the allowable velocity.

Where it is difficult to make current velocity measurements at the depth of the module, the velocity is calculated from the surface velocity or by consulting local fishermen.

Where waves and currents co-exist, the allowable velocity is determined through a combination of the velocity of the current and the water particle velocity of wave.

(6) Tidal range

(a) General points

Tides are a periodic rising and falling of the sea level caused by the gravitational attraction of the moon, sun and other astronomical bodies acting on the rotating earth. Tidal level is an important element in the determination of the transformation of waves and the calculation of wave force, which are required when determining the site for the module.

(b) Evaluation of tidal range

When designing a module, the following items must be surveyed with regard to the tidal level.

D.L (datum level): this is the standard height used in charts, and the tidal level in the tide table is based on this datum level. The datum level is determined by subtracting the sum of tide amplitudes from the four major tidal components (M_2, S_2, K_1, O_1) which are obtained by harmonic analysis of the tides. Therefore, this water level almost corresponds to the lowest low-water level.

HWL and LWL: high-water level is the average monthly highest water level occurring within five days of the new moon and the full moon, and the low-water level is the average monthly lowest water level.

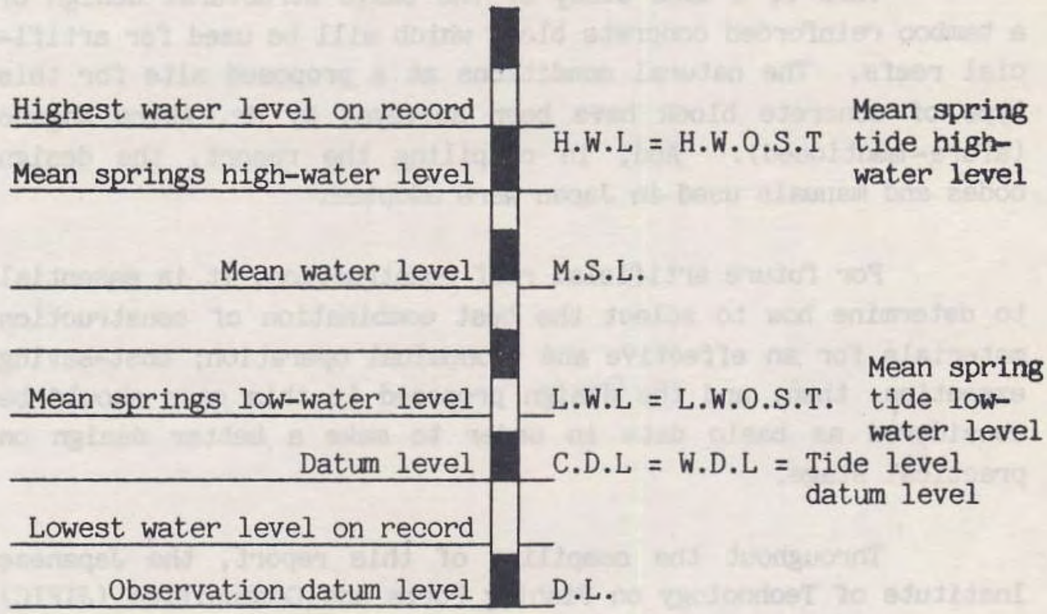


Fig. 10 Relationship between tidal levels

Appendix V

Case study of a bamboo reinforced concrete module

This is a case study of the basic structural design of a bamboo reinforced concrete block which will be used for artificial reefs. The natural conditions at a proposed site for this type of concrete block have been surveyed by Mr. Akira Nagano (afore-mentioned). And, in compiling the report, the design codes and manuals used in Japan were adopted.

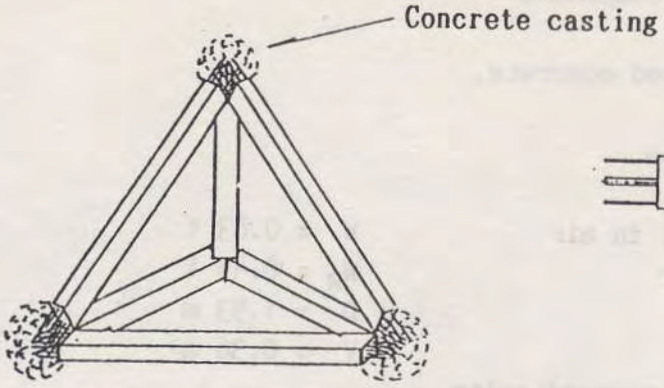
For future artificial reef construction, it is essential to determine how to select the best combination of construction materials for an effective and economical operation; cost-saving execution, then, and the design proposed in this case should be considered as basic data in order to make a better design on practical stage.

Throughout the compiling of this report, the Japanese Institute of Technology on Fishing Ports and Communities (JIFIC) has gratefully received the cooperation of the Fisheries Infrastructure Development Centre (a non-profit organization authorized by the Japanese Ministry of Agriculture, Forestry and Fisheries) which is an organization set up to study how to improve the civil engineering operations in fisheries infrastructures, such as fishing ports and artificial reefs.

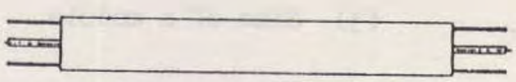
1. Basic Proposal

1.1 Sketches of the proposed module and its components

The proposed module consists of six precast concrete components of equal size, and it takes the form of a hollow regular tetrahedron (Fig. 1).



(1) Perspective of the module



(2) On-site precasting member

Fig. 1 Sketches of the proposed module and its precasting components

1.2 Natural conditions at a supposed site

Wave height	$H = 2.7$ m
Wave cycle	$T = 6.0$ sec
Wave length	$L = 48.4$ m
Tidal current	$U_z = 0.16$ m/sec
Seabed conditions	"Sand" or "sandy gravel"

1.3 Method of placing the modul setting on the seabed

Modules constructed on dry land should be carried by barge to the proposed site, lowered and placed on the seabed one by one.

1.4 Size of each component and a module

(1) Size of an individual component

Length	$l = 1.5$ m
Height	$h = 0.2$ m
Width	$b = 0.2$ m

(2) Materials of a component

Bamboo reinforced concrete.

(3) Size of a module

Ordinary weight in air	$W = 0.83$ t
Weight in water	$W_W = 0.46$ t
Height	$D = 1.53$ m
Net volume	$V = 0.36$ m^3
Projected area perpendicular to the current due to waves	$A = 1.96$ m^2

2. Calculation of the maximum velocity due to waves at the top of a block

The maximum velocity of the current, due to waves (horizontal component of waves' partial velocities) at the top part of a reef block set on the seabed, is calculated as follows:

$$u_m = \frac{\pi H}{T} \frac{\cosh 2\pi D/L}{\sinh 2\pi h/L}$$

$$= \frac{\pi \times 2.7}{6.0} \frac{\cosh 2\pi \times 1.53/48.4}{\sinh 2\pi \times 10.0/48.4} = 1.414 \times \frac{1.020}{1.695} = 0.85\text{m/sec}$$

2.2 Calculation of drag force and mass force

$$F_D = C_D A \frac{W_o}{2g} U_m^2 = 2.0 \times 1.96 \times \frac{1.03}{2 \times 9.8} \times (0.85)^2 = 0.15\text{t}$$

$$F_M = C_M V \frac{W_o}{g} \frac{2\pi}{T} u_m = 2.0 \times 0.36 \times \frac{1.03}{9.8} \times \frac{2 \times \pi}{6.0} \times 0.85 = 0.07\text{t}$$

$$\alpha = \frac{u_z}{u_m} = \frac{0.16}{0.85} = 0.19$$

$$\beta = \frac{F_m}{2F_v} = \frac{0.07}{2 \times 0.15} = 0.23$$

where drag force co-efficient $C_D = 2.0$
apparent mass force co-efficient $C_M = 2.0$

2.3 Calculation of the maximum fluid force

The maximum fluid force, F_{max}, is calculated by obtaining phase, θ, that would maximize the fluid force, F, when waves and a current exist together:

$$F = F_D(\sin\theta + u_z/u_m)^2 - F_M \cos\theta$$

A sin θ and a cos θ that would give the maximum value are given by the following equations:

$$S^4 + 2\alpha S^3 + (\alpha^2 + \beta^2 - 1)S^2 - 2\alpha S - \alpha^2 = 0$$
$$S^2 + C^2 = 1.0$$

Where $S = \sin\theta$, and $C = \cos\theta$, the real roots in the equations are the values satisfied.

Additionally, the following conditional equations should be satisfied:

$$C_i(S_i + \alpha) + \beta S_i = 0$$

$$1 - 2S_i^2 - \alpha S_i + \beta C_i < 0$$

As the results

$$S = 0.9823$$
$$C = -0.1873$$

then is the result that

$$\sin\theta = 0.9823$$
$$\cos\theta = -0.1973$$

is the phase of F_{max}:

$$F_{max} = 0.15 \times (0.9823 + 0.19)^2 - 0.07 \times (-0.1873) = 0.22 \text{ t}$$

3. Investigation into the stability of a module on the seabed

3.1 Stability with regard to sliding, under the supposed conditions

$$S_{FS} = \frac{W \cdot \mu\ (1 - W_o/\sigma_G)}{F} = \frac{\mu \cdot W_W}{F_{MAX}}$$

$$= \frac{0.6 \times 0.46}{0.22} = 1.25 > 1.20 \qquad \text{OK}$$

where

F_{max} : maximum fluid force

S_{FS} : safety factor (against sliding)

Wo : unit weight of sea-water

σ_G : unit weight of concrete

W : weight of a module on dry land

W_W : weight of a module in water

μ : friction co-efficient of a concrete module on sand or sandy gravel (seabed) (μ = 0.6)

3.2 Stability with regard to overturning, under the supposed conditions

$$S_{FS} = \frac{W\ (1 - w_o/\sigma_G)}{F} \times \frac{l_V}{l_A} = \frac{W_W}{F_{max}}\ \frac{l_V}{l_A}$$

$$= \frac{0.46 \times 0.54}{0.22 \times 0.51} = 2.21 > 1.20 \qquad \text{OK}$$

where

l_V : the shortest distance from the projected centre of gravity centre to a fringe of a fabricated block. (l_V = 0.54 m)

l_Λ : height to the centre of figure in orthogonal projection of a fabricated block on the vertical face perpendicular to the direction of the fluid force. (l_Λ = 0.51 m)

4. Calculation of impact force (on a module)

A module is subject to an impact force both when it is lowered into the sea and when it touches the seabed. It is assumed here that a block is usually lowered and not dropped off, and that its faces, not corners or fringes, touch the seabed first. Under this assumption, the impact forces calculated through the following procedure and converted into equivalent static forces.

4.1 When the lowering speed V = 0.5 m

$$L_\Lambda = \frac{g \cdot K}{3 \cdot w_o \cdot V} = \frac{9.8 \times 5000}{3 \times 1.03 \times 0.36} = 44048.90$$

$$M = g\left(\frac{\sigma_G}{w_o} - 1\right) - \frac{C_D \cdot A}{4\,V} v^2$$

$$= 9.8 \times \left(\frac{2.30}{1.03} - 1\right) - \frac{2.0 \times 1.96}{4 \times 0.36} \times (0.5)^2$$

$$= 11.42$$

$$N = \left(\frac{\sigma_G}{w_o} + C_{MA}\right)\frac{v^2}{2} = \left(\frac{2.30}{1.03} + 1.0\right) \times \frac{(0.5)^2}{2}$$

$$= 0.4$$

where

A : projected area perpendicular to the current due to waves

C_{MA}: additional mass co-efficient

C_D : drag force co-efficient

g : the acceleration of gravity (m/sec^2)

V : net volume of a block (m^3)

v : lowering speed module (m/sec)

σ_G : unit weight of concrete (t/m^3)

Wo : unit weight of sea-water (t/m^3)

ε : displacement value of the seabed (m)

The seabed displacement value is calculated as follows:

$M/L = 11.42/44048.90 = 2.59 \times 10^{-4}$

$N/L = 0.40/44048.90 = 0.09 \times 10^{-4}$

from a monograph recommended in the design guidelines

$\varepsilon = 2.4 \times 10^{-2}$ (m), K = 5000

then, the equivalent static load, q, is calculated as follows:

$$\delta_G = \frac{K}{V}\varepsilon^2 = \frac{5000}{0.36} \times (2.4 \times 10^{-2})^2 = 8.00 t/m^3$$

$$q = \delta_G \quad a = 8.00 \times (0.20)^2 = 0.32 \ t/m$$

$$k = \frac{\delta_G}{\sigma_G} = \frac{8.00}{2.30} = 3.48$$

where

a : area of the cross-section of each member (0.2 m x 0.2 m)

K : conversion co-efficient to static load

q : equivalent static load on a member

4.2 When the lowering speed v = 1.0 m/sec

From the afore-mentioned monograph

$\varepsilon = 3.5 \times 10^{-2}$(m), $K = 5000$,

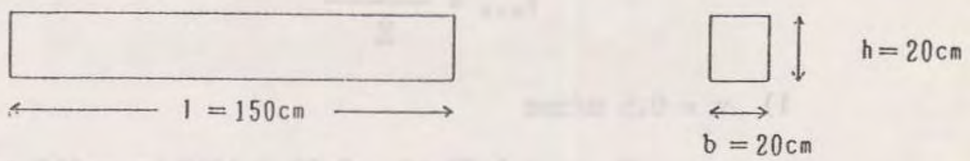
$$\delta_G = \frac{K}{V}\varepsilon^2 = \frac{5000}{0.36} \times (3.5 \times 10^{-2})^2 = 17.01 t/m^3$$

$$q = \delta_G \cdot a = 17.01 \times (0.20)^2 = 0.68 t/m$$

$$k = \frac{\delta_G}{\sigma_G} = \frac{17.01}{2.30} = 7.40$$

5. Calculation of stress on the component

5.1 Dimensions of the geometrical features of a component



(a) a side view (b) a cross-section

Fig. 2

$$I = \frac{bh^3}{12} = 13,300 cm^4$$

$$Z = \frac{bh^2}{6} = 1,330 cm^3$$

where

I : moment of inertia of cross-section about neutral axis

Z : section modulus about neutral axis

5.2 Calculation of maximum moment

Assumed as a simple beam of uniform loading

$$M_{max} = \frac{1}{8} q l^2$$

1) The case of v = 0.5 m

where uniform load q = 0.32 t/m

$$\therefore M_{max1} = 0.32 \times 1.50^2/8 = 0.09 \text{ tm}$$

2) The case of v = 1.0 m/sec

$$q = 0.68 \text{ t/m}$$
$$\therefore M_{max2} = 0.68 \times 1.50^2/8 = 0.19 \text{ tm}$$

5.3 Maximum tension and compression stress as a plain concrete beam

If the concrete component is made of plain concrete, the maximum tension or compression stress (σ_{max}) is calculated as follows:

$$\sigma_{max} = \frac{M_{max}}{Z}$$

1) v = 0.5 m/sec

$$M_{max1} = 0.09 \text{ tm} = 0.09 \times 1000 \text{ kg} \times 100 \text{ cm}$$
$$\therefore \sigma_{max1} = 9000/1330 = 6.8 \text{ kg/cm}^2$$

2) v = 1.0 m/sec

$$M_{max2} = 0.19 \text{ tm} = 19000 \text{ kgcm}$$
$$\therefore \sigma_{max2} = 19000/1330 = 14.3 \text{ kg/cm}^2$$

With regard to safety design, the allowable tension stress of a plain concrete beam should be equal to or less than 3 kg/cm^2, based on the Japanese concrete design standard of Japan, although test values are usually larger than the standard value.

Both σ_{max1} = 6.8 kg/cm^2 and σ_{max2} = 14.3 kg/cm^2 exceed the value 3 kg/cm^2, with the result that each member needs to have reinforced bars.

6. Arrangement of bamboo strips

6.1 Assumption of bamboo strip arrangement

The basic idea of the bamboo strip arrangement is shown in Fig. 3

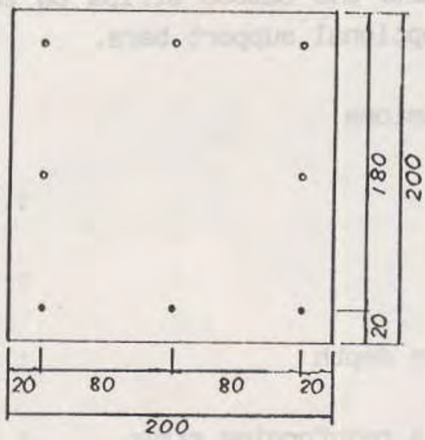


Fig. 3. Arrangement of assumed bamboo strips

In Fig. 3,

1) the upper five spots stop are the assumed centres of the bamboo strips, and the black ones (the bottom row) are assumed tension strips;

2) assumed cross-section of a bamboo strip is 1.5 cm^2 (thickness 0.6 mm x width 2.5 cm)

6.2 Design values

σ_{ba} = 300 kg/cm^2 (allowable bamboo strip stress)

σ_{ca} = 90 kg/cm^2 (allowable concrete compression stress)

τ_a = 4.5 kg/cm^2 (allowable concrete shear stress)

$n = E_b/E_c \doteqdot 1.0$ (E_b : modulus of elasticity in tension of bamboo

E_c : modulus of elasticity in tension of concrete

n : the modular ratio)

6.3 Calculation of bamboo strip stress

The bamboo strip stress is calculated on the assumption that the bamboo reinforced component is a singly reinforced rectangular beam, and the bamboo strips on the compression side are considered as optional support bars.

Beam dimensions

width	: $b = 20$ cm
height	: $h = 20$ cm
effective depth	: $d = 18$ cm
area of a reinforcing strip	: $a_b = 1.5$ cm^2
gross area of reinforcing strips	: $A_b = a_b \times 3$ strips $= 4.5$ cm^2

$$p = \frac{A_b}{bd} = \frac{4.5}{20 \times 18} = 0.0125$$

$$k = \sqrt{2np + n^2p^2} - np$$

$$= \sqrt{2 \times 1.0 \times 0.0125 + 1.0^2 \times 0.0125^2} - 1.0 \times 0.0125$$

$$= 0.1586 - 0.0125$$

$$\fallingdotseq 0.146$$

$$j = 1 - k/3 = 0.951$$

from the above values

$$\sigma_c = \frac{2M}{kjbd^2}$$

$$\sigma_b = \frac{M}{A_b jd}$$

$$\tau_c = \frac{S}{bjd}$$

The results of the calculations are shown in the following table.

Table 1.

case	v(m/sec)	q (t/m)	M_{max}(tm/m)	S (t/m)	σ_c(kg/cm²)	σ_b(kg/cm²)	τ_c(kg/cm²)	
1	0.5	0.32	0.09	0.24	20.0	116.8	0.70	OK
2	1.0	0.68	0.19	0.51	42.2	246.7	1.49	OK

The results of the calculations are shown in Table 1, so that the assumed arrangement of the reinforcing strips satisfies the conditions of the design code.

6.4 Bond stress of bamboo strips

The maximum values of bond stress in laboratories are reported to be from 2 kg/cm² to 11 kg/cm² depending on the type of bamboo. The following calculation shows that the bond stress is sufficiently safe.

$$S = q \cdot l \cdot 1/2$$

$$= 0.68\text{t/m} \times 1.5\text{m} \times 1/2 = 0.51\text{t}$$

$$= 510\text{kg}$$

$$U = 3\ (2\ b_t + 2b_w)$$

$$= 3 \times (2 \times 0.6\text{cm} + 2 \times 2.5\text{cm})$$

$$= 18.6\text{cm}$$

$$\tau_b = \frac{S}{U \cdot j \cdot d}$$

$$= \frac{510\text{kg}}{18.6\text{cm} \times 0.951 \times 18\text{cm}}$$

$$= 1.6\text{kg/cm}^2$$

where

b_t : thickness of a bamboo strip

b_w : width of a bamboo strip

d : effective depth

l : length of a member

q : equivalent static load on a member

S : maximum shear force on a member

U : total peripheral length of bamboo strips

τ_b : bond stress of bamboo strips

6.5 Arrangement of auxiliary bamboo strips

The main flexural bars should be placed exactly, so that auxiliary strips as stirrups are required. (Fig. 4)

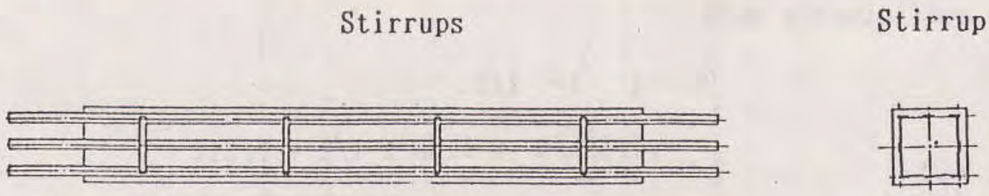


Fig. 4. Arrangement of stirrups

Stirrups arranged at proper intervals function as effective reinforcing bars, preventing the occurrence of diagonal cracks caused by shear stress. In this case, the calculated shear stresses, compared with the allowable shear strength (4.5 kg/cm^2) of the code in Japan, are small enough for stirrups not to be required.

6.6 Hooks at the ends of strips

At an actual stage, it is recommended to have hooks on both sides of the reinforcing bamboo strips, similar to those on steel bars (Fig. 5) in order to provide special anchorage at each corner where the ends of the three members are jointed together, as shown in Fig. 6. Because a fabricated block is usually hooked to a rope at a jointed corner and lifted for transportation.

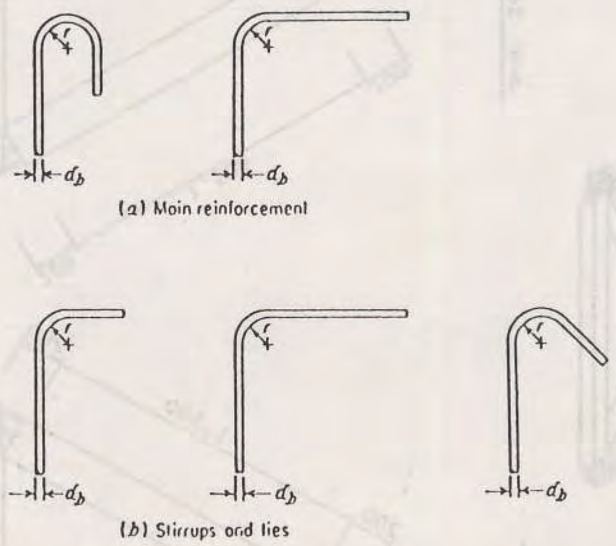


Fig. 5. Examples of steel bar hooks

6.7 Arrangement of bamboo strips

The arrangement of bamboo strips, as a result of the above-mentioned calculations, is shown in Figs. 7 & 8.

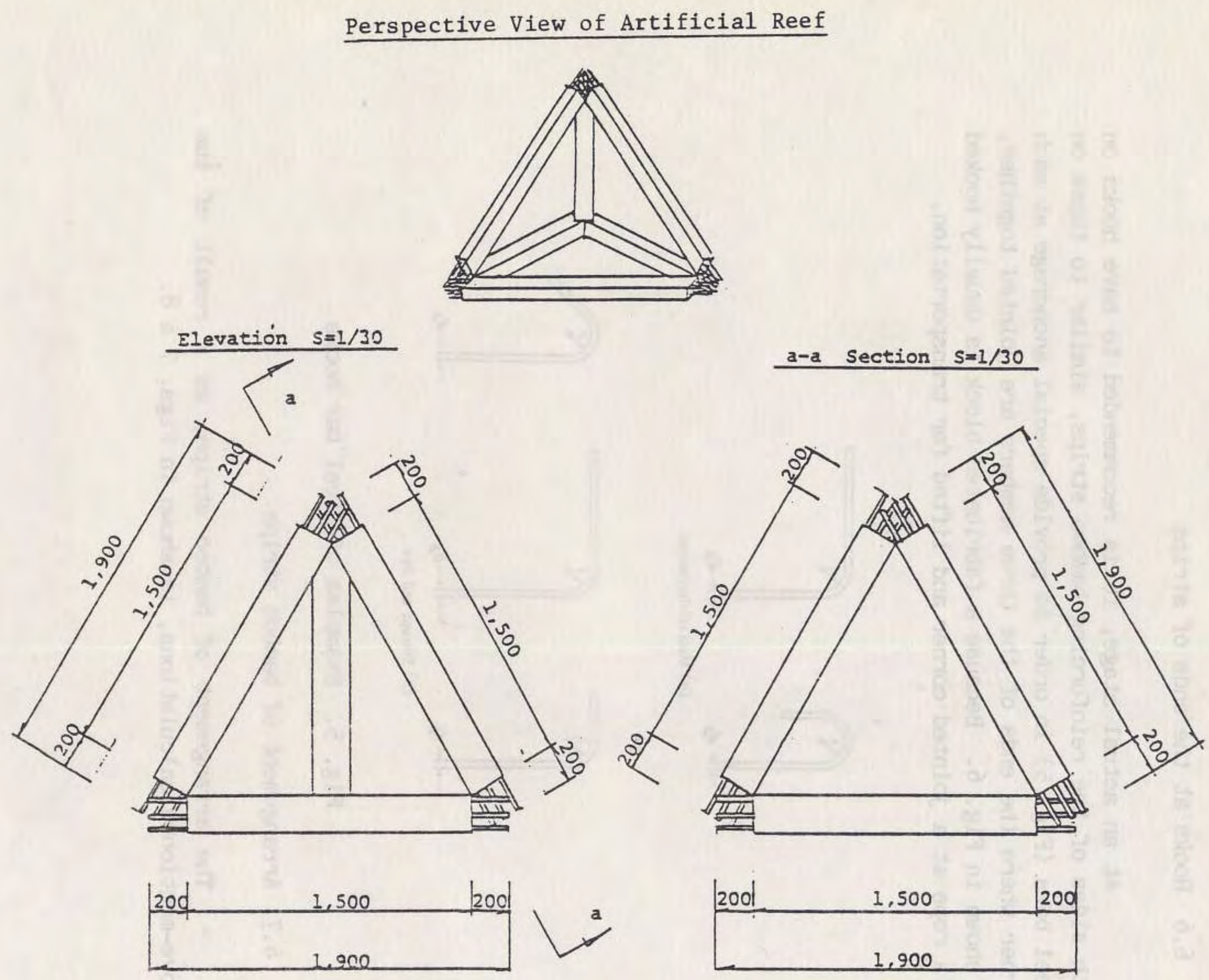


Fig. 6 Perspective of the artificial reef block

Member Section of the Artificial Reef S=1/10

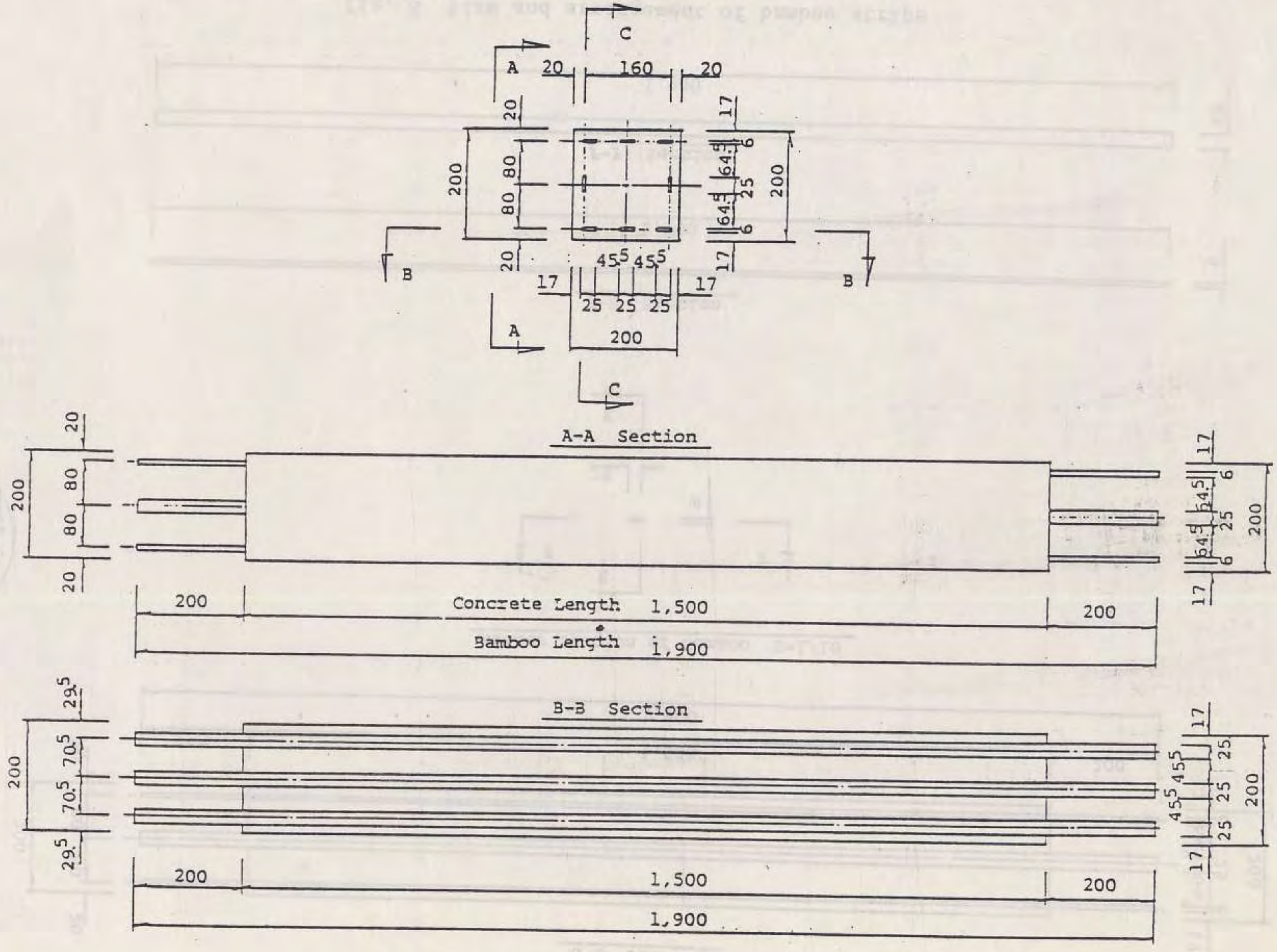


Fig. 7 Arrangement of bamboo strips

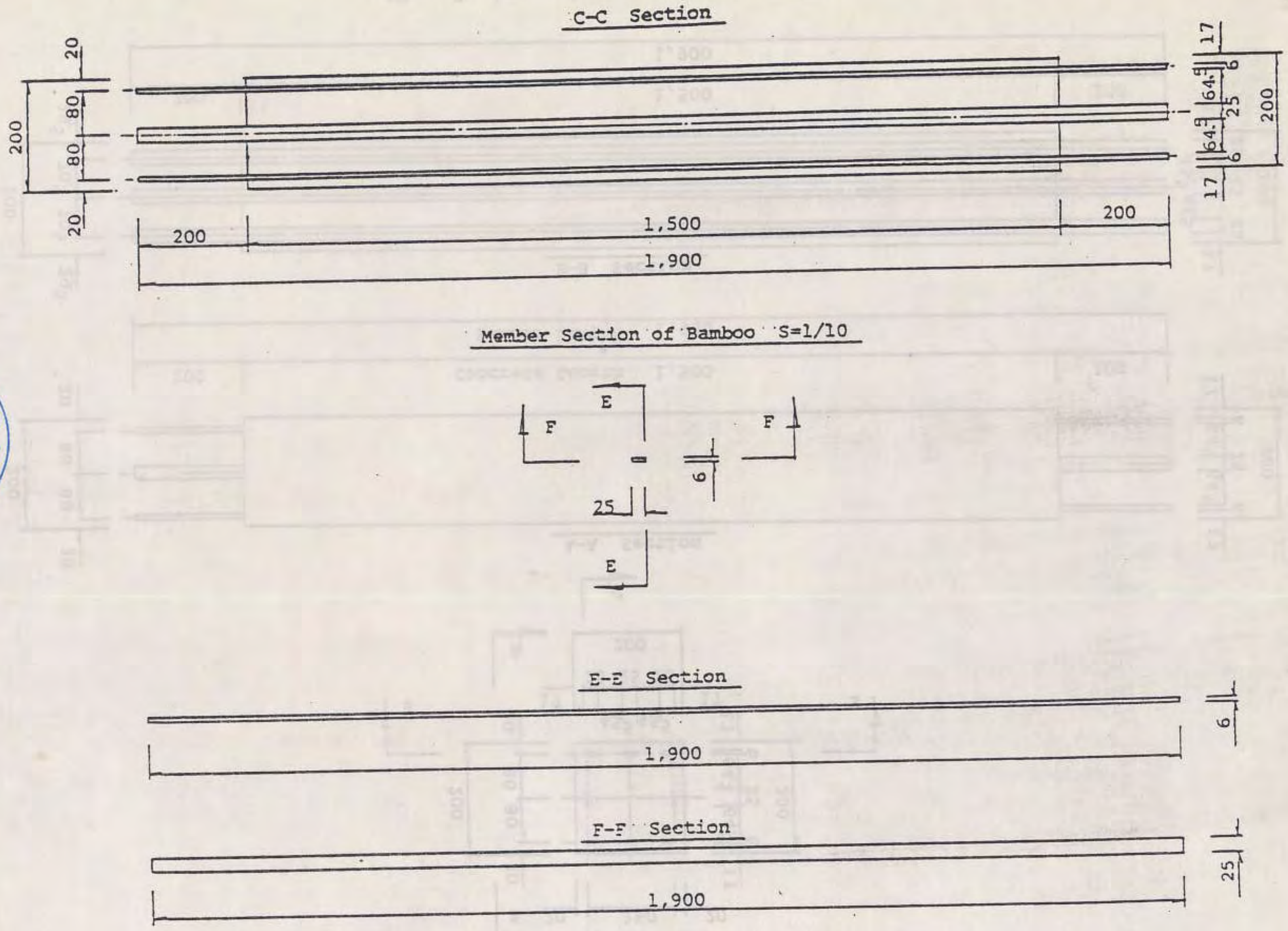


Fig. 8 Size and arrangement of bamboo strips