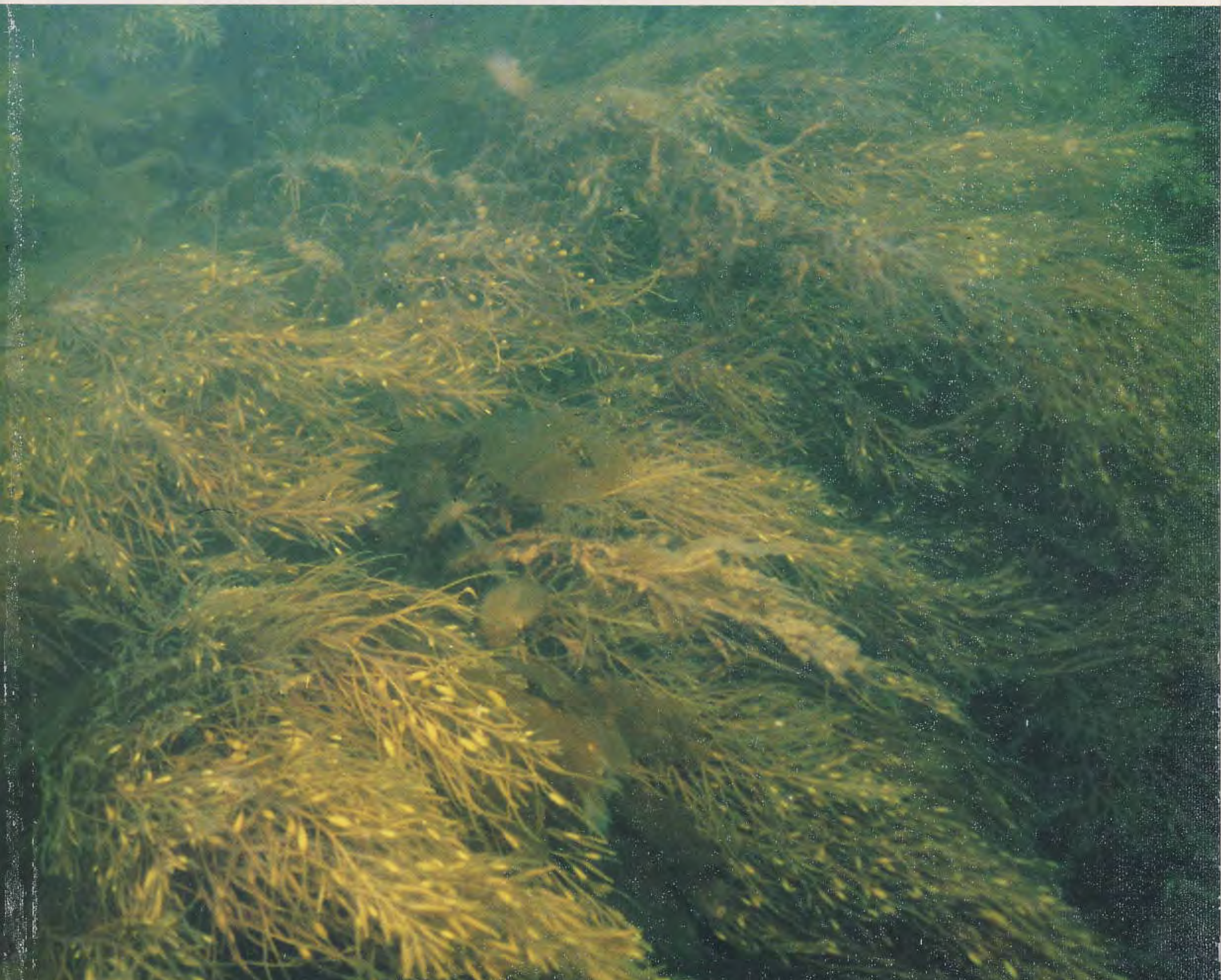
SOUTHEAST ASIAN FISHERIES DEVELOPMENT CENTER
TRAINING DEPARTMENT
in collaboration with
Department of Fisheries
Ministry of Agriculture and Cooperatives

TD/RES/29

July 1991

THE ARTIFICIAL REEFS EXPERIMENT IN THAILAND



The Artificial Reefs Experiment in Thailand

by

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Preface

In the last two decades, many countries throughout the world have declared their own Exclusive Economic Zones (EEZ), usually extending two hundred nautical miles seaward. However, in the case of some neighbouring countries, agreement has yet to be reached on their common nautical border, and thus ownership of territorial waters for inclusion in their EEZs remains in dispute.

During this time, the world-wide situation with regard to fishing gear and fishing technology has improved considerably. This modernization however, has brought about a rapid decline in marine fishery resources, due to the increase and greater efficiency of fishing activities. As a result, the demand for more advanced technology to enhance and increase marine resources has grown strongly and rapidly, particularly for those regions where the boundaries of EEZs are still unresolved.

This report contains the details, results and recommendations of an artificial reef experiment, which was performed as a contribution to advancing marine resources technology. It was conducted by a joint team comprising the Department of Fisheries (DOF), Thailand, and SEAFDEC.

INTRODUCTION

A joint survey team was formed in 1987 at the request of the Department of Fisheries (DOF), Thailand, to evaluate an artificial reef project in Thailand. The multidisciplinary survey was completed in 1989, and a report entitled "MULTIDISCIPLINARY EVALUATION OF THE ARTIFICIAL REEF PROJECTS" was published. In 1990 a "TECHNICAL MANUAL FOR RESOURCE ENHANCEMENT" was issued to assist SEAFDEC member countries in improving artificial reefs from a fishery engineering viewpoint.

As the second step of the project, a new experiment was conducted to ensure the practicality and effectiveness of the new modules recommended by the original team in the above reports. The new experiment was co-funded by the Japan International Cooperation Agency and implemented off Ban Phe, Rayong Province, Thailand, beginning in January 1990. The survey was successfully completed in February 1991. This resulting report is intended as a valuable aid in the design of suitable artificial reef modules for the region.

Acknowledgements

The team leader and staff wish to express their appreciation to the DOF, Thailand for granting permission for the project and for the assistance received.

The team leader would also like to express his appreciation to the staff who implemented the survey on time during his absence.

Finally, the team leader and SEAFDEC/TD Research staff are indebted to the former SEAFDEC Secretary General Dr. Veravat Hongskul, who approved the original plan of the experiment, and to the present Secretary General, Dr. Thiraphan Bhukaswan, who agreed to this publication.

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1. Objectives

The actual modules recommended in the report issued by SEAFDEC (TD/RES/22 1989) were constructed and installed in the Gulf of Thailand mainly to verify their physical stability from a hydrodynamic point of view, which is described in the recommendations section. Also some biological surveys were carried out.

The verification was concluded by means of a follow-up survey for one year after the installation.

2. Project team members

The experiment was implemented by a joint team composed of SEAFDEC personnel and members of the Marine Fisheries Division (MFD), Eastern Marine Fisheries Development Center (EMDEC), Thailand.

The team members and their duties were as follows:

Team leader
Mr. W. Fujisawa
(SEAFDEC)

- Preliminary survey: Mr. Santee Sungthong (EMDEC)
  Mr. Supachai Ananpongsuk (SEAFDEC)
- Construction & installation work: Taisei Thailand Co., Ltd. (Italtai Co., Ltd.)
- Transplantation of sargassum: Dr. V. Srimanobhas
  Mr. S. Ananpongsuk
- Follow-up survey: Mr. A. Munprasit (SEAFDEC)
  Mr. S. Ananpongsuk (SEAFDEC)
  Mr. S. Sae-Ung (Ex. SEAFDEC*)
  Miss S. Sawatpeera (Institute of Marine Science, Bangsae)
  Mr. S. Sungthong (EMDEC)

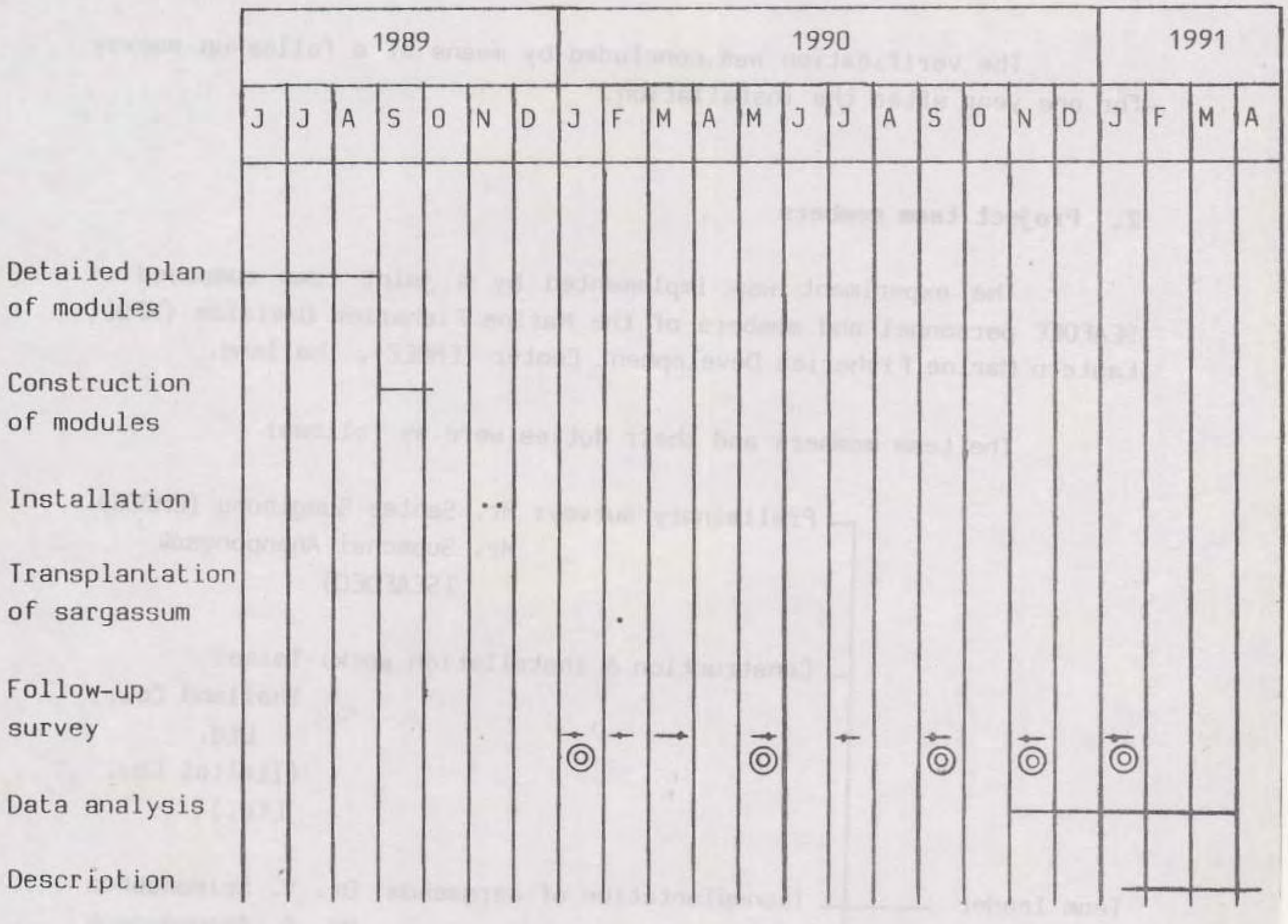
Coordinator
Dr. V. Srimanobhas
(Ex.-MFD*)

Remark: Ex. - at June 1991)

3. Outline of the experiment

3.1 Records

The experiments were implemented as follows:



◎ Analysis of collected sessile organisms

3.2 Choice of site

Generally, the slope of the sea-bed in the Gulf of Thailand is very gentle and flat. For instance, off Ban Phe in Rayong Province, the gradient is less than 1/1000, which can be seen on the chart. However, the sea-bed off the south west part of Samet Island, located near Ban Phe, is a little complicated compared with other areas (Fig. 1). So, at first, the team leader had the intention of using this area for the proposed site because it was a small-scale experiment.

On the other hand, the Department of Fisheries (DOF), Thailand, is carrying out a fish-farming project between Ban Phe and Samet Island. To support this project, the team leader agreed, at the request of the DOF, to install the modules at that site, although it was not ideal.

The exact location of the site and the points of installation are shown in Fig. 2.

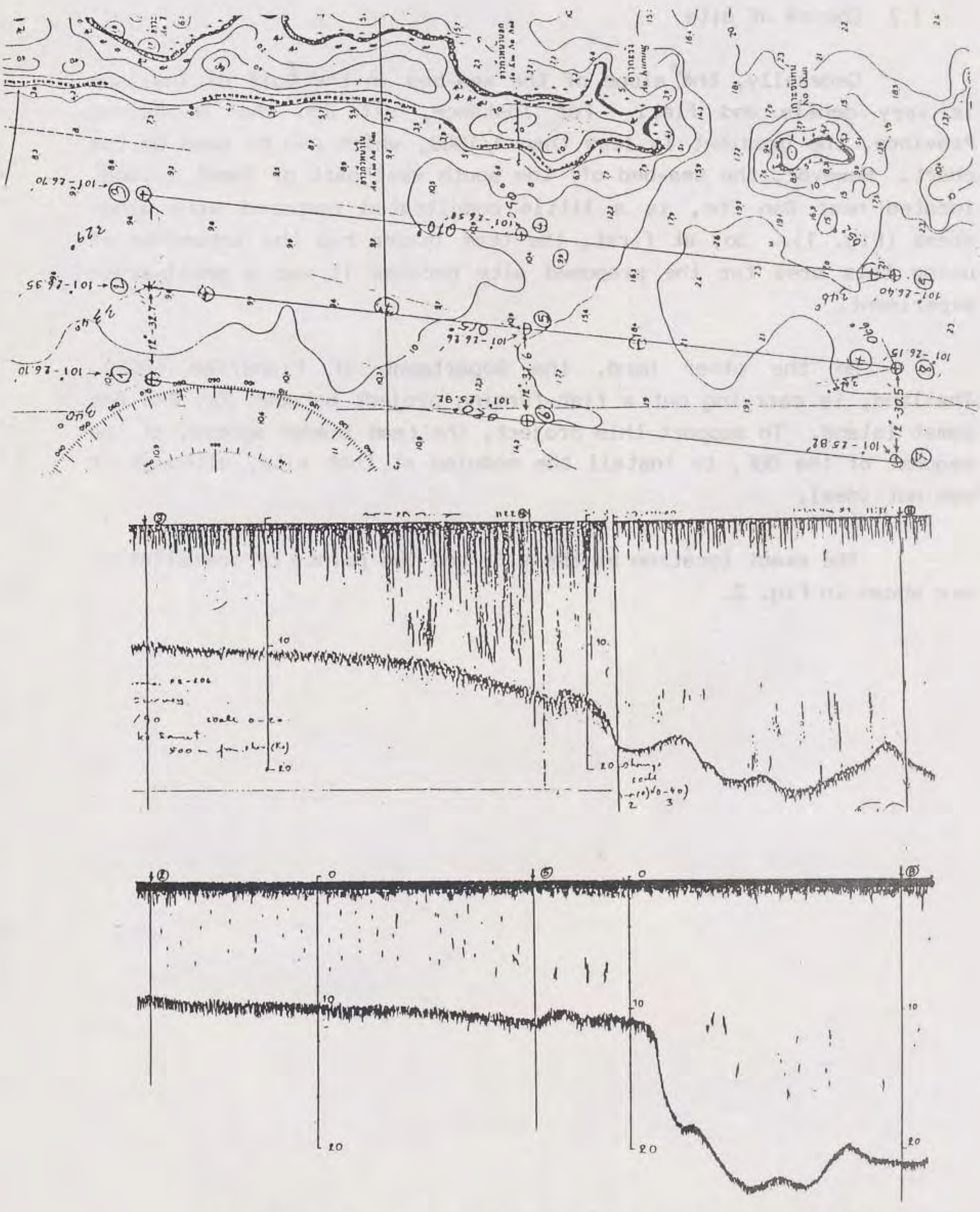


Fig. 1-a The echo-sounder record at the proposed site.

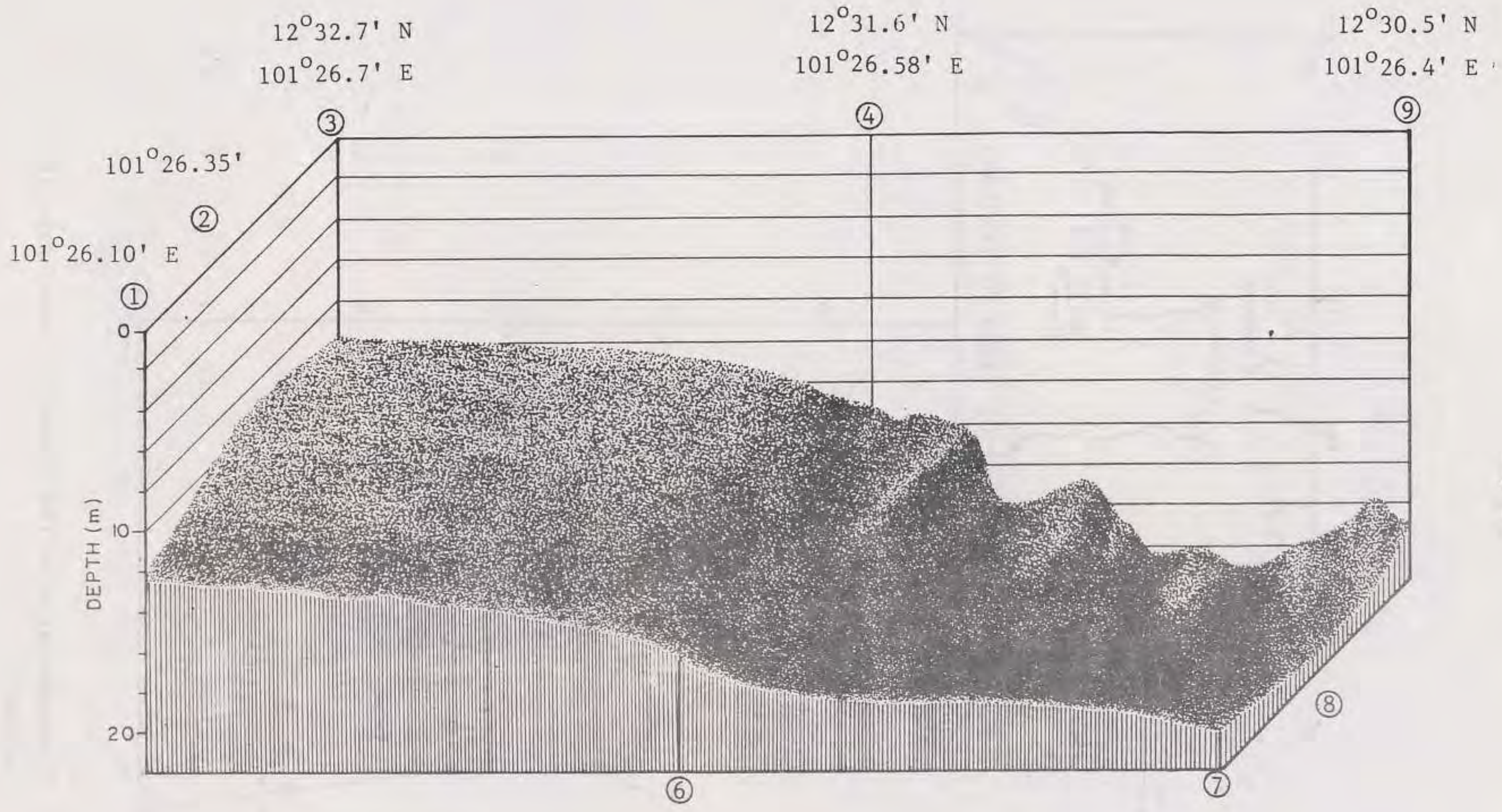


Fig. 1-b Description of the underwater topography at the proposed site.

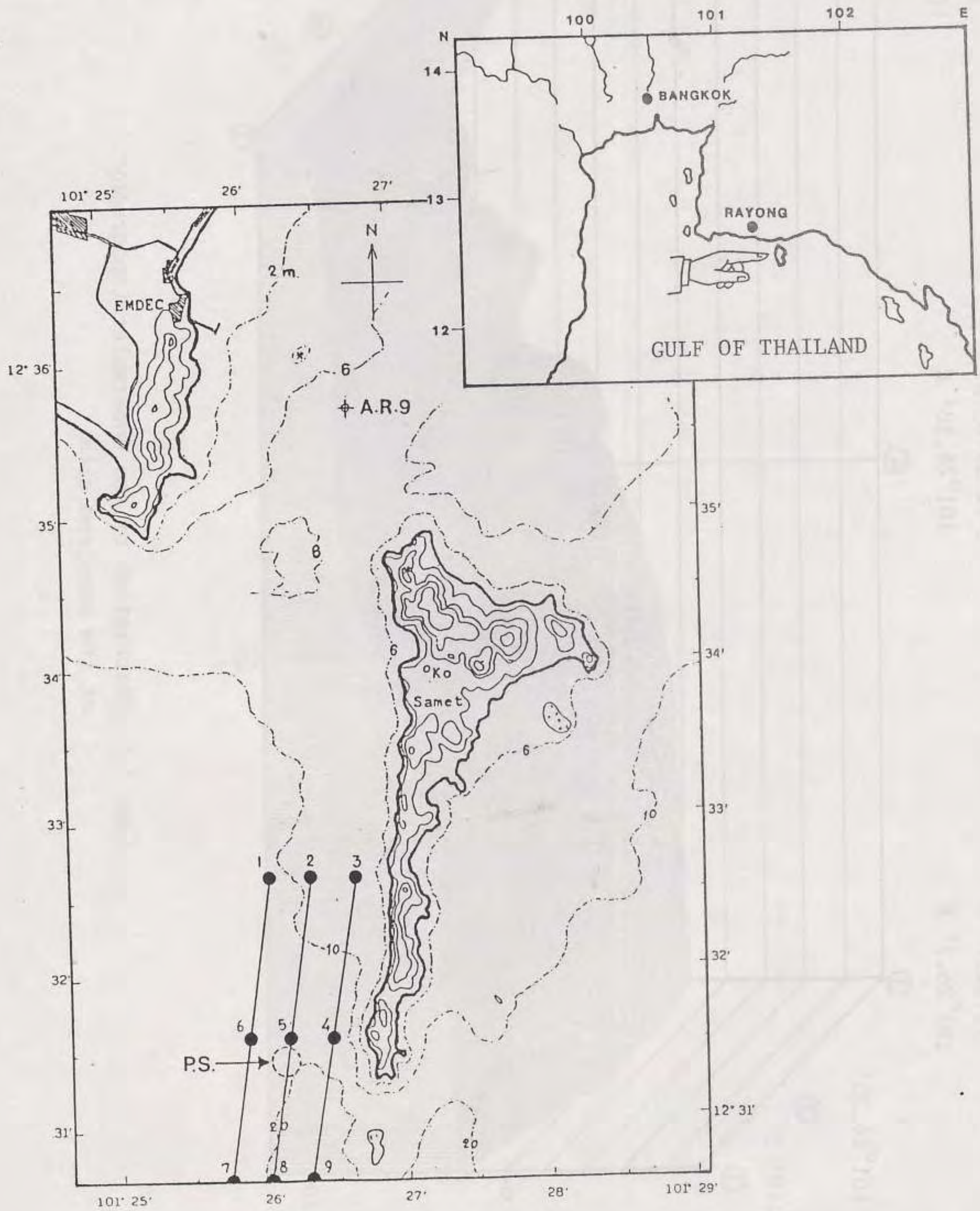


Fig. 2 Experimental site (AR 9) and proposed site (P.S.) (actual).

4. Results

4.1 Construction of the modules

(1) Shape

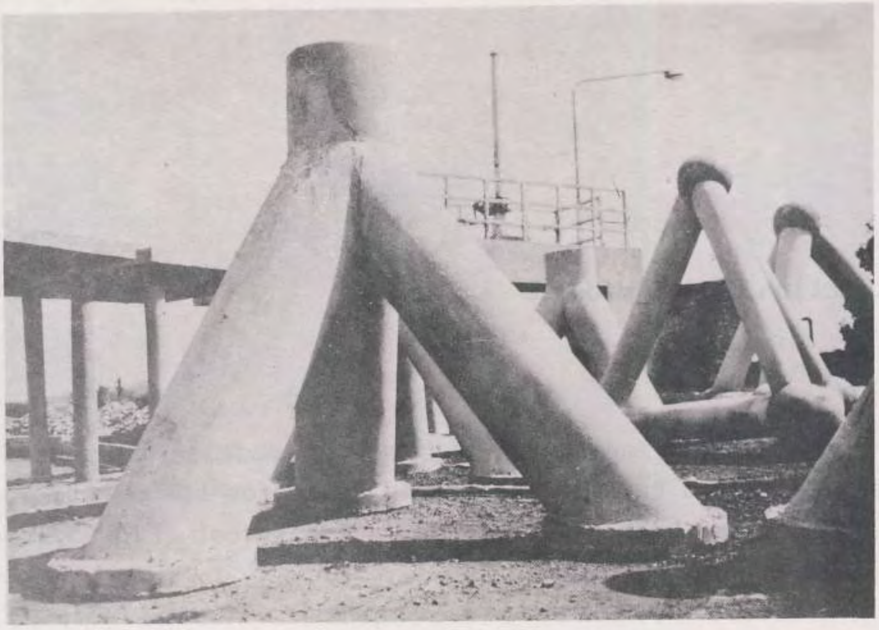
For the experiment, three types of modules were used: the triangular pyramid and ball-joint pyramid (both for the artificial reef) and the cubic algae base type for the marine forest (Fig. 3).

The sea-bed at the site is composed of sand (Table 1). Generally, if certain kinds of structures are placed on sand, corrosion will occur around them, due to the wave action and the force of the current. The result is that the structures overturn or move. It is almost impossible to predict when this will occur after installation because of the lack of baseline data. However, if this period can be extended for as long as possible, the installed modules should work effectively. Long-lasting and durable modules, therefore, neither overturn nor move, which results in economic efficiency.

To reduce the rate of corrosion, the part that comes into contact with the sea-bed or floor should be minimized or attached to a plate. Consequently, in this experiment, two types were used to enable comparison of the data to see which type was more effective.

The shape of the base for the marine forest construction was similar to that used in work which is being carried out in Japan. Sea-algae can grow up only the rock surface which is exposed to sunlight. In the same way, with the module, it is hoped that the algae will only grow on the surface of the module.

In order to keep the module stable against the wave action, a lower plate is attached. There is a two-meter space between the two plates which could be reduced, depending the hydrodynamic features of the area.



Triangular module

Ball-joint module

Base for sea algae

Fig. 3 Shape of module used.

Table 1. Statistical Analysis of Sediment near the site.

St. No.	Rayong	Medium grain size (mm)	Grade of particle size	Sorting Coef. (s)	Degree of sorting	COD mg/g
1.	1st	0.51	coarse sand	1.670	well-sorted	0.38
	2nd	0.43	medium sand	2.710	moderately	1.66
	3rd	0.66	coarse sand	1.960	well-sorted	0.67
	average	0.53	coarse sand			0.90
2.	1st	0.38	medium sand	3.960	moderately	1.80
	2nd	0.42	medium sand	2.898	moderately	4.16
	3rd	0.86	coarse sand	2.360	well-sorted	2.00
	average	0.55	coarse sand			2.65
3.	1st	0.31	medium sand	2.370	well-sorted	0.95
	2nd	0.68	coarse sand	2.369	well-sorted	0.69
	3rd	0.22	medium sand	3.740	moderately	5.35
	average	0.40	medium sand			2.33
4.	1st	0.08	fine sand	2.230	well-sorted	2.34
	2nd	0.52	coarse sand	2.250	well-sorted	3.51
	3rd	0.09	fine sand	1.950	well-sorted	2.16
	average	0.23	fine sand			2.67
5.	1st	0.45	medium sand	2.260	well-sorted	1.35
	2nd	0.27	medium sand	2.638	moderately	3.46
	3rd	0.32	medium sand	2.480	well-sorted	2.66
	average	0.34	medium sand			2.49
6.	1st	0.90	medium sand	4.670	poorly-sorted	1.96
	2nd	0.38	medium sand	3.162	moderately	1.79
	3rd	0.64	coarse sand	4.400	poorly-sorted	2.96
	average	0.64	coarse sand			2.23

(Source: Multidisciplinary Evaluation of the Articial Reef Projects in Thailand: a Report SEAFDEC TD/RES/22 1989).

(2) Materials used for the module

The three types of modules were made of bamboo-reinforced concrete. The reason for using bamboo for reinforcement was not only that bamboo is easy to gather but also because it is inexpensive, compared with steel in this region. The bamboo in each module was arranged in a similar way as the steel shown in Fig. 4.

After the construction and installation of the modules, it is better to use fewer bamboo-bars because they are easy to manufacture and their strength is not reduced. For instance, dividing one piece of bamboo into two parts and covering them with concrete makes manufacturing easier. However, attention should be paid to the compatibility of both the bamboo and the concrete (refer to Appendix 1). In particular, the bamboo-bars should be bound with rope at intervals or cuts should be made in the bamboo.

(3) Stability of the module

The stability of the three types depends on external force, i.e. wave action and the force of the current, which have been calculated as follows:

$$F = C_D . A . W_o \frac{(U_o + U_m)^2}{2q} \qquad Um = \frac{\pi H}{T} \frac{\cos h \frac{2\pi D}{L}}{\sin h \frac{2\pi h}{L}}$$

Terms for wave conditions and current:

Wave height (H) : 2.9 m.
Frequency (T) : 6.6 sec.
Wave length (L) : 68 m.
Current velocity (U) : 0.4 m/sec.

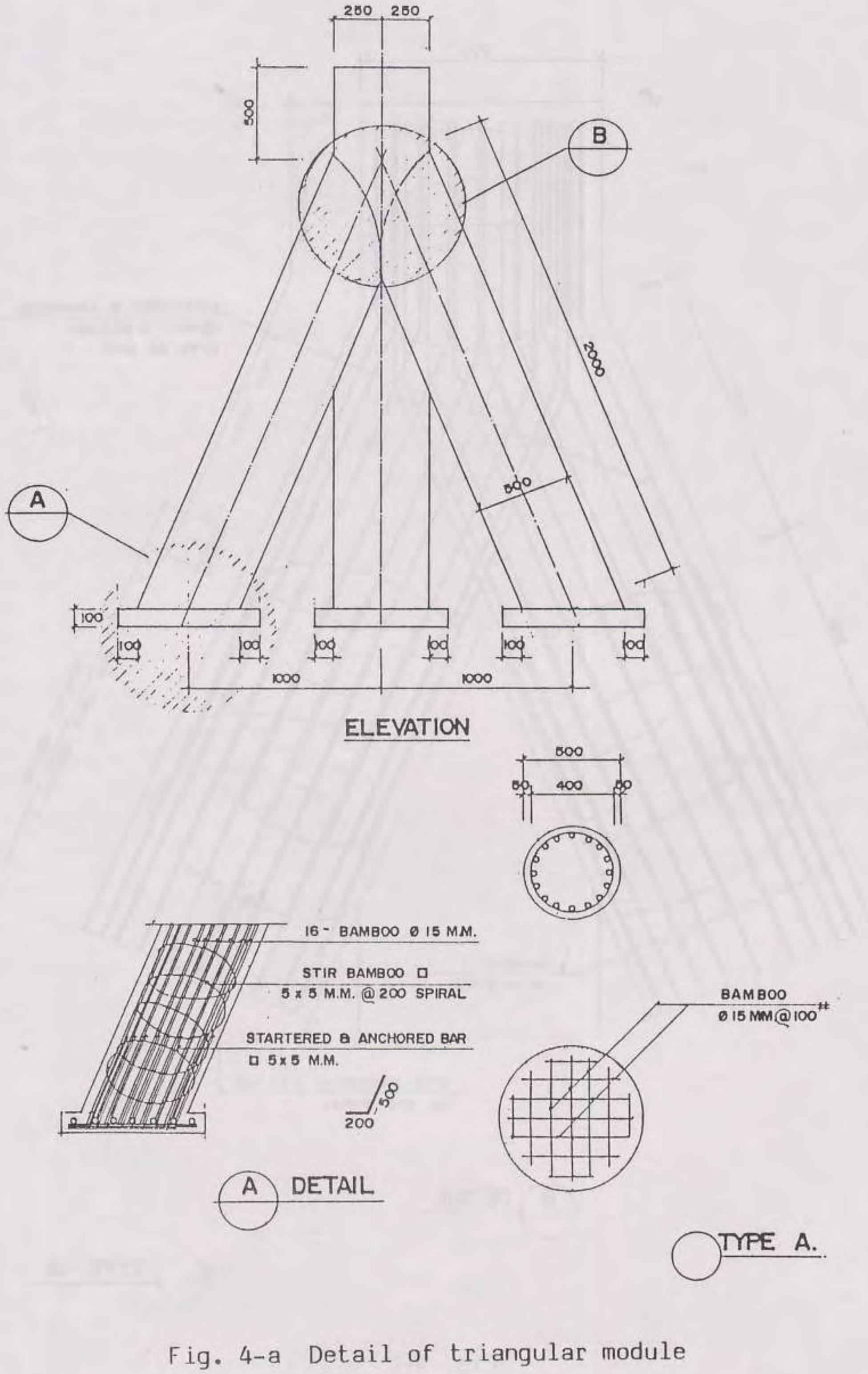


Fig. 4-a Detail of triangular module

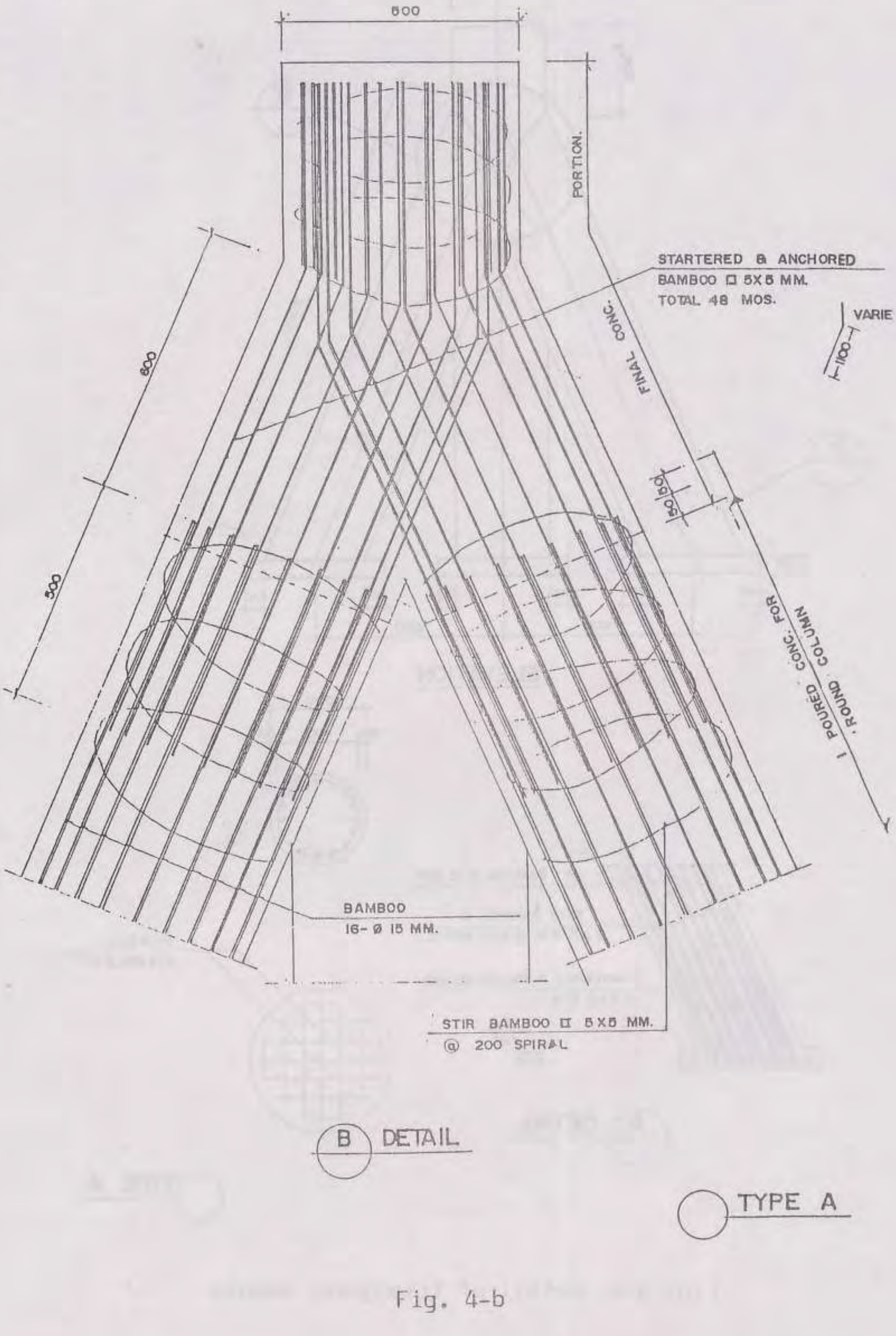

600
PORTION.
FINAL CONC.
STARTERED & ANCHORED
BAMBOO ☐ 5X5 MM.
TOTAL 48 MOS.
VARIE
1100
600
500
50
50
POURED CONC. FOR
ROUND COLUMN
BAMBOO
16- Ø 15 MM.
STIR BAMBOO ☐ 5X5 MM.
@ 200 SPIRAL
B DETAIL
TYPE A

Fig. 4-b

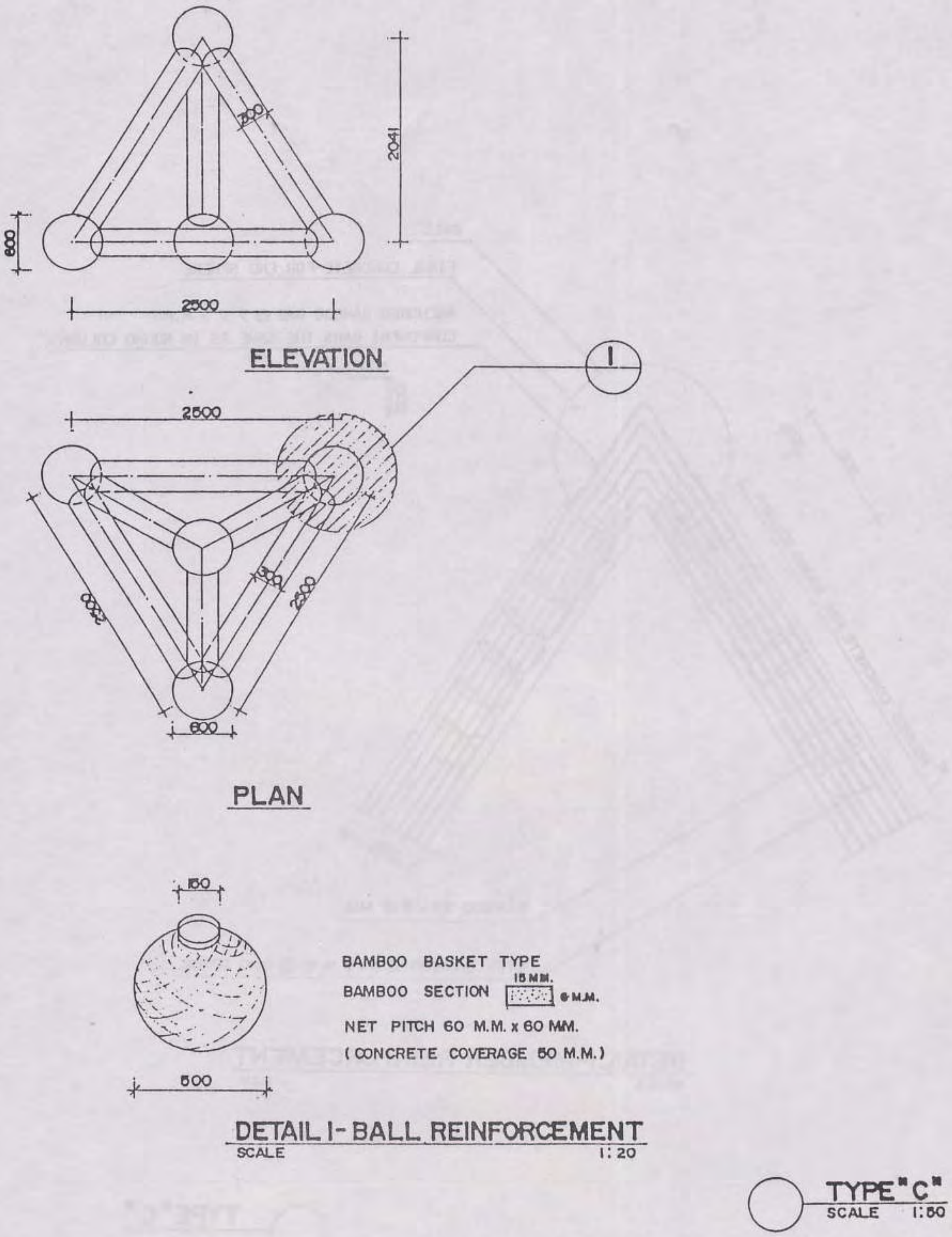


Fig. 4-c Detail of ball-joint module

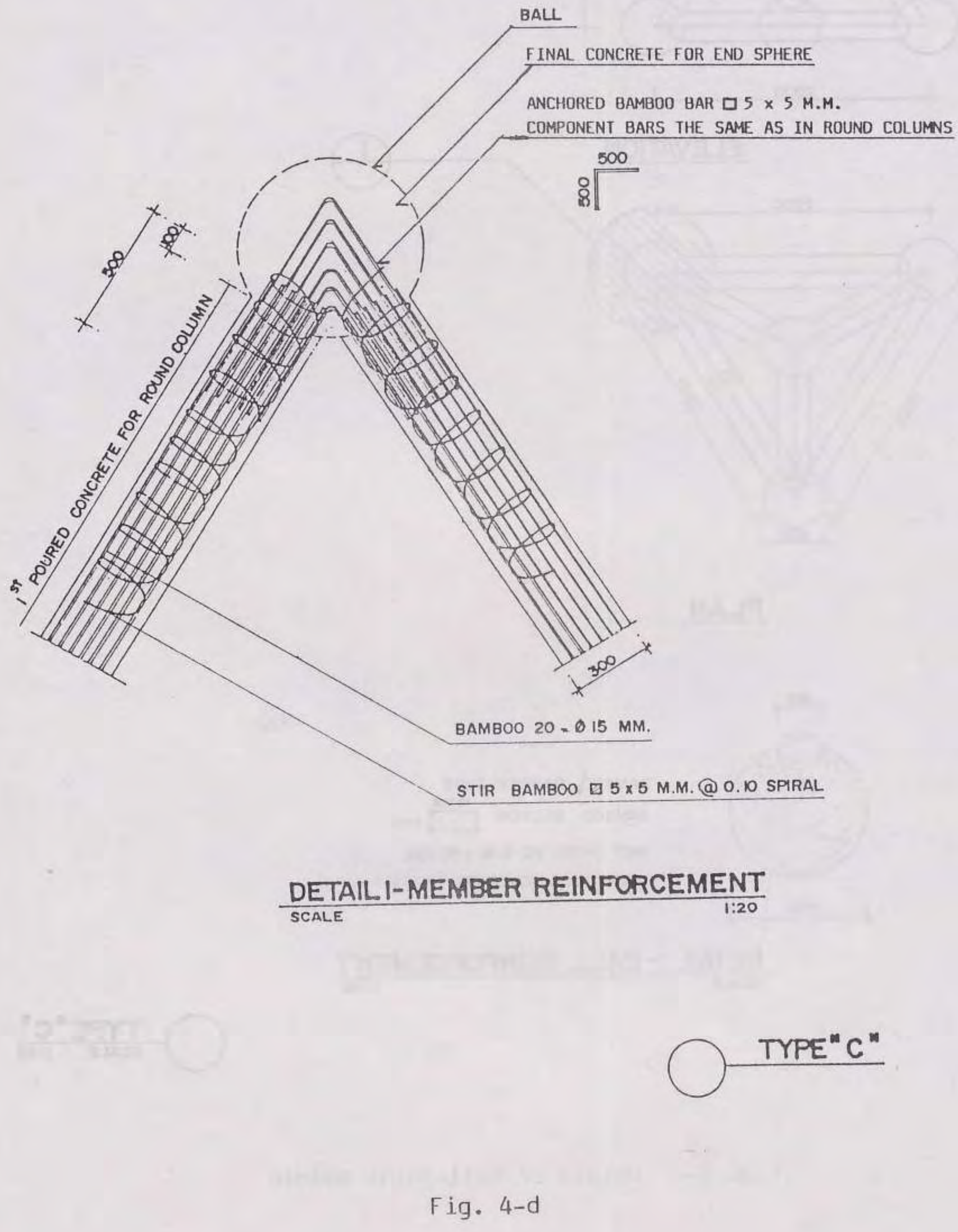

BALL
FINAL CONCRETE FOR END SPHERE
ANCHORED BAMBOO BAR □ 5 x 5 M.M.
COMPONENT BARS THE SAME AS IN ROUND COLUMNS
500
500
500
100
1st POURED CONCRETE FOR ROUND COLUMN
300
BAMBOO 20 - Ø 15 MM.
STIR BAMBOO □ 5 x 5 M.M. @ 0.10 SPIRAL
DETAIL I-MEMBER REINFORCEMENT
SCALE 1:20
TYPE "C"

Fig. 4-d

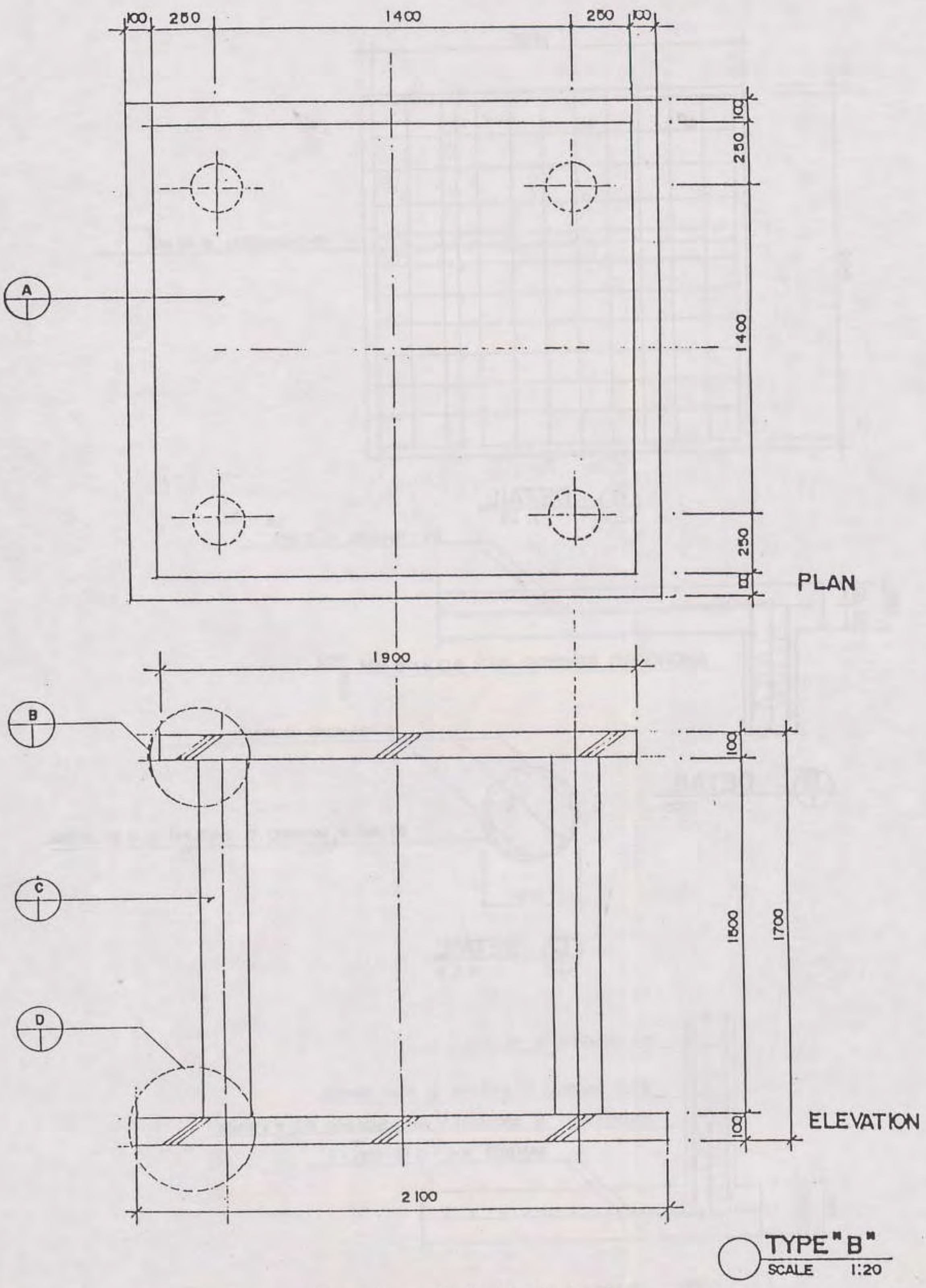


Fig. 4-e Detail of base

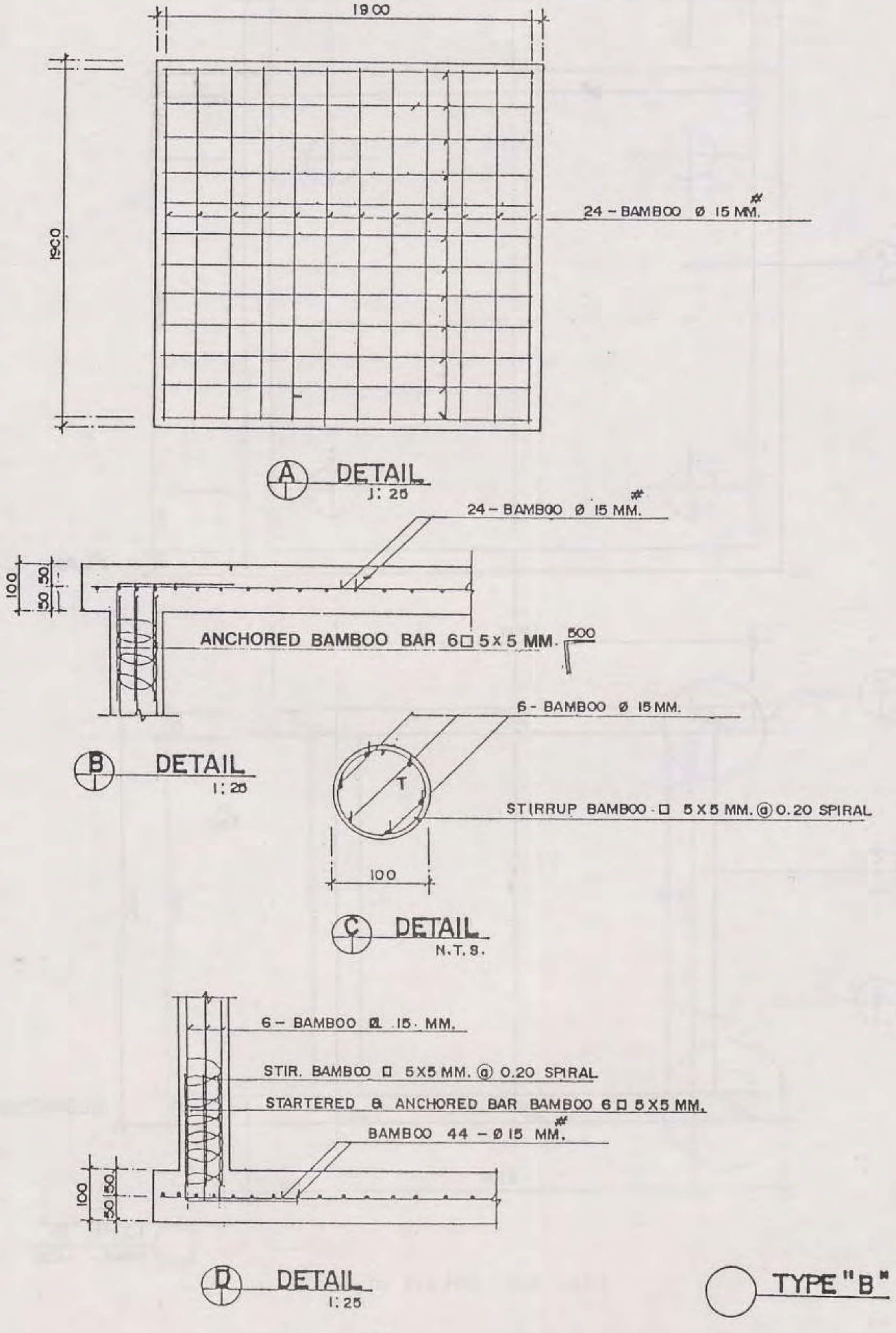

1900
1900
24 - BAMBOO Ø 15 MM.#
A DETAIL
1: 25
24 - BAMBOO Ø 15 MM.#
100
50
50
ANCHORED BAMBOO BAR 6□ 5 x 5 MM.
500
B DETAIL
1: 25
6 - BAMBOO Ø 15 MM.
T
STIRRUP BAMBOO □ 5 X 5 MM. @ 0.20 SPIRAL
100
C DETAIL
N.T.S.
6 - BAMBOO Ø 15 MM.
STIR. BAMBOO □ 5X5 MM. @ 0.20 SPIRAL
STARTERED & ANCHORED BAR BAMBOO 6 □ 5X5 MM.
BAMBOO 44 - Ø 15 MM.#
100
50
50
D DETAIL
1: 25
TYPE "B"

Fig. 4-f

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

W : weight of module (ton)

C_D : drag co-efficient

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

q : gravitational acceleration ($9.8\ m/sec^2$)

U_o : current velocity (m/sec)

U_m : velocity of water particles due to wave motion

D : height of module (m)

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

W_w : submerged weight of module
($W_w = W - F_o$; F_o : buoyancy, W : Weight of module)

S_1 : optimum slide resistance co-efficient, and figure 1.2 is based on the guidelines of the Fisheries Agency of Japan

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

l_G : distance from sea-bed to center of gravity

l_A : distance from the sides of the module to its centre

The calculations for each type of module are as follows:

1. Triangular module

$$W = \left\{ \left(\frac{0.5}{2}\right)^2 m^2 \times 3.14 \times 0.5\ m + \frac{0.65}{3} m\ (0.57^2 + 0.25 \times 0.57 + 0.25)^2\ m^2 + \frac{0.5}{2}^2 m^2 \times 3.14 \times 1.15\ m \times 3 + \left(\frac{0.57}{2}\right)^2 m^2 \times 3.14 \times 0.1\ m \times 3 \right\} \times 2.3^t/m^3 = 2.8^t$$

$$A = 0.5\ m \times 0.5\ m + \frac{(1.14 + 0.5)\ m \times 0.65\ m}{2} + 1.15\ m \times 0.5\ m \times 2 + 1.15\ m \times 0.5\ m \times 0.7 + 0.77\ m \times 0.1\ m \times 3 = 2.56\ m^2$$

$$U_m = \frac{3.14 \times 2.9}{6.6} \times \frac{\cos h\ \dfrac{2 \times 3.14 \times 2.3}{68}}{\sin h\ \dfrac{2 \times 3.14 \times 10}{68}} = 1.33$$

$$F = 1.0 \times 2.56 \times 1.03 \times \frac{(0.4 + 1.33)^2}{2 \times 9.8} = 0.4$$

$$W_w = 1.213 \times (2.3 - 0.03) = 1.54$$

$$S_1 = 1.2 < \frac{1.54 \times 0.6}{0.4} = 2.3$$

$$S_2 = 1.2 < \frac{1.54 \times 0.575}{0.4 \times 0.77} = 2.9$$

2. Ball-joint module

$$W = 1.9 \text{ m} \times \left(\frac{0.3}{2}\right)^2 \text{ m}^2 \times 3.14 \times 6 + \frac{4}{3} \times 3.14 \times \left(\frac{0.6}{2}\right)^3 \text{ m}^3$$

$$\times\ 4 \times 2.3^{t}/\text{m}^3 = 2.9 \text{ t}$$

$$A = 1.9 \text{ m} \times 0.3 \text{ m} \times 3 + \left(\frac{0.6}{2}\right)^2 \text{ m}^2 \times 3.14 + 2.16 \text{ m} \times 0.3 \text{ m}$$

$$= 2.64 \text{ m}^2$$

$$U_m = \frac{3.14 \times 2.9}{6.6} \times \frac{\cos h \ \dfrac{2 \times 3.14 \times 2.6}{68}}{\sin h \ \dfrac{2 \times 3.14 \times 10}{68}} = 1.34$$

$$F = 0.75 \times 2.64 \times 1.03 \times \frac{(0.4 + 1.34)^2}{2 \times 9.8} = 0.32$$

$$W_w = (0.81 + 0.45) \times (2.3 - 1.03) = 1.6$$

$$S_1 = 1.2 < \frac{1.6 \times 0.6}{0.32} = 3$$

$$S_2 = 1.2 < \frac{1.6 \times 0.65}{0.32 \times 0.87} = 3.7$$

3. Algae base for marine forest

$$W = (2.1 \text{ m} \times 2.1 \text{ m} \times 0.1 \text{ m} \times 2 + 1.5 \text{ m} \times 0.05^2 \text{ m}^2 \times 3.14 \times 4) \times 2.3\text{t/m}^3 = 2.14^{\text{t}}$$

$$A = 2.1 \text{ m} \times 0.1 \text{ m} \times 2 + 0.1 \text{ m} \times 1.5 \text{ m} \times 4 = 1.02 \text{ m}^2$$

$$U_m = \frac{3.14 \times 2.9}{6.6} \times \frac{\cos h \; \frac{2 \times 3.14 \times 1.7}{6.8}}{\sin h \; \frac{2 \times 3.14 \times 10}{68}} = 1.3$$

$$F = 1.2 \times 1.02 \times 1.03 \times \frac{(0.4 + 1.3)^2}{2 \times 9.8} = 0.19$$

$$W_w = (0.882 + 0.047) \times (2.3 - 1.03) = 1.18$$

$$S_1 = 1.2 < \frac{1.8 \times 0.6}{0.19} = 3.7$$

$$S_2 = 1.2 < \frac{1.18 \times 0.85}{0.19 \times 0.85} = 6.2$$

4.2 Transportation and installation

A total of 17 modules of the three different types were constructed and installed but, only in the experiment, the number was lower. Also, the methods of construction and installation adopted in this experiment were not similar to those adopted for the actual work. In particular, installation was implemented using the same method as that used in Japan (Fig. 5 & 6), so some differences may exist between the actual situation in the region and the experiment. Anyway, with regard to the installation, reference should be made to the recommendations (SEAFDEC TD/RES/22 1989). Transportation and installation work is illustrated below.

(4) The interruption of the installation work by typhoon "GAY"

Installation work was started on 3rd November, 1989, fortunately for experimental purposes only. Just after the triangular module and ball-joint module were installed, a depression intensified in the Gulf of Thailand and developed into typhoon "GAY", hitting the south, as shown in Fig. 7. The typhoon was the most violent storm Thailand had experienced in the previous 35 years, with a wind speed of 120 km per hour at its center, and it capsized many fishing boats and ships, and sadly left over four hundred victims in its wake.

The effects of the typhoon on the installed modules were as follows. From records kept by the Meteorological Department of the Royal Thai Navy, the tropical storm "RUTH", which hit the south of Thailand on the 28th November 1970, took a similar course to typhoon GAY. According to the records, the maximum wave height at that time was calculated at 2.5 meters at Surat Thani. On the other hand, typhoon GAY's wave height was calculated to be five meters at its highest off Rayong, and the same method of calculation was used. These calculations are based on Royal Thai Navy manuals.

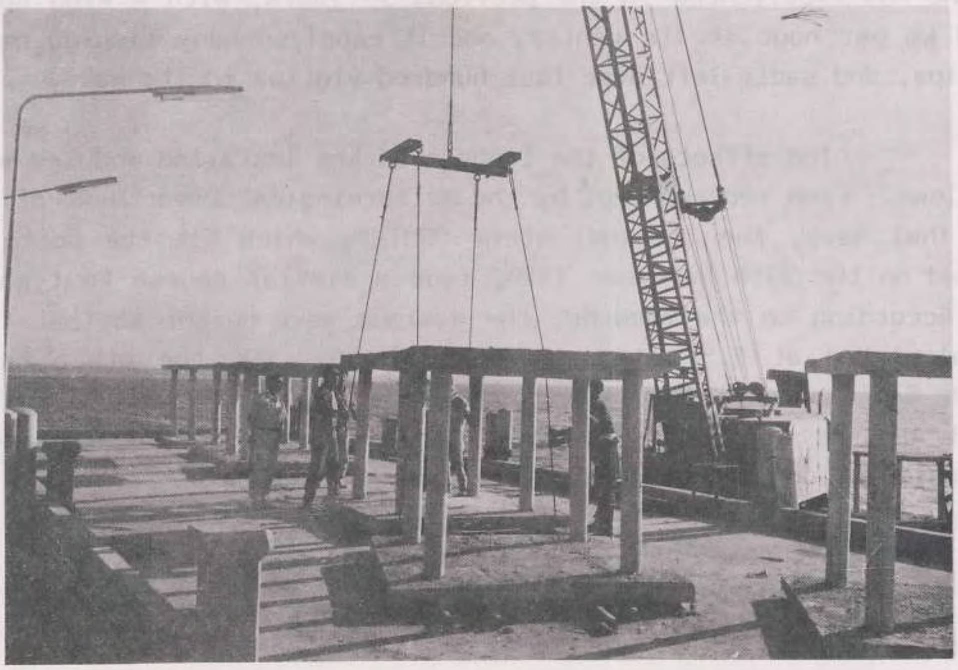
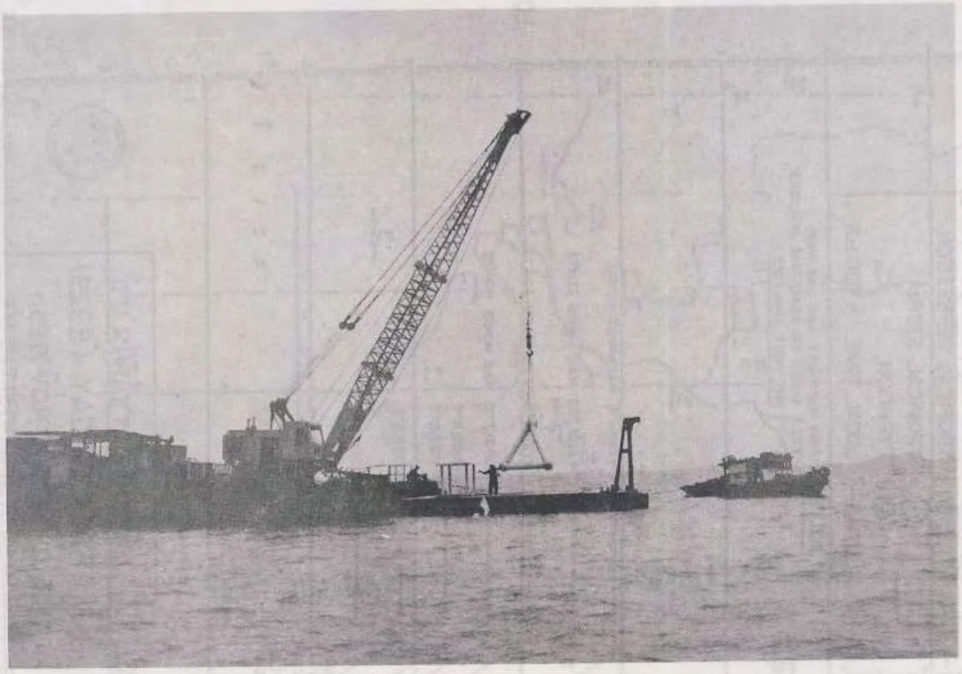


Fig. 5 Loading the module onto the barge.



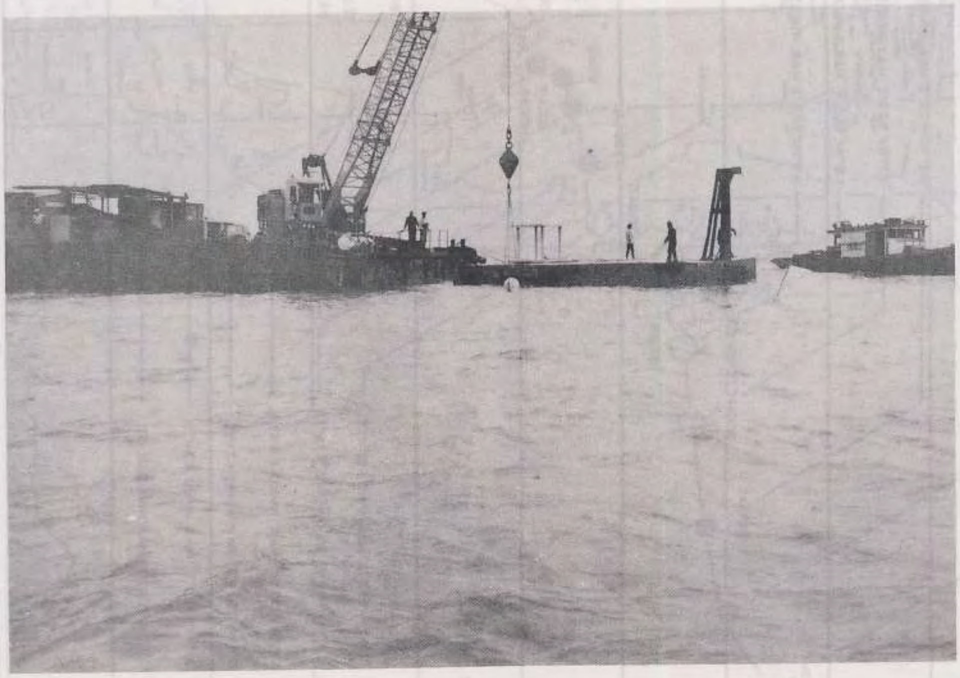
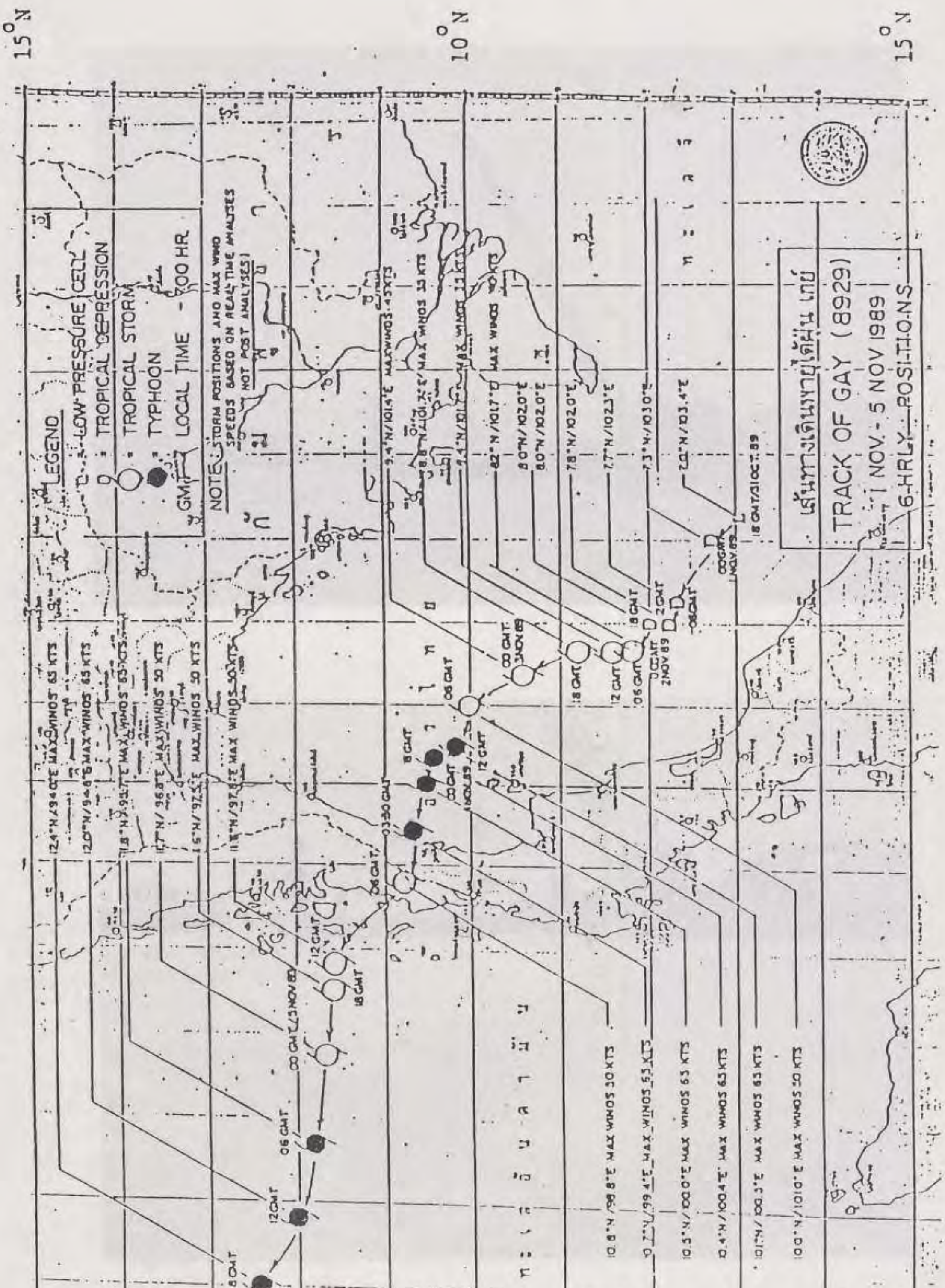


Fig. 6 Lowering the module by crane at the point of installation.



(Source: Meteorological Department, Thailand)

Fig. 7 The course of typhoon "GAY"

The actual wave height resistance adopted in the design of the module was 2.9 meters. This figure was based on a fifty-year return period, as previously calculated by the Asian Institute of Technology. When comparing the two figures given of wave height, the team leader questioned typhoon GAY's five meters as possibly being an over-estimate.

However, off the coast of Ban Phe, 3.3 kilometers from the site, waves between two to three meters in height, by eye measurement, were seen between 10 a.m. and 11 a.m. on the morning of November 4th (Fig. 8). That was also the time of the normal high spring tides. Later, it was reported that the waves grew stronger, and the 300 ton barge, leased for the installation work, sunk due to a loose anchor mooring. Therefore, at the site, higher waves than the 2.9 meters used in calculation for the designs must have existed, especially as the current speed at this time of high spring tides was also at its greatest.

Immediately after installation, therefore, the modules must have had an external force exerted against them of either very close to or over the calculated design limits. The contents of this chapter were reported at the INDOPACIFIC FISHERY COMMISSION FAO, held in Colombo, May 1990.

The other modules were installed on 23 November 1989, on schedule.

4.3 Transplantation of sea-algae

The importance of marine forest is well understood today, as are nursery grounds and/or sanctuaries for marine life at the juvenile stage. In this experiment, a new type of base was installed to enable the sea algae to grow to the surface, with the intention of constructing a marine forest.

Fig. 8 Coastal view at Ban Phe, (1000-1100 am. 4th November 1989) after which the wooden pier broke up and was washed away.

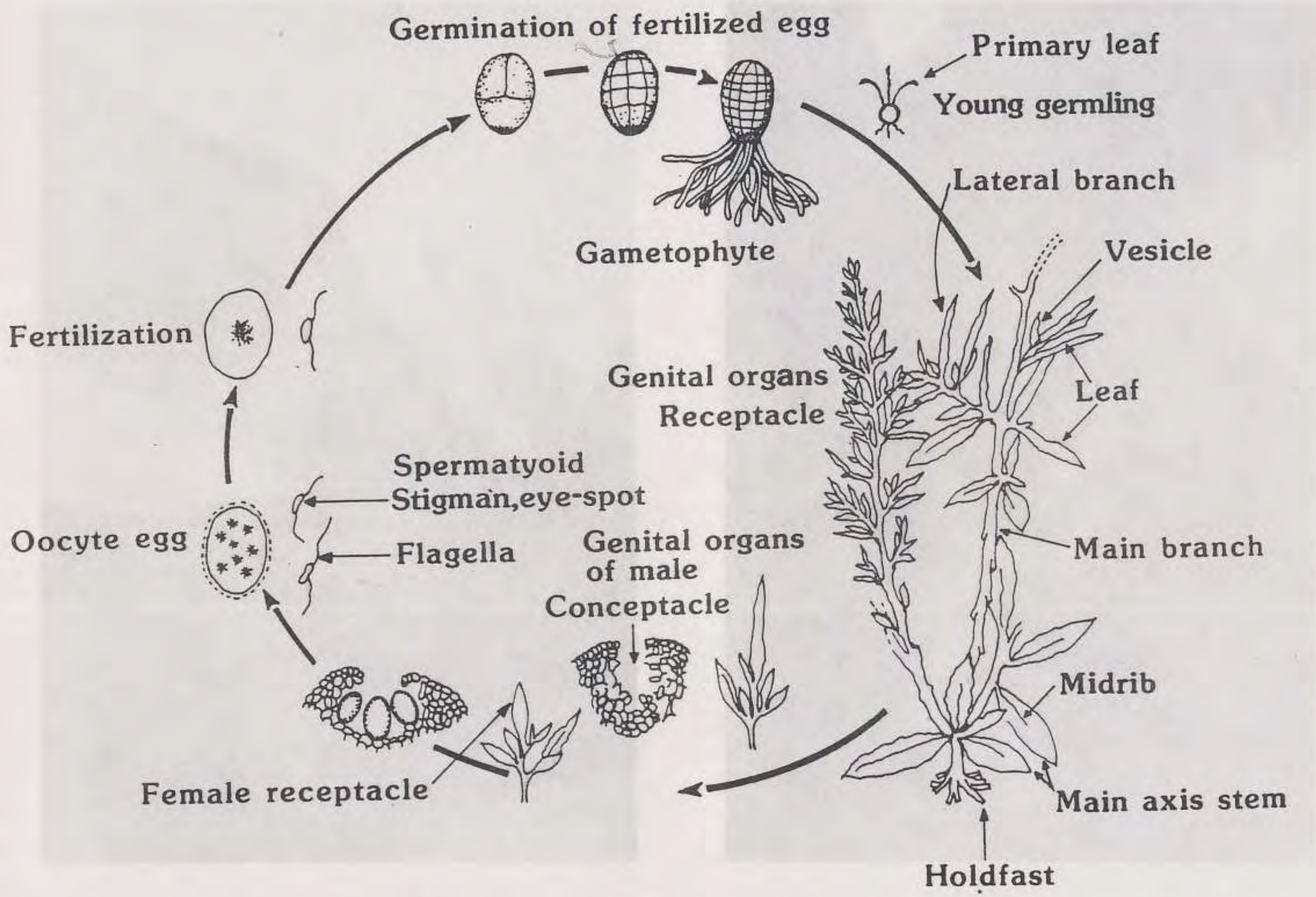


Fig. 9 Life History of Sargassum (Chihara: 1970)

Fig. 10 Microphoto of gametophyte.

The target perennial species, *Sargassum polycystum* C. Agardh, which was distributed near the site, was used for transplantation.

Generally, the life history of sargassum is as shown in Fig. 9. Then, in this experiment, after confirming the existence of sporophytes (gametophytes) Fig. 10, *S. polycystum* was transplanted to the surface of the base in order for a second generation to grow. However, regrettably, it could not be observed for some unknown reason, the reason possibly being that there was a difference in the depths between the base of the module (6 m.) and the site where the samples were collected (3-4 m.). Additionally, the thickness of the sediment on the base prevented the growth of the gametophyte which fell to the surface of the base.

4.4 Follow-up survey **by A. Munprasit, S. Sae-ung**

The life-span and the durability of modules are very important factors in evaluating the results of artificial reef construction. Usually, the condition changes after a time following installation, due to many factors such as materials used, methods of construction and transportation, sea conditions, operation of fishing gear, illegal fishing operations and so on. The effectiveness of artificial reefs is directly related to the life span and condition of the modules. Those which remain in their original position for a long time are more effective than others with a short life-span. The follow-up survey is, therefore, necessary for the study of variations in module types after installation.

In this experiment, the follow-up survey was composed of two main items, as follows:-

1) Physical features, according to diving observations

2) Biological features, concerning the following items

- Volume of fish caught at the site
- Sessile organisms

(1) Physical features, according to diving observations

1) Survey Methods and Materials

The survey was conducted from two main viewpoints: physical and biological conditions. The survey was started in December 1989, three weeks after the installation of the modules had been completed. At that time, a survey was carried out every month for three months and then every two months until a one-year cycle had been completed. One demonstration trip and eight field surveys were carried out throughout 1990. Each survey was conducted mainly by means of diving observations, while the others involved oceanographic observations and sampling.

The diving observations were conducted in order to check on the position of the modules, to investigate the condition and environment of the modules, and to collect samples of sessile organisms. The observations were recorded in photos, on video cassette tapes, echographs and in notes taken by the divers. Many kinds of equipment were used in order to record useful data and information, such as an underwater camera, an underwater TV. camera, an automatic underwater camera, an automatic underwater fishfinder and scuba diving equipment.

The oceanographic observations were important for the determining of physical features in the sea at the site. Data on wind, waves, swell, currents and transparency was checked and recorded. A forty-eight hour continuous and mini current meter recorder (DPCM-4 and SD2) was placed and operated at the site; and data on wind, waves and swell was recorded by an experienced researcher. The topography of the sea-bed at the site and nearby areas was examined and recorded with a 50 Khz Echo-Sounder.

Sampling methods were used for the two main groups of marine organisms, sessile organisms and fish. The sessile organism samples were collected by scientist divers, and the fish were collected by means of fishing gear operations, handlines and fish traps. Both sessile organisms and fish were also observed by scientist divers with an underwater camera as well as a TV. camera.

The follow-up surveys were completed on January 11, 1991, with one demonstration and eight follow-up surveys. There are various kinds of data, and samples were taken for analysis. The period of each survey and the details are shown in Table 2.

Table 2. Period and details of the follow-up survey.

Month / Survey Item	1989	1990							1991
	Dec.	J	F	M	M	J	S	N	Jan.
1. Demonstration	11-15								
2. Survey		8-12	26-2	26-30	7-11	9-13	3-7	5-9	7-11
3. Diving Observations	*	*	*	*	*	*	*	*	*
4. Oceanographic Observations	-	-	*	*	*	*	*	*	*
5. Sessile Organism Sampling	-	*	-	-	*	-	*	*	*

2) Results

Results of the follow-up surveys are shown in Table 3 and are divided into 2 main areas, as mentioned above.

1) Physical condition of modules

a. Location and distribution of modules

The central group of modules at the site was confirmed to be at latitude 12°-35.6' N, longitude 100°-26.7' E, northwest of Samet Isl. about 1,800 meters away from the island. The depth of the sea at the site was about 7-9 meters as shown in Fig. 2. It is called Rayong Artificial Reef No. 9 (AR. 9), which is about 500 meters away from AR. 8, where some small experimental modules were installed.

The pattern of installation was confirmed by several diving observations, and the modules were placed in 5 separate groups. Each group of modules consists of 2 modules (ball-joint and triangular, except in group No. 2 which is located to the north 35 meters from the central group (No. 1) and consists of 4 module units, one ball-joint, one triangular and two algae base modules. Group No. 3 is 55 meters from the center to the east, group No. 4 is 55 meters to the south and group No. 5 is 50 meters to the west, as shown in Fig. 12.

The modules in each group were placed about 0.5-3 meters away from each other. The first two modules in the central group (No. 1) were installed on November 3, 1989, before typhoon "Gay" affected the site. Then, the remainder were completed on November 23, 1989, after the typhoon had passed.

Then, ten bamboo reinforced concrete modules were installed at the site just after the installation of the concrete modules was completed. Nine bamboo modules were checked in the (AR. 9) area, as shown in Fig. 11.

Table 3 One Year Follow-up Survey of The Resource Enhancement Experiment Project

Description of the Survey	Demonstration 12-14/12/89	1st FS 9-11/1/90	2nd FS 28/2-2/3/90	3rd FS 27-29/3/90	4th FS 22-24/5/90	5th FS 10-12/7/9	6th FS 4-6/9/90	7th FS 13-15/11/90	8th FS 8-10/1/91	Remarks
Life span of modules (months)	3 weeks	1½	3¼	4½	6	7¾	9½	11¾	13½	
Type of Monsoon	NE	NE	-	SW	SW	SW	-	NE	NE	
Wind dir/spd.(kt.) Wave dir/height(m) Swell dir/height(m)	- - -	-/0 -/0 -	SSW/5-8 SSW/0.5-1 S/1	SSW/3-5 SSW/0.3-0.5 SSW/1	SSW/5-7 SSW/0.7-1 SSW/1-2	SW/7-12 SSW/1-1.5 SSW/2-2.5	ENE-SW/3-7 ENE-SW/0-0.5 SSW/1.5-2	N-NE/5-10 N-NE/0-0.7 -	NE-E-S/0-5 -/0 -	
Current dir/spd.(kt.)	NNE ⟷ SSW /0-0.8	NNE ⟷ SSW /0-0.3	NE ⟷ SW /0-0.6	NNE ⟷ SSW /0.0.7	WSW, W /0.3-0.8	NE,E⟷ WSW /0.4-0.7	NE ⟷ WSW /0.3-0.7	ENE /0.1-0.4	ENE,ESE,S /0-0.6	
Transparency(m)	7	5	5	7.5	4-5/1*	2-3/<1*	2-3.5	9	5-7.5	* Trans. at bottom
Average sedimentation at base of modules (cm.)	0/-	** 0/15-20	** <5/15-20	** 5/15-25	** 10-15/20-25	** 20/30-40	** 15-25/30-40	** 10-20/25-35	** 10-15/25-35	**modules installed before typhoon "Gay"
Stability of modules	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK = same as beginning
Module condition	- all modules were placed on sea bed (sandy) - AB broken - most Bam. fixed at 0.5-1 meter above sea bed	- same condition and bigger barnacles - Bam. was fully covered with barnacles	- same as beginning - many grown sessile organisms - Bam. coconut leaf decay	- bristle worms(bw.) bloom on modules - most Bam. laid on bottom	- all bw. drop off	- sediment cover on surface of modules - hole under BJ. - all Bam. collapsed.	- sediment cover on modules - hole under BJ.	- sediment was washed out from surface of modules - few remaining broken Bam. on sea bed	- sessile organism start grow up again - no remaining broken Bam. on sea bed,	Bam.- Bamboo module TP - Triangular module BJ - Ball Joint Mod. AB - Algae base module
Sessile organism	- barnacles (bn.)	bn., bryozoa (bz.)	- early stage bristle worm (bw.), sponge (spn.)	bw. bloom	bw. fall, spn., pearl-shell (ps.),bz.,	spn.,ps., polychaete (pc.)	spn., pc., & ps.	spn.,pc., ps. bw	bw., spn., pc., bz., ps., sea-cucumber	Bristle worms (bw.) Fam. Serpulidae
Fish	- sea bream (sb.) slip mouth (sm.)	- siganid (sn.)	- sn., sm., grouper (gp.)	- sweet lip (sl.) juvenile snapper (sp.), gp.	- gp.,sp.	-sl., sp., <u>Plotosus lineatus</u>	- gp.,sp., sn., toad-fish	- juvenile sp., apogon, anchovy, gp.	- sl.,sn., juvenile sp., apogon, <u>Gerres</u> sp.	

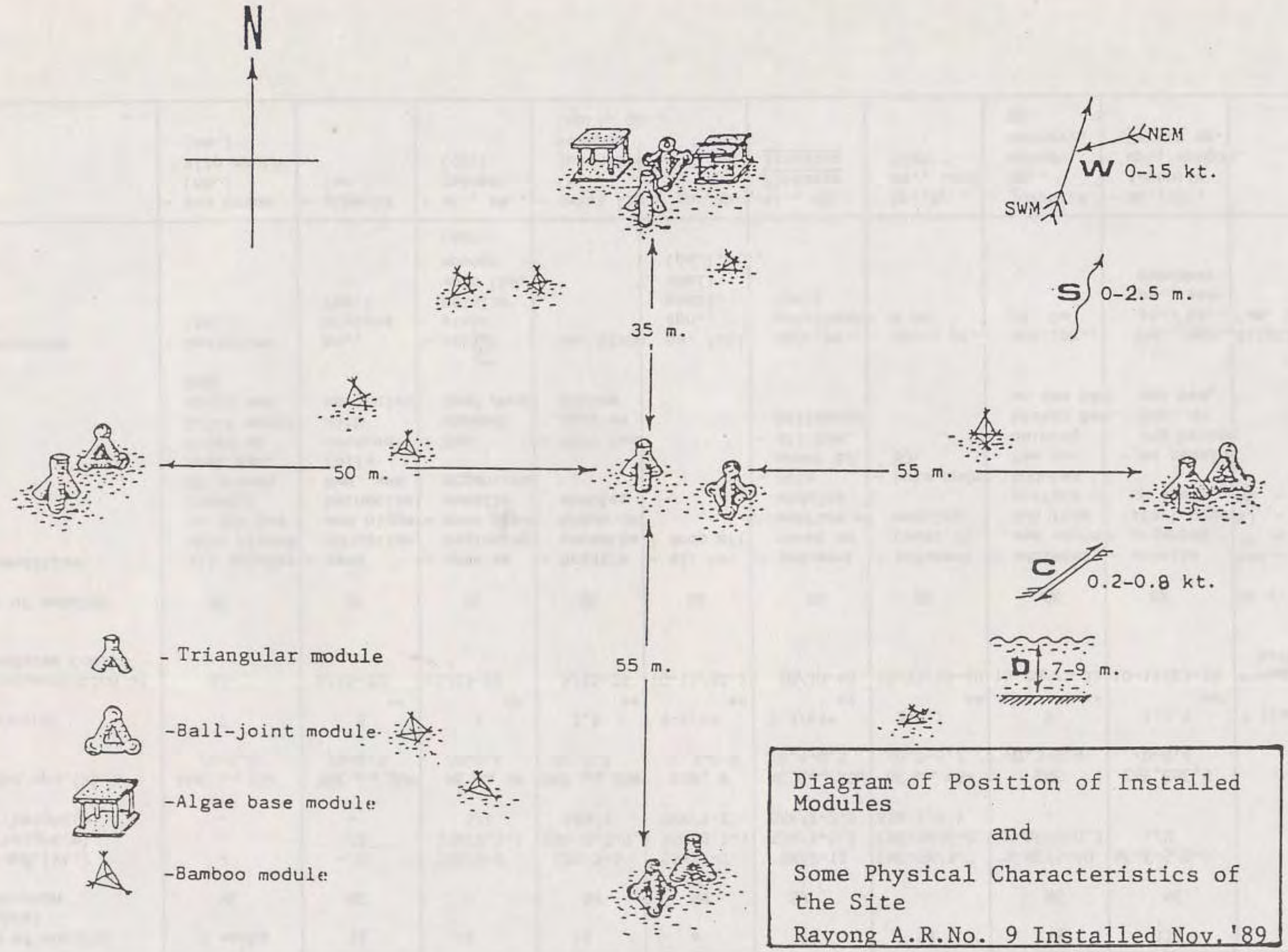


Fig. 11 Arrangement of Modules at the site

b. Physical oceanographic factors at the site

The AR. 9 site is located in a shallow water area and is in the channel between Samet Island and the coast at Leam Hya, so the modules were affected by especially the current and the waves (including swells). The summary results of the oceanographic observations at the site throughout the year (1990) are shown in Table 3. Wind varied depending on the path of the monsoon either from north-northeast to south-southwest, and vice versa; and wind speed varied from 0-12 nautical miles per hour. The direction of the waves depended on the wind, and wave-height varied from 0-1.5 meters. Swell came mostly from the south-southwest, with heights ranging from 0-2.5 meters.

The currents move mainly in two directions: to the northeast, when the tide goes out, to the southwest when the tide comes in. Current velocity varies from 0-0.8 nautical miles per hour. And the transparency of the sea water also related to the monsoon season: it was clear during the northeast monsoon season, but very unclear during the southwest monsoon season. The transparency of the sea water at the site varied from 2-9 meters from the surface downwards. The sediment on the sea-bed at the site is sand.

c. Condition of the modules

Most of the modules were very stable on the sea-bed throughout the year. There was sedimentation at the base of the concrete modules. The average rate of sedimentation for the first three months was very slow, being less than 5 centimeters thick. The rate of sedimentation was higher during the period of the southwest monsoon (April to August), with sand 15-25 centimeters thick at the base of the modules whose life span was four to nine months. Then, a little of the sediment was washed away when the northeast monsoon started again, with only 10-15 centimeters of sand still remaining at the base of the modules.

Exceptional conditions existed in the central group (No. 1) which was installed before typhoon "Gay" affected the site area. There was 15-25 centimeters of sediment at the base of the ball-joint and triangular modules which were covered by bottom sediment by the time of the first observation in January 1990, two months after installation. Then, the rate of sedimentation continued in the same way as for the other modules until the one-year cycle was completed. 25-35 centimeters at the base of the modules were covered with sand (Fig. 12, 13).

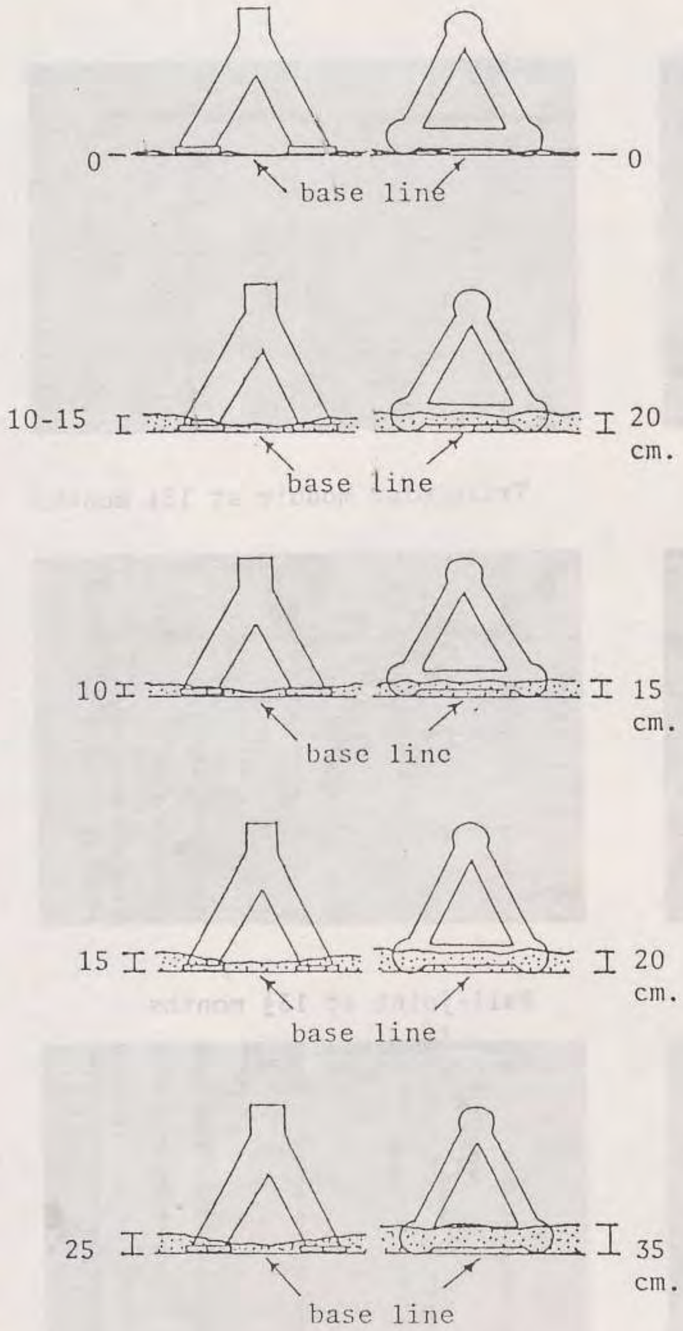
The bamboo modules were constructed with 6 bamboo bars, 10-12 centimeters in diameter and 2 meters in length; and 3 coconut palm fronds were attached to the 3 legs of each module (Fig. 14). Nine units of the bamboo modules were installed at the site, and they were fixed on the sea-bed with 2 kilogram concrete blocks. Most of the coconut fronds decayed within 3 months and four months after they were installed most of the bamboo modules were lying on the sea-bed, which was the case with all of them after being installed for 8 months. A few broken bamboo remains were observed during the seventh follow-up survey after 11½ months. In the last survey in January 1991, there were no broken bamboo remains found on the sea-bed, but only a large number of pieces of the concrete blocks (Fig. 15).

2) Observation of the biological condition of the modules and the areas around them

Two main groups of marine organisms were observed, photographed and videotaped: sessile organisms and fish, as recorded in Table 3.

a. Sessile organisms

Rough observations were carried out by scientist divers in order to report the situation of the modules, step by step, from the beginning until the end of the one-year cycle. Barnacles were the first group of sessile organisms found on the surface of the modules within three weeks. These were followed by



Modules observed after 3 weeks in December, 1989, during the northeast monsoon.

Modules observed after 8 months in July, 1990, during the south-west monsoon.

Mondules observed after 13 months in January, 1991, during the north-northeast monsoon, after the end of the south-southwest monsoon.

Modules installed before typhoon "Gay" after 2 months in January, 1990.

Modules, installed before typhoon "Gay" observed after 14 months in January, 1991.

Fig. 12 The condition of the modules observed throughout 1990

Triangular Module at 3 weeks

Triangular Module at 13½ months

Ball-joint at 3 weeks

Ball-joint at 13½ months

Module installed before typhoon "Gay" at 3 weeks.

Module installed before typhoon "Gay" at 13½ months.

Fig. 13 Condition of the modules over the one-year cycle.

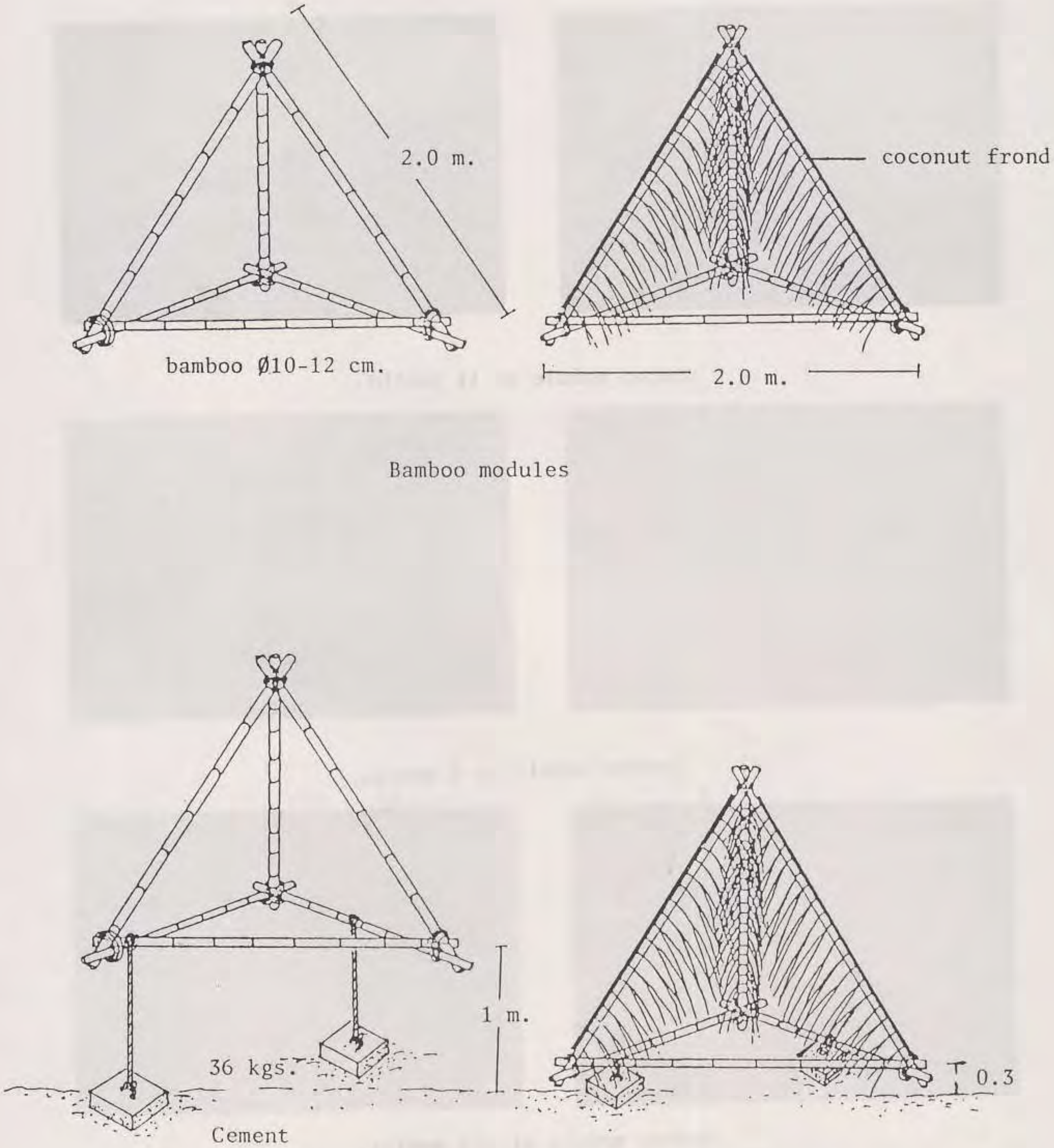
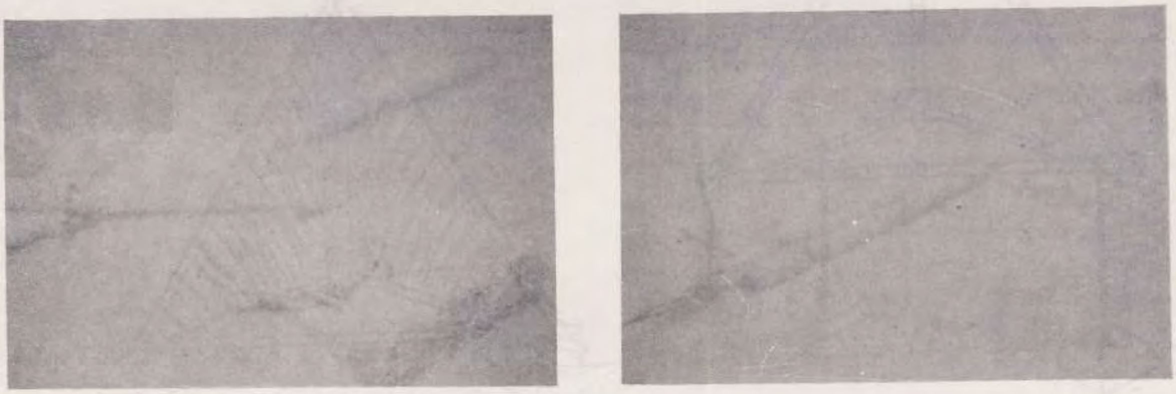


Fig. 14 Dimensions and position of bamboo modules

Bamboo module at 1½ months.

Bamboo module at 4 months.



Bamboo module at 11½ months.

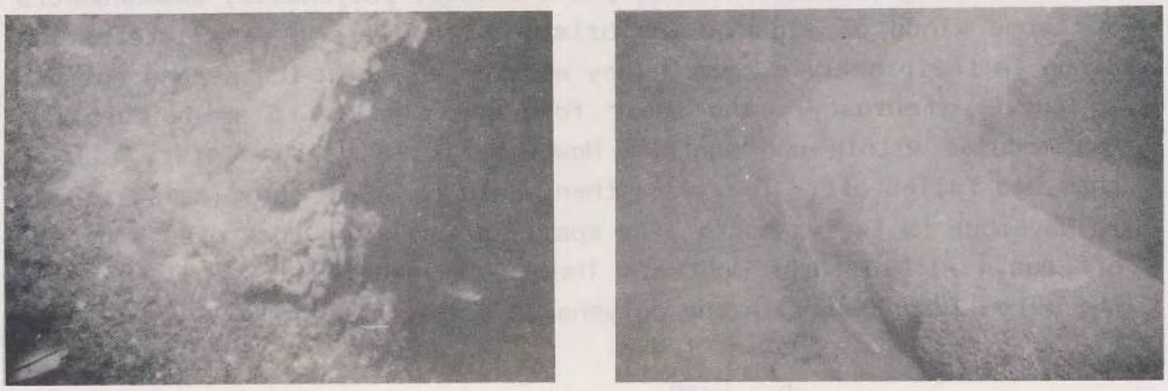
Fig. 15 Condition of the bamboo modules over the one-year cycle.

bryozoa, sponge, bristle worms, pearl shells, polychaete, seacucumbers and some kinds of algae. The bristle worms were a very interesting group in their early stages. They were observed in the second follow-up survey (February), and their form was similar to spiny coral on the modules within one month. However, three months later, all of them had fallen off. They were then again found in their early stages in November (a twelve-month life span), after which they grew and fell off again within three months. They were identified as belonging to the serpulidae family in the polychaeta class (Fig. 16).

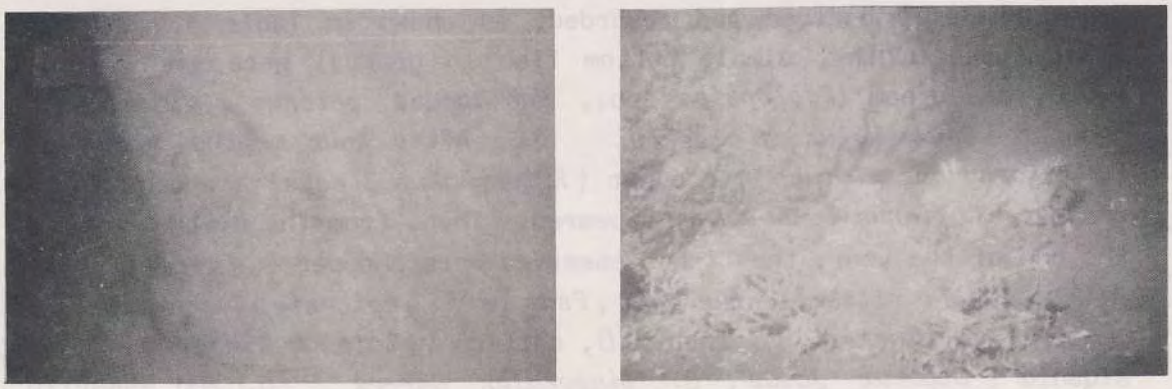
b. Fish

The composition of fish species and their behavior were observed and recorded, as shown in Table 3. In the first three months, simple bottom fish in general were seen: slipmouth, sea bream (*Scolopsis* spp., *Pentapodus setosus*), siganid and grouper (*Epinephalus bleekeri*). After four months, sweetlip (*Plectorhyncus pictus*), grouper (*Epinephalus bleekei*), and juvenile snapper (*Lutianus lineolatus*) appeared. Then, from the sixth month to the end of the year, the fishes observed were snapper (*Lutianus lineolatus*, *L. vitta* , *L. russelli* , *Psamoperca vagiensis*), grouper (*L. taurina*, *E. bleekeri*, *E. russilli*), catfish (*Plotosus lineatus*), siganid (*Siganus javas* , *S. lineolatus Gerres* sp.) and sweetlip (*Plectorhyncus pictus*). Juvenile snapper (*L. lineolatus*), *L. vitta* , *Apogon* sp. and anchovy were observed in November and January, 12 and $13\frac{1}{2}$ months after the modules had been installed. Schools of some pelagic fish, such as scad (*Caranx sela mate*, C. leptolepis), were found swimming over the modules (Fig. 17).

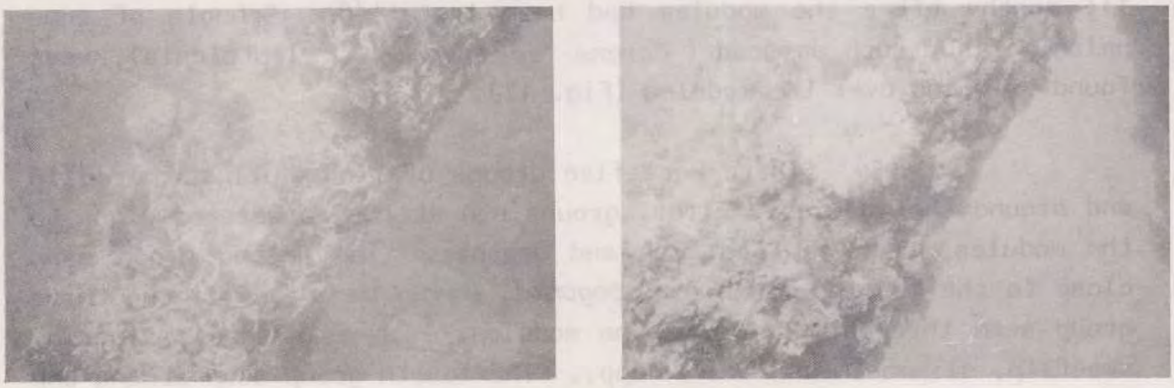
There were five groups of fish which gathered in and around the modules. First, groups hid at the corners or close to the modules, such as toad fish and grouper. The second group swam close to the modules, such as *Apogonid*, *Pomacentrid* , sp.. The third group swam through and around the modules, such as snapper, siganid, sweetlip, slipmouth and *Gerres* spp.. The fourth group swam around and close to the sea-bed such as threadfin bream (*Scolopsis* spp., *Pentapodus setosus*), and goat fish. And, the last group was pelagic fish, which usually swam in schools over the module and included such fish as scad, (*Caranx sela mate* , *C. leptolepis*), anchovy, sardine and barracuda (Fig. 18).



Sessile organisms at 3 weeks.



Sessile organisms at 6 months.



Sessile organisms at 13½ months.

Fig. 16 Sessile Organisms.

Fish at 3 weeks

Demersal fish found around a module as usual.

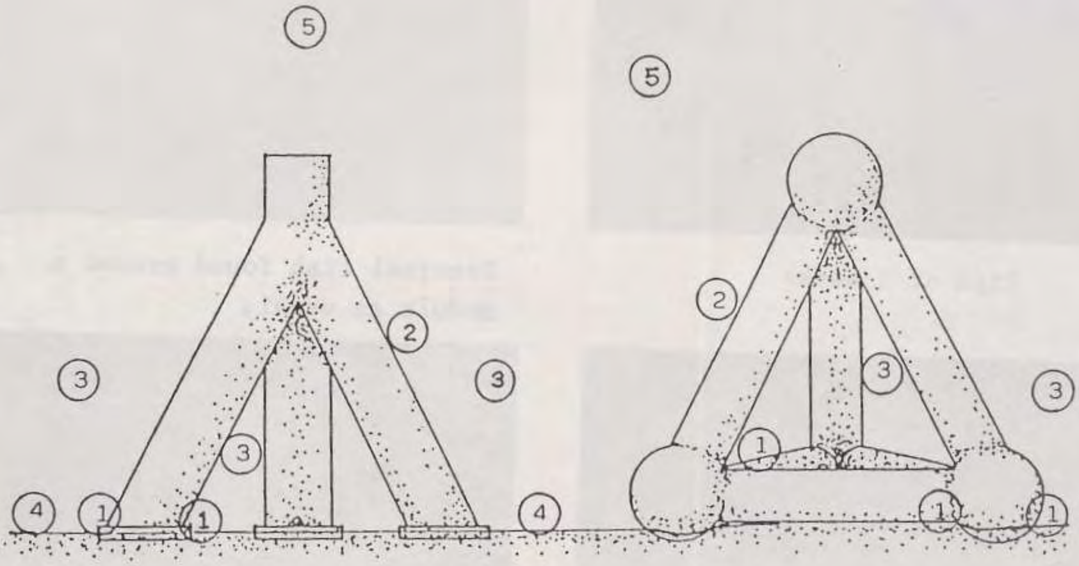
Reef fish at a ball-joint module at 4 months.

Siganid feeding on a ball-joint module at 4 months.

Snappers around module at $9\frac{1}{2}$ months.

Juvenile yellowish striped snapper at $13\frac{1}{2}$ months.

Fig. 17 Fish gathering around modules.



(1) - hiding at the corners or close to the module
(grouper, toad fish, crab.)

(2) - swimming close to the module.
(apogonid, pomacentrid, *Pempheris* sp.)

(3) - swimming through and around the module
(snapper, siganid, sweetlip, slipmouth and *Gerres* sp.)

(4) - swimming around the module and close to the sea-bed
(threadfin bream, goat fish)

(5) - swimming over and around the module
(scad, anchovy, sardine, barracuda)

Fig. 18 Fish behaviour around the module

(2) Biological features **by S. Sungthong**

1) The volume and type of fish caught at the site

While the follow-up survey was being carried out, fish sampling was also conducted using two fishing methods namely handlines and fish-traps, every month from January to September 1990. Fish sampling was carried out once a month, with four fishing lines being used in one hour for handline sampling and one fish-trap with an immersion time of five days once a month. Fish sampling was conducted eight times, but the data for July was unsatisfactory. The results were as follows:

- The fish caught by handline were mainly threadfin bream (*Pentapodus setosus*), monocle bream (*Scolopsis* sp.) and gold striped snapper (*Lutianus lineolatus* and *L. vitta*), while the rest were threadfin bream (*Nemipterus* spp.), whiting (*Sillago* spp.), barracuda, coral cod, rock cod, russelli's snapper and sea bass grouper, as shown in Table 4.

- The fish caught in the fish-trap were similar to those caught by handline, and the three main species, monocle bream (*Scolopsis* spp.), gold striped snapper (*L. lineolatus*, *L. vitta*) and threadfin bream (*Pentapodus setosus*), were the same and, the rest were threadfin bream (*Nemipterus* spp.), red spotted emperor (*Lethrinus* sp.), russelli's snapper (*L. russelli*), rock cod, rabbit fish (*Siganus* spp.), box fish and Chinese file fish (*Monacanthus* chinensis), as shown in Table 5.

However, the results of the fish sampling at the site within nine months of the installation of the modules were very thin and not particularly related to the artificial reef. Two of the the three main species were not reef fish: threadfin bream (*Pentapodus setosus*) and monocle bream (*Scolopsis* spp.) usually inhabit the flat, sandy sea-bed. Gold striped snapper (Lutianus lineotatus and *L. vitta*) is a tropical species of reef fish, but the catch per unit effort was still very small. The average catch was only 142 gram/line/hour and 87 gram/trap/day. Others caught were reef fish, such as red spotted emperor, rock cod, rabbit fish and grouper but, again, the catches per unit effort were very small.

These results may be related to the pattern of module installation. In this experiment, the modules were arranged quite separately from each other, with five locations mostly with two-unit modules being set, as shown in Fig. 11. And according to the diving observations, there were not so many fish gathering at each group of modules, so that the catch efficiency of both sampling methods was not effective, either.

Table 4. Fish catch record at the site, by handline (kilogram/line/hour).

Species \ Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Average	Remarks
Threadfin bream *Pentapodus setosus*	0.55	0.47	0.7	0.39	0.33	0.36	0	0.79	0.39	0.4975	
Monocle bream *Scolopsis* spp.	0.224	0.347	0.322	0.14	0.1	0.205	0	0.27	0.1	0.2135	
Gold striped snapper *Lutianus lineolatus*	0.06	0.09	0	0.11	0.19	0.02	0	0.2	0.322	0.1417	
Threadfin bream *Nemipterus* spp.	0.184	0.15	0.1	0.08	0	0	0	0	0	0.1285	
Sand whiting *Sillago sihama*	0.1	0	0	0	0	0	0	0	0	0.1	
Barracuda *Sphyraena areolatus*	0.7	0	0	0.06	0	0	0	0	0	0.38	
Blue-line coral cod *Cephalopholis boenack*	0	0	0.104	0	0	0	0	0.08	0	0.092	
Rock cod *Epinephelus areolatus*	0	0	0	0.06	0	0	0	0	0.07	0.065	
Russell's snapper *Lutianus russelli*	0	0	0	0	0.07	0	0	0	0.102	0.086	
Sea bass grouper *Epinephelus sexfasciatus*	0	0	0	0	0.08	0	0	0.07	0.08	0.0767	
CPUE	1.718	1.057	1.226	0.84	0.77	0.585	0	1.41	1.064		

Table 5. Fish catch record at the site, by fish trap (kilogram/day).

Species \ Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Average	Remarks
Threadfin bream *Pentapodus setosus*	0.11	0.11	0.07	0	0.01	0.08	0	0.08	0	0.0767	
Monocle bream *Scolopsis* spp.	0.102	0.16	0.307	0.33	0.202	0.1	0	0.09	0.205	0.187	
Gold striped snapper *Lutianus lineolatus*	0	0.03	0.19	0.06	0.204	0.04	0	0.06	0.03	0.0877	
Threadfin bream *Nemipterus* spp.	0.08	0	0	0	0	0	0	0	0	0.08	
Red spotted emperor *Lethrinus* spp.	0	0	0.15	0	0	0	0	0	0	0.15	
Russell's snapper *Lutianus russelli*	0	0	0	0.104	0	0.1	0	0	0	0.102	
Rock cod *Epinephelus areolatus*	0	0	0	0.08	0.08	0	0	0.08	0.08	0.08	
Box fish *Ostracion* spp.	0	0	0	0.06	0	0.05	0	0.1	0.06	0.0675	
Chinese file fish *Monacanthus chinensis*	0	0	0	0	0.06	0	0	0.13	0.12	0.1033	
Rabbit fish *Siganus* spp.	0	0	0	0	0	0.07	0	0.07	0	0.07	
Rock cod *Epinephalus* spp.	0	0	0	0	0	0	0	0	0.06	0.06	
CPUE	0.292	0.30	0.717	0.624	0.556	0.44	0	0.61	0.555		

2. Sessile organisms **by S. Anunpongsuk, S. Sawadppera**

1) Materials and methods

One-foot square concrete plates were attached to the triangular module, one on the upper part and the other on the lower part (Fig. 19). The concrete plates were attached to the module in order to collect samples of marine sessile organisms.

There were five surveys of sessile organisms throughout the eight stages of the follow-up survey. The first observation was made in January 1990, one month after the module had been installed, while the rest took place in May, July and November, 1990, and then in January, 1991; which was six, eight, twelve and fourteen months after installation, respectively.

The study of the sessile organisms was carried out by using a sample that had become attached to the concrete plates which were representative of the whole module and reef site. The first couple of concrete plates were raised from the central group of modules, while the rest were raised from the north, east, west and south locations, in that order and corresponding to the above-mentioned months.

Bringing the concrete plates on board was carried out by scuba divers who detached the plates from the triangular module and carried them to the surface in a plastic bag. Then the plates were photographed from above.

A solution with 10 percent formalin was afterwards used to preserve the samples in plastic containers, and photographs were also taken.

A colour control patch was used during the photographing in order to determine the typical colours of the sessile species and for colour comparison.

Finally, sorting and identification of the sessile organisms and associated sessile organisms was carried out in a laboratory.

2) Results

In the first month, the animals predominant on the sampling plates were barnacles. They were still small and had not reached maturity. The number of barnacles found on the upper plate was greater than on the lower plate. The other animals were bryozoans (25%), ascidean and sponges (around 1%), and hydroids (less than 1%).

There were 14 types which were not attached to the upper plate, namely, forams, nematods, sipunculids, 3 groups of annelids, harpacticoid copepods, mantis shrimps, caridean shrimps, crabs, gammarid amphipods, gastropods, bivalves and brittle stars. On the lower plate, there were only 4 types of animals, namely, forams, nematods, harpacticoid copepods and bivalves. The unattached animals were predominantly small nematods and caridean shrimps, more of which were found on the upper plate than on the lower plate, which may have been because the conditions on the upper plate were better than on the lower plate i.e. there was less sediment and concentration of diatom.

After six months of the experiment, the barnacles reached the maximum size and most of them were encrusted in sponges. By this time, two types of animals were dominant: sponges (around 90%) and barnacles (around 80%). The other attached animals were ascideans (10%), bryozoans (1%), and attached bivalves (1%). Macro algae, (*Ceramium* spp. and *Gracillaria* spp.), also began to be found in small numbers (less than 1%).

The ascideans found in the first month were all encrusting colonial ascideans. In this month, solitary ascideans were 1-1.5 centimetres high. The number of unattached animals increased to 20 types on the upper plate and 18 types on the lower plate. The predominantly attached animals found in this month were free-living brittle worms, bivalves, ribbon worms, gammarid amphipods, isopods, gastropods, crabs and caridean shrimps.

The free-living brittle worms, ribbon worms and bivalves grew in height at agreater rate in this month, compared to the first month. There was a high density of free-living bristle worms, isopods and caridean shrimps on the upper plate, which may have been due to the apparently better environmental conditions on the upper plate.

However, some kinds of animals were abundant on the lower plate, such as nematods, crabs, gammarid amphipods, gastropods and bivalves. Most of the nematods and ark-shell bivalves were feeding on detritus and usually buried themselves in the sediment or in dark spaces. This may be the reason why the nematods and the bivalves were more abundant on the lower plate than the upper plate. Normally, crabs, gammarid amphipods and caridean shrimps should be more abundant on the upper plate than on the lower plate, or there should be a similar number on both plates, but some of them swam away from the plate along with the current, so the results were not so accurate.

In the eighth month, barnacles were still the predominantly attached animal group and they covered around 90% of both plates. On the upper plate, it was found that the percentage covered with encrusted ascidean was higher than on the lower plate, around 50% on the upper plate and 10% on the lower plate. However, the percentage covered with sponges was higher on the lower plate (around 25%), whereas it was 5% on the upper plate.

It could be concluded, therefore, that both kinds of animals have different habits. The number of non-attached animal types was similar to that for the sixth month, namely, 19 types on the upper plate and 17 types on the lower plate. Predominantly, there were ribbon worms, free-living brittle worms, bivalves, gammarid amphipods and tube worms. The number of ribbon worms and tube worms increased sharply from the sixth month onwards. In this month there were more attached bivalves on the sampling plate than buried bivalves, e.g., mussels, oysters, as well as jewel box and rock shells.

In the eleventh month of the experiment, the appearance of the plates changed. The percentage covered with barnacles decreased to around 30% on both plates, the percentage covered with encrusted ascidean increased to around 40% and most of them were calcified ascideans. The other attached animals were sponges (around 5%), bivalves and tube worms (around 1%). The number of non-attached animal types remained similar to the number for the eighth month, but the density of each type decreased (Table 6). This may have been because of rough seas during the 5 months. The previous predominantly non-attached types were bristle worms, most of which were tube worms that were found more on the upper plate than on the lower plate. Other animals, like nematods, gammarid amphipods, ascideans larvae and crabs, were also observed.

Two months after the eleventh month, the animals on the plates appeared more active than in the eleventh month: the barnacles on both plates increased to more than 90%. The percentage of non-calcified encrusted ascideans on the upper plate was around 90% and almost covered the barnacles but, on the lower plate, was around 5%. The percentage of sponges on the lower plate was around 10% and 1% on the upper plate. This result may show the optimum habitat of ascideans and sponges. The number of non-attached animal types remained similar to that for the eighth and eleventh, months, but the density of each type tended to increase in the eleventh month (Table 6). The species were predominantly nematods, ribbon worms, bristle tube worms, grammarid amphipods, and bivalves. By this time, the bivalves that appeared were mostly non-attached.

3) Summary of sessile organisms

The results of the follow-up survey on sessile organisms are very general. The main species found were phylum Arthopoda and, secondly, phylum Mollusca, Annelida and Echinodermata.

The highest number of sessile animals was Heternemertini (the ribbon worm group) which become attached to the upper and lower plates. Next were Monhysterida (eg. nematods) and crawling types (eg. bristle stars).

Not only sessile animals are shown in the table but also sponges, bryozoans, moss animals and barnacles (phylum arthropod). The barnacles were attached to the plates in each survey.

From analysis of the plates, the quantity (density) of marine sessile organisms and associated animals attached to the lower plate was greater than on the upper plate, because of the animals' environment, including conditions on the sea bottom, as well as oceanographical factors.

In the fourteen-month survey period, the peak period of attachment of the sessile organisms came in the July observation when the reef module had already been installed for eight months. It is possible to conclude, therefore, that the sessile organisms are widely distributed on the plates, due to the nutrient salts in southwest monsoon season (Takahashi K., et al, 1983).

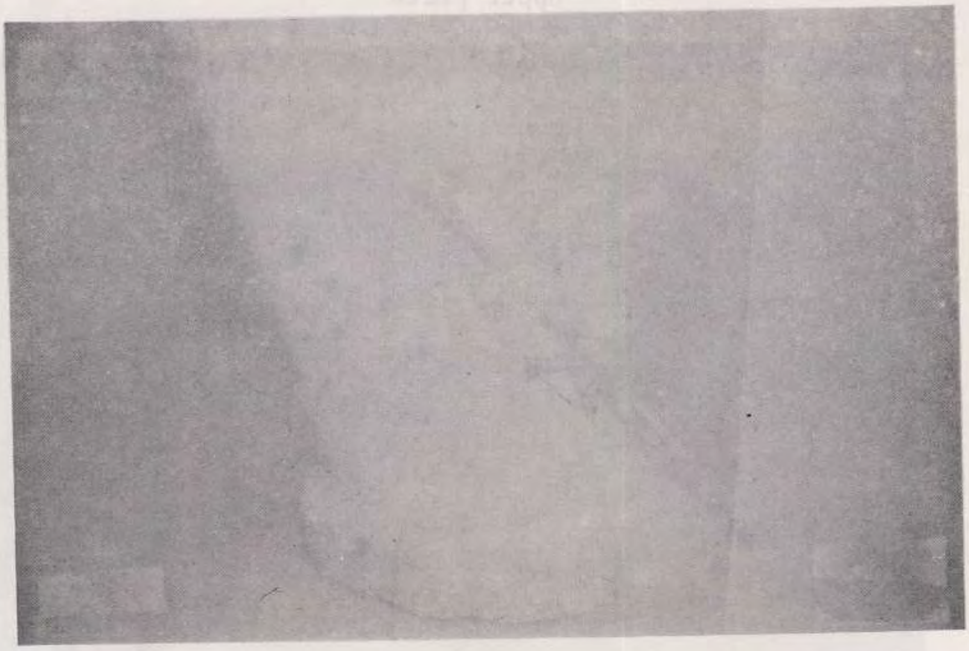
Because of the lack of stomach contents analysis data, the relationship between prey and predator in the reef community could not be exactly specified. The identification of sessile organisms in this report represents basic information for further research activity.

Table 6. The organisms and the number of individuals/ft^2 which were observed on the artificial reef in the Ban-Phe District, Rayong Province.

		DATE	11-1-90		24-5-90		12-7-90		15-11-90		10-1-90	
Phylum		Common name	upper plate	lower plate	upper plate	lower plate	upper plate	lower plate	upper plate	lower plate	upper plate	lower plate
SARCODINA	O. Foraminiferan	forams	2	5	18	5	0	7	0	11	12	26
CNIDARIA	F. Actiniidae	sea anemones	0	0	0	0	13	0	53	1	0	2
PLATYHELMINTHES	O. Polycladida	polyclads	0	0	28	17	15	9	0	0	0	0
NEMERTINA	O. Heteronemertini	ribbon worms	0	0	68	566	1510	2997	29	6	0	312
	O. Hoplonemertini	ribbon worms	0	0	0	0	96	69	0	0	468	0
NEMATODA	O. Monhysterida	nematods	41	7	43	10	3	6	171	130	228	1320
SIPUNCULA	O. Bolfingiidae	peanut worms	3	0	4	9	11	8	30	39	7	51
ANNELIDA	Clawling types	bristle worms	8	0	1107	555	527	270	26	45	60	73
	Tube woras types	tube worms	3	0	4	2	131	163	149	73	375	333
	F. Megascolecidae	oligohetes	1	0	0	0	0	0	9	3	24	18
ARTHROPODA	Cl. Ostracoda	ostracods	0	0	15	6	0	0	1	0	7	2
	O. Calanoida	calanoids	21	5	6	3	0	0	8	1	0	0
	O. Harpacticoida	harpacticoids	0	0	2	0	0	0	20	17	32	93
	O. Cyclopoida	cyclops	0	0	3	0	0	0	0	0	0	0
	Cl. Stomatopoda	mantis shrimps	1	0	0	0	1	0	0	0	0	0
	IO. Caridea	caridean shrimps	22	0	57	93	12	13	18	30	0	6
	Sect. Brachyrhyncha	true crabs	3	0	114	48	63	41	55	70	8	25
	F. Paguridae	hermit crabs	0	0	0	0	0	0	2	0	1	0
	O. Tanaidacea	tanaidaceans	0	0	2	7	0	7	0	0	0	0
	O. Isopoda	isopods	0	0	163	29	13	17	8	7	1	0
	SO. Gammaridae	gammarids	2	0	53	193	201	158	88	147	36	277
	Shrimp naupleus		0	0	0	13	0	0	0	0	0	0
	megalop larvae		0	0	0	0	0	4	0	0	0	0
MOLLUSCA	Cl. Gastropoda	gastropods	1	0	21	144	24	11	2	2	8	7
	F. Vermetidae	worm shells	0	0	0	0	5	0	0	9	0	0
	O. Nudibranchia	sea slugs	0	0	0	0	6	0	1	3	0	0
	Cl. Bivalvis	bivalves	5	1	370	575	210	88	31	74	18	129
ECHINODERMATA	Cl. Ophiuroidea	brittle stars	1	0	12	17	16	13	4	4	6	10
	O. Spatagoida	sea urchins	0	0	1	0	0	0	0	0	0	0
	O. Holothuriidae	sea cycumbers	0	0	0	0	0	8	0	0	0	0
CHORDATA	F. Ascidiidae	sea squirts	0	0	0	0	0	0	96	11	50	55
	Ascidean larvae		0	0	0	0	0	0	20	22	0	26

Note: Cl = class, D. = order, SO. = suborder, IO. = infraorder, Sect. = section, F. = family

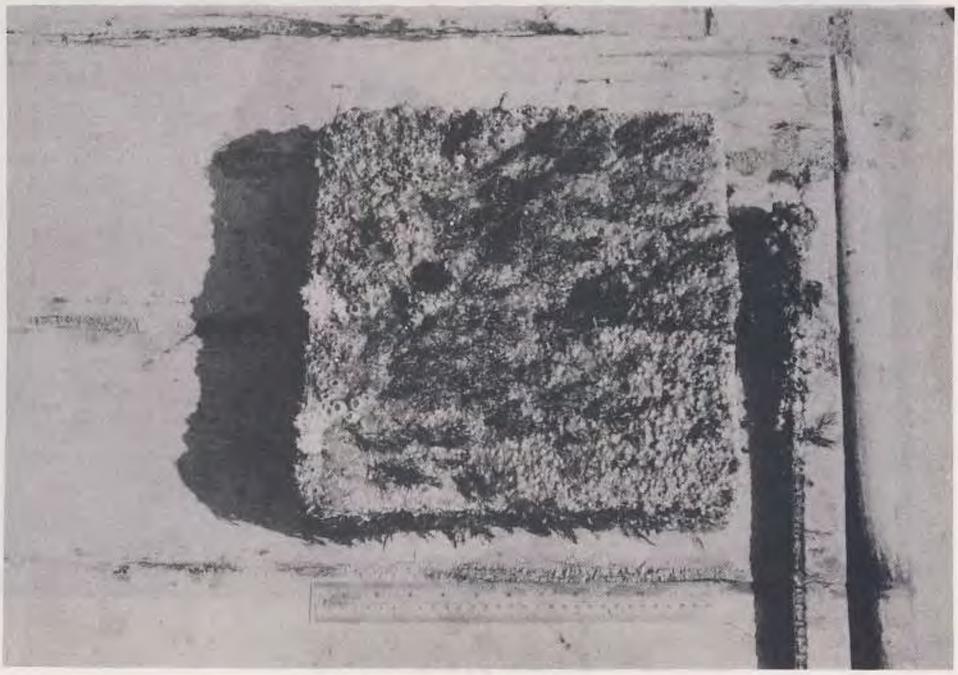
Upper plate



Lower plate

Fig. 19 Plates attached to both the upper and lower parts of the triangular module.

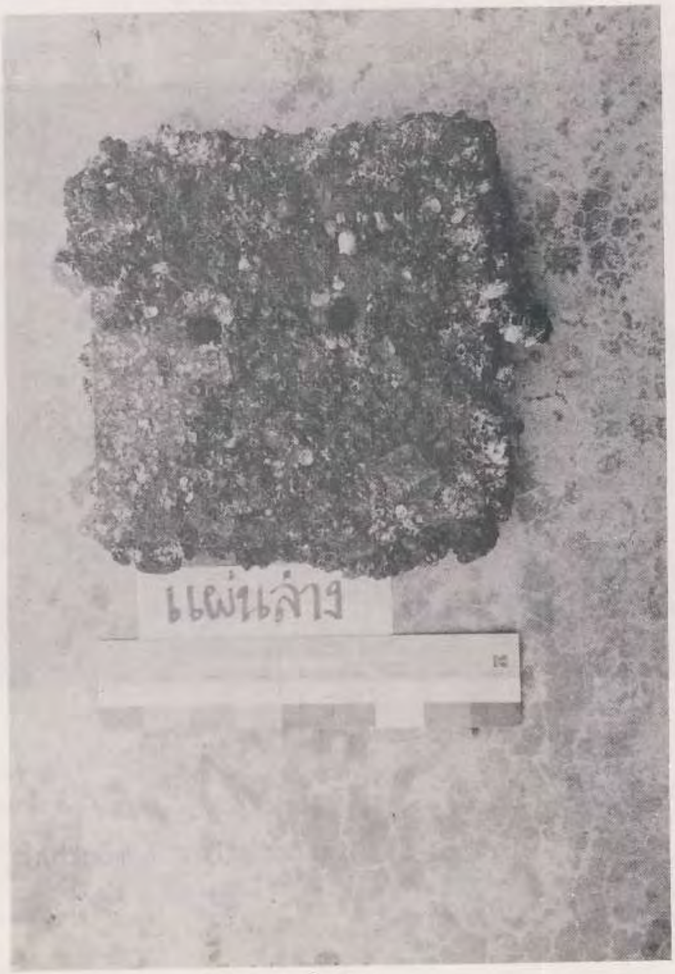
Upper plate



Lower plate

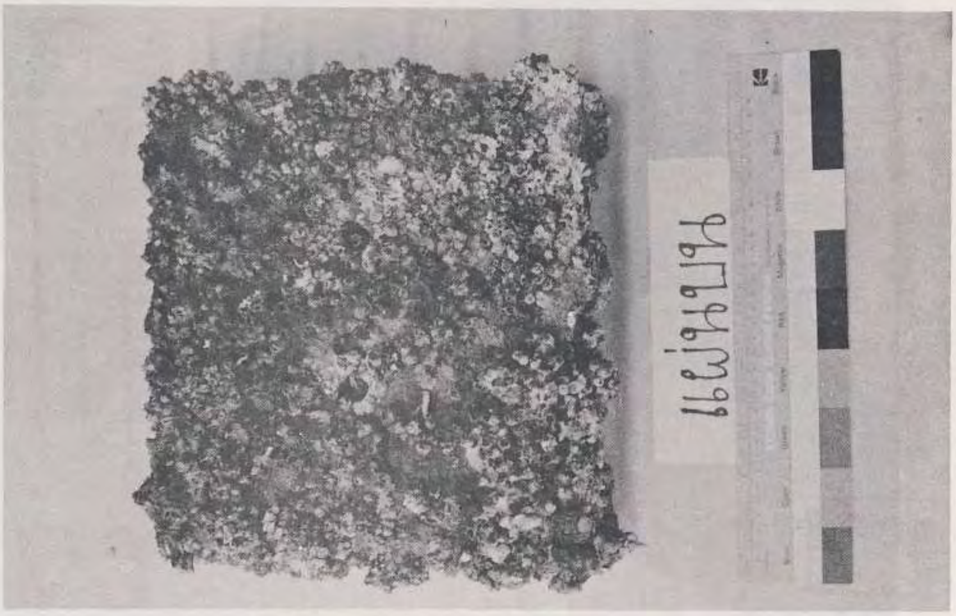
Fig. 20-a Plates collected in January, one month after the installation.

Upper plate



Lower plate

Fig. 20-b Plates after 5 months.

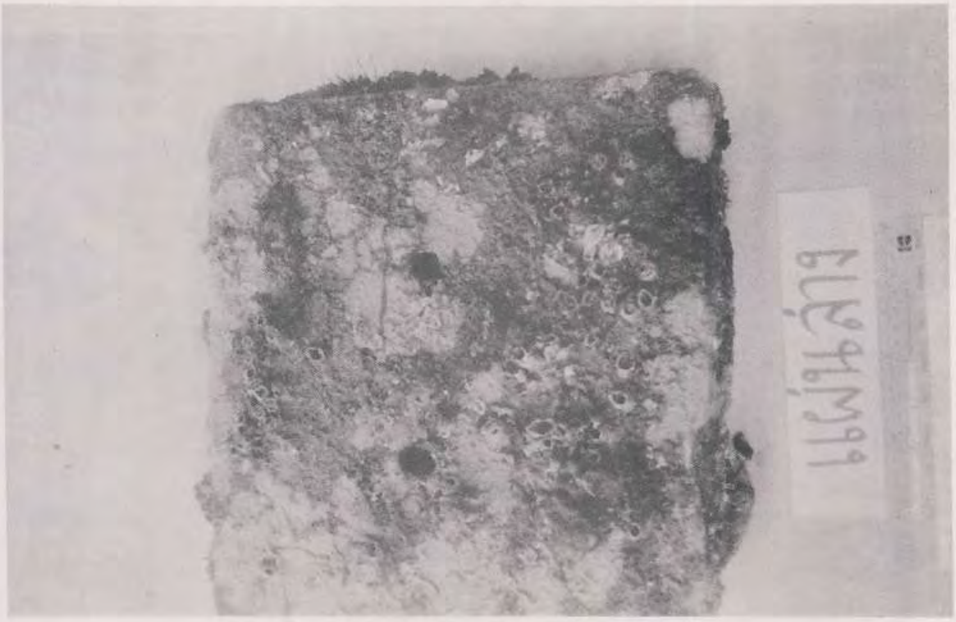


Upper plate

Lower plate

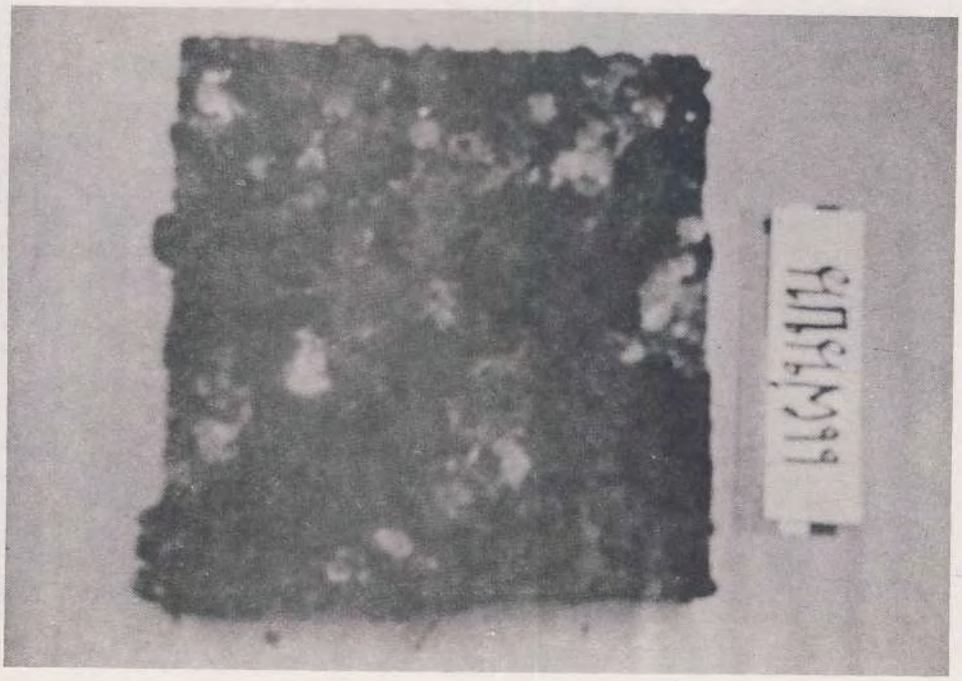
Fig. 20-c Plates after 7 months.

Upper plate

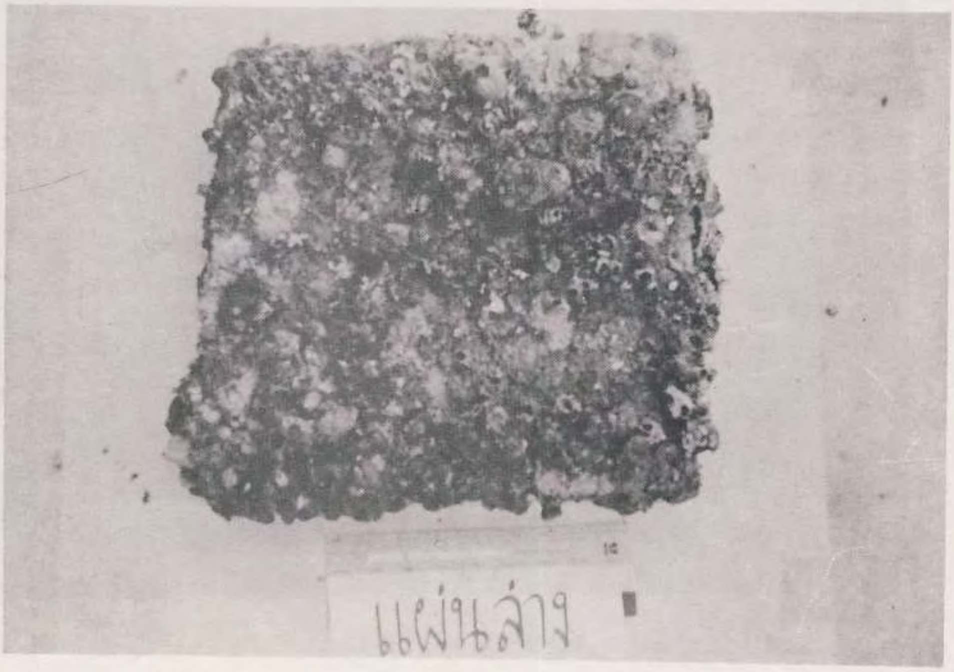


Lower plate

Fig. 20-d Plates after 11 months.



Upper plate



Lower plate

Fig. 20-e Plates after 13 months.

(3) Summary of the follow-up survey

Within a year, eight separate diving observations had been carried out, in order to check the stability of the modules installed. The result was that all the bamboo-reinforced concrete modules kept to their original position, neither overturning nor sliding, and there was no damage.

Slight differences existed between the two types of module, shown in Fig. 12. Ball-joint modules were covered with a little more sand than the triangular type. The extent to which sand may cause corrosion is not, at present, clear. However, after the end of the monsoon season, the thickness of sand on the modules seemed to decrease with the opposite wave action, due to the wind. Therefore, it is possible to say that this is a two-way phenomenon.

To reduce the sand thickness, it must be best to make the space between the bar and sea-bed wider, so that the water can pass through smoothly. For this purpose, only three balls make large, except the upper ball, maintain the bar at same size. At any rate, the triangular type is more suitable than the ball-joint type, with regard to corrosion. However, the ball-joint type is easier to manufacture than the triangular type. Thus, in conclusion, it may be appropriate to select one of the types, depending on economic considerations.

From the biological point of view, the number of modules installed was very small, apart from the bamboo type, so it is hardly possible to judge their effectiveness as an aggregate device. However, the data concerning sessile organisms should be considered more carefully to understand better the relationship between prey and predator around the modules.

4.5 Conclusion

As mentioned in the objectives section, this experiment was implemented mostly to verify, from the physical point of view, the stability of artificial modules which were constructed and installed on the sea-bed.

Fortunately, immediately after the installation of the modules, they proved to have stronger resistance to external forces than stated in the design calculations, as was seen when they were subjected to the most violent storm Thailand had experienced in the previous 35 years. Nevertheless, the modules were found during the follow-up survey to be stable and undamaged.

The data obtained can certainly be applied in the Southeast Asian region but, in the experiment, the economic aspects of the artificial reef project were not touched upon. So, the team leader wishes to pass comment on it here.

To clarify the effectiveness and economic efficiency of artificial reef projects is fundamental to deciding whether to proceed with them or not. However, acceptable explanations concerning this area have not even been given yet in Japan, where they have most experience of this kind of work. However, some recent investigations have been seen to have been both positive and effective (A. Chii et al: 1990).

Anyway, the team leader wishes to point out the following. After the implementation of artificial reef project, it would not have been satisfactory to obtain only data on whether fishermen get increased catches and higher incomes or not, in order to clarify the economic efficiency of the project. The most important point is that, in general, fisheries work should be continued, which is a fact that the team leader would like to emphasize.

In recent years, many Southeast Asian countries have been rapidly modernizing. Modernization means, mainly, industrialization based on a huge level of investment. However, industrialization also certainly causes water pollution, especially pollution of the sea, which threatens the existence of fisheries. To prevent this, all of the officers in charge of fisheries should help to ensure the survival of fisheries. And to do this the local fishermen, who will not only be engaged in fishing but will also work as guardians of the sea, should be entrusted with the responsibility for protecting fisheries. Moreover, although a large investiment is required to confront the overall problems related to industrialization, only a small percentage of their investiment would be required for fisheries development and counservation. The team leader believes that the true value of the artificial reef project will become clear within the overall industrial budget.

For the future, artificial reef projects may be important in two ways: first, for development by small-scale fisheries and, second, for conservation of fishing-grounds industrialized areas.

When the team leader looks at the situation in this region, he understands that the second direction is the more important and there is a need to plan measures as soon as possible.

5. Recommendations

5.1 Considerations concerning modules

For modules to function as artificial reef fish aggregate devices, they should be able to remain in their original position and should be stable against external forces, i.e. wave action and the force of the current, which means they have to considerable weight. On the other hand, the methods of placing some structures on the sea-bed, either by lowering them by crane or by allowing them to drop freely from a barge, should be considered carefully.

Since public works artificial reef projects in Japan started approximately four decades ago, both cubic and cylindrical type modules have been used and, in each case, they have been allowed to drop freely from a barge. Unfortunately, with this method, some modules have been broken or damaged on impact with the sea-bed. Also, all modules do not descend in the same way, i.e. some modules swivel downwards and some descend horizontally onto the sea-bed. When a module swivels downwards, the impact is greatest on its corners and so it gets damaged or breaks. However, the corners of the cubic type are reinforced with haunches.

As project budgets have increased, the modules used now are bigger than before: the biggest module is over 10 m in height and weighs approximately 70 tons. The reason that bigger modules are now being used is not only because the budget for this work has grown, but is also due to the results of natural reef surveys. And, because the local fishermen understand the usefulness of large natural reefs which are good fishing-grounds, cranes are used to lower bigger modules down to the sea-bed itself. This is now the chosen method.

Generally, there has been insufficient experience in this kind of work in the target region which is reported on here, so it is necessary to make decisions on not only module shape but also on methods of installation. There follows a consideration of the suitability and cost of various compound materials.

A compound module is one which consists of one or more made materials, for instance, bamboo-reinforced concrete. Single material modules may be of bamboo or wooden modules for example. Used tyres should not be used, because they cause water pollution (refer to the FAO-IPFC Symposium agenda, Colombo, 1990).

Specifically, the wooden module consists of the trunk of a palm tree covered with concrete, which increases both density and durability, because the inner part of a palm tree is generally soft and so corrosion is avoided. These modules can be manufactured at the actual project site and installed using different arrangement techniques. For instance, a bamboo-reinforced concrete module can be placed in the central area of a site, with other modules made of bamboo or wood in the outer areas.

The reason compound modules are recommended is to keep the investment costs as low as possible, until base-line data has been collected. However, depending on site conditions, the use of single or compound material modules has to be decided.

5.2 Considerations concerning installation equipment

Generally, in the target region, modules should weigh 2-3 tons per unit (Table 7, Fig. 21) to keep them stable and in their original position. However, artificial reef project sites are generally located in or near small fishing villages. Therefore, some ingenious devices are required to move the modules from the construction site (land) to the point of installation (sea). And, naturally, transportation at sea is more complicated.

Concerning land transportation, generally, the hoist crane is suitable and also cheaper than other types of crane. Also, sea transportation and installation requires some suitable equipment and, nowadays in Japan, barges with cranes are widely used. Here, a crawler crane which is used at the construction site is fixed onto a barge and is then used for installation (Fig. 22).

When this equipment cannot be procured, which is often the case, it is best to construct a simple barge with a crane at the construction site. In this situation, two types of crane (crawler and gantry) can be used, and it has to be decided, in each situation, which is suitable, depending on sea conditions. At any rate,

Table 7. 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. This table is based on the prototype module (Fig. 21); for details, refer to "Technical Manual for Resource Exhancement" (SEAFDEC TD/RES/25 1990).

2. The relationship between wave height (H) and wave cycle (T) and between wave height and wave length (L) can be calculated as follows: $T = 3.86 \sqrt{H}$, $L = 1.56\ T^2$

3. 0 : stable

4. Safety factor : 1.2

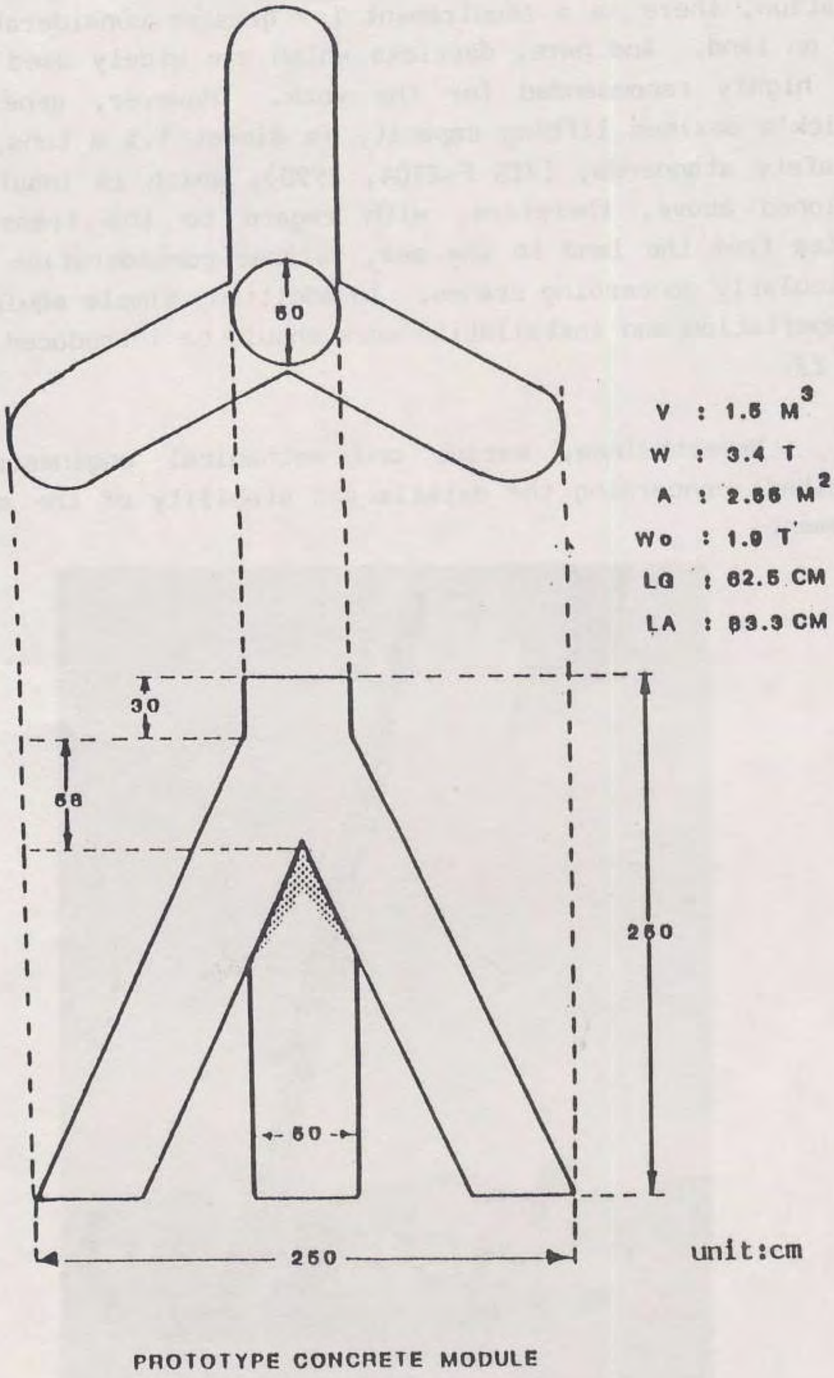


Fig. 21 Prototype concrete module.

installation work is carried out at sea and, with regard to a stable operation, there is a requirement for greater consideration than the work on land. And here, derricks which are widely used on ships are most highly recommended for the work. However, generally a ship derrick's maximum lifting capacity is almost 1.5 m tons, as required by safety standards, (JIS F-2104, 1990), which is insufficient. As mentioned above, therefore, with regard to the transportation of modules from the land to the sea, further consideration is required, particularly concerning cranes. In addition, simple equipment for the transportation and installation work should be introduced, as shown in Fig. 23.

Nevertheless, marine and mechanical engineers should be consulted, concerning the details and stability of the most suitable equipment.

Fig. 22 Barge and crane used in the experiment.

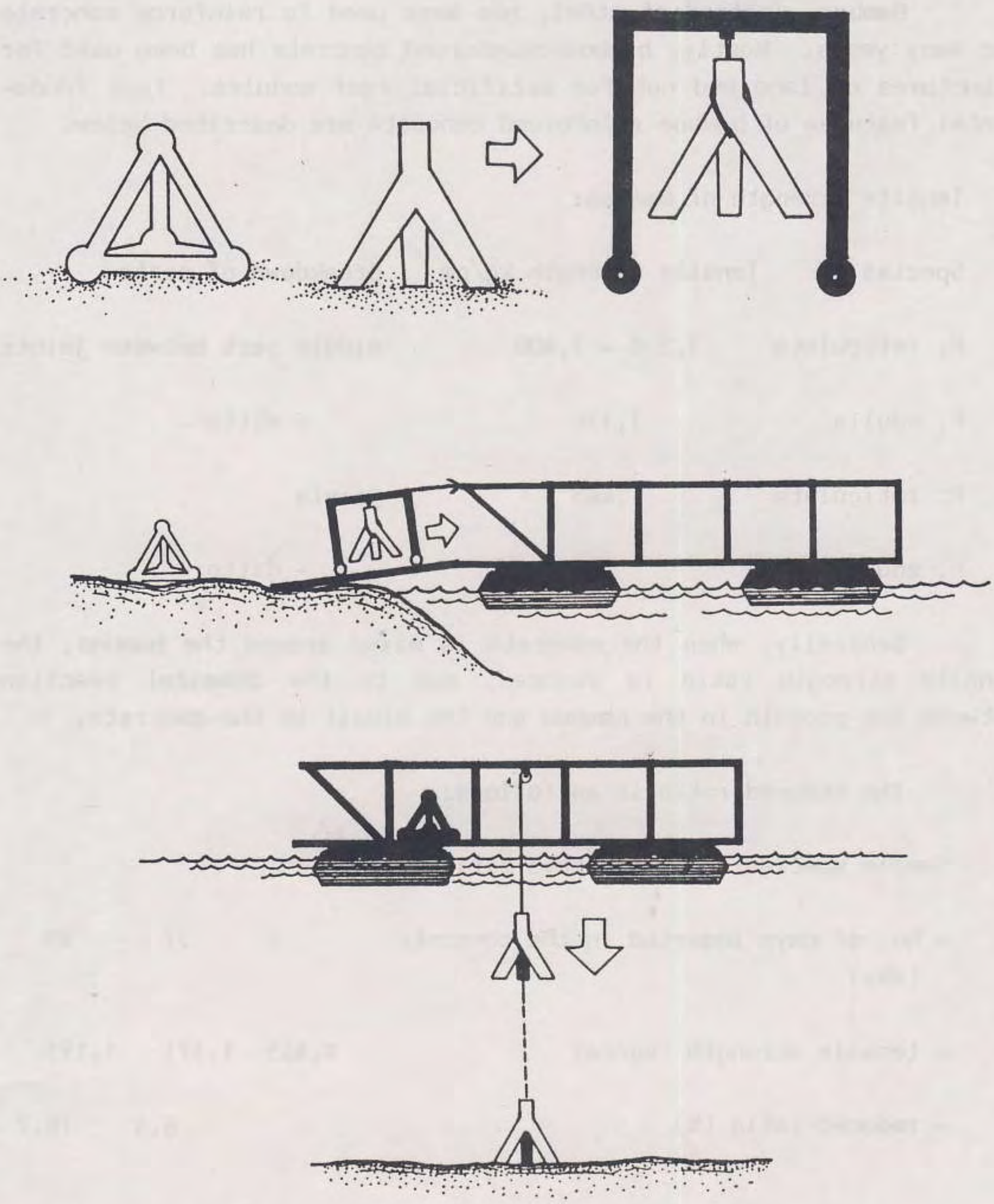


Fig. 23 Concept of the installation equipment.

Appendix 1: Features of bamboo-reinforced concrete

Bamboo, instead of steel, has been used to reinforce concrete for many years. Mostly, bamboo-reinforced concrete has been used for structures on land and not for artificial reef modules. Four fundamental features of bamboo reinforced concrete are described below.

1. Tensile strength of bamboo:

Species	Tensile strength kg/cm	Breakdown of parts
P. reticulata	3,250 - 3,400	middle part between joints
P. edulis	1,170	- ditto -
P. reticulata	1,465	joints
P. edulis	988	- ditto -

Generally, when the concrete is mixed around the bamboo, the tensile strength ratio is reduced, due to the chemical reaction between the protein in the bamboo and the alkali in the concrete.

The reduced ratio is as follows:

Sample species: Phyllostachys reticulata:

- No. of days inserted in the concrete (day)	0	57	99
- tensile strength (kg/cm)	1,465	1,371	1,191
- reduced ratio (%)	-	6.4	18.7

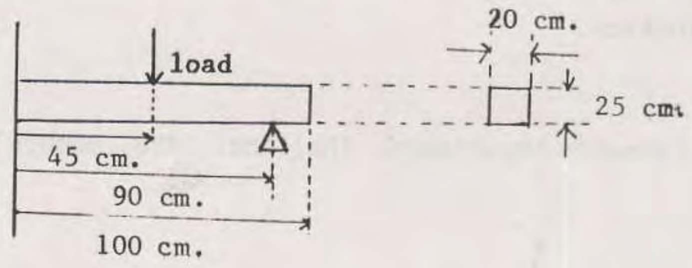
2. Elastic coefficient of bamboo:

The elastic coefficient of steel and concrete is 21×10^5 kg/cm^2 and 1.4×10^5 kg/cm^2, so the elastic coefficient of steel and concrete is 15, which is higher and more effective. On the other hand, the elastic coefficient of bamboo ranges from 1.6×10^5 to 2.3×10^5 kg/cm^2, and so it has great tensile strength and, consequently, a large elastic coefficient. Therefore, using the average figure 2.1×10^5 kg/cm^2, the elastic coefficient of bamboo and concrete is 1.5.

As a result, the use of bamboo for reinforcement is less effective, compared with steel.

3. Unit strength of beams made of bamboo-reinforced concrete.

A breakdown test was implemented under the conditions shown in the figure below.



The two types of beams used were made of concrete, not reinforced concrete, and three pieces of bamboo (P. reticulata) were inserted. As a result, the concrete beam cracked and simultaneously broke under a 2.26 ton load. On the other hand, the bamboo-reinforced concrete cracked under a 2.95 ton load and broke under a 4.5 ton load. Therefore, bamboo-reinforced concrete beams are twice as strong, with regard to crack load, showing the effectiveness and relative usefulness of bamboo as reinforcement.

4. The unit strength of columella made of bamboo-reinforced concrete

The use of bamboo for compression is not so effective, because the elastic coefficient is not as great as for concrete. Therefore, bamboo-reinforced concrete collumella do not have a high resistance level, compared with non-reinforced concrete collumella, although, at the breaking point, it is not so fragile that they break immediately.

(Source: J. Sen: Strength of bamboo and bamboo-reinforced concrete, Bll. of the Architectural Institute of Japan, 1940 - in Japanese)

Appendix 2: Distribution of bamboo

In Thailand, it is said that 60 species of 11 genus of bamboo are widely distributed. Of these species, some of the most useful species used for bamboo-reinforced concrete are listed with their general characteristics below, including their scientific names and areas of distribution.

(Source: Royal Forestry Department, Thailand: 1988, Bamboo)

Table. Types of Bamboo in Thailand (Niranam, 1985 and Saard, 1985)

Scientific Name	Area of Distribution	General Characteristics	Utilization
1. Genus - Arundinaria A. Ciliata (Pai Jode, Yaah, Hua Khang)	- All areas of Thailand, especially in the northeast	- Green and grey stem - Found in thick clusters - Height ≃ 5 m. - Internode length ≃ 10-20 cm. - Diameter ≃ 7-10 mm. - No thorns - Grey and bright yellow shoots	- Stems used to make broom handles - The rhizome has many strange shapes so can be used to make ornaments - Stem used to build fences - House plants - Edible shoots
2. Genus - Bambusa 2.1 B. tulda (Pai Bong)	- Evergreen forest	- Large - The internode diameter - 6-10 cm. and length ≃ 20-30 cm. - Height ≃ 9-12 m.	- Stems used to make bamboo handicrafts, mats and paper - Edible shoots
2.2 B. arundinacea (Pai Pa or Pai Nham)	- All areas of Thailand	- Young plants are green, old plants yellow-green - Large - Thorny, with many branches - Internode diameter ≃ 10-15 cm.	- Stems used to build scaffolding, or painting, - Edible shoots
2.3 B. longispiculata (Pai Lam Ma Lok)	- All areas of Thailand but not much in the South	- Dark green stem - No thorns - Internode diameter ≃ 7-10 cm. - Height ≃ 10-15 m.	- Stems used to build scaffolding, animal traps, furniture and handicrafts - Edible shoots
2.4 B. Rulgaris (Luarg or Pai Chin)	- Mostly house plants	- Presumed to be from China - Yellow stem with different kinds of green along the inter-node - Diameter ≈ 5-10 cm. - Internode length ≃ 20-25 cm. - Height ≃ 10-15 m.	- Used for decorations - Furniture and other utensils - Edible shoots, but not so popular

Scientific Name	Area of Distribution	General Characteristics	Utilization
2.5 B. polymorpha (Pai Hob or Pai Hom)	- Chieng Rai Province	- Stem height ≃ 10 m. - Internode diameter ≃ 7.5-15 cm. and length ≃ 40 cm. - The shoots are big and covered with know hair - Weight ≃ 3-5 kg.	- Utilization of stem is not popular - Bitter shoots, edible but not common
2.6 B. sp. (Pai Bong Wan)	- Northeast, especially in Loey Province	- Young plant is green, the old plant dark-green - Diameter ≃ 5-8 cm. - Height ≃ 5-10 m. - Green shoots - Weight ≃ 1.5 kg.	- Stems used for bark-rope and handicrafts - Shoots common for food
2.7 B. nana (Pai Kan Rom, Pai Pai Preng or Pai Lieng)	- All areas of Thailand, especially in Prachinburi, Trad and Rayong Provinces	- The stem is thick and green - No thorns - Diameter ≃ 3-5 cm. - Height ≃ 8-10 m. - Green shoots with grey and red peel	- Stems used for ladders, traps and furniture
2.8 B. sp. (Pai Dum or Pai Ta Dum)	- Found in thick forest in Kanchanaburi and Chantaburi Provinces	- The stem is dark-green - No thorns - Internode diameter ≃ 7-10 cm. and length ≃ 30-40 cm. - Height ≃ 10-12 m.	- Stems used for construction and handicrafts - Edible shoots
2.9 B. ventricosa (Pai Nam Tao)	- Found in all areas of Thailand	- Presumed to be from China - Short, green stem and yellow bands in the internode - Diameter ≃ 4-5 cm. - Height ≃ 3-4 m. - Yellow shoots	- Used for decorating

Scientific Name	Area of Distribution	General Characteristics	Utilization
3. Genus - Cephalostachyum			
3.1 C. pergracitle (Pai Khao Larm)	- The North - Northern part of Kanchanaburi Provice - Some areas of the North-east	- Stem diameter is 5-7.5 cm. - Internode length ≈ 30 cm. - Height ≈ 7-8 m. - Green and grey stems - Big shoots	- Stems used for sticky rice bamboo, handicrafts - Shoots not so common to eat
3.2 C. virgatum (Pai Hui)	- The North	- Stem diameter is 5-10 cm. - Internode length ≃ 50-70 cm., with branches - Height ≃ 10-18 m.	- Stems used to build house-structure and handicrafts - Shoots not so common to eat
4. Genus - Dendrocalamus			
4.1 D. strictus (Pai Sang, Pai Nual, Pai Plong or Pai Si Nual)	- Found in wet evergreen forest	- Green stem - Internode very long, ≃ 50-70 cm. length - Height ≈ 8-10 m. - No thorns - Brown shoots with brown hair - Diameter ≈ 5-12 cm.	- Stem used to make bark-rope for handicrafts - Edible shoots
4.2 D. hamiltomii (Pai Hok or Pai Nual Yai	- The North and Kanchana-buri Province)	- Green and grey stem - Diameter ≈ 15-20 cm. - Height ≃ 10-15 m.	- Stem used for construction, paper and handicrafts - Edible shoots
4.3 D. giganteus (Pai Poh or Pai Proh)	- The North and Northeast	- Brittle, green stem with diameter of ≃ 10-20 cm. - Internode length length ≃ 30 cm. - Height ≃ 30 cm.	- Stem used for sticky rice bamboo, broom handles

Scientific Name	Area of Distribution	General Characteristics	Utilization
4.4 D. asper (Pai Tong)	- Popular for planting in the Central regions, especially Prachinburi Province	- Large with diameter ≃ 6-15 cm. - No thorns - Internode length ≃ 20 cm. - Shoot weight ≃ 3-10 kg.	- Stems used for house constru-tion, handicrafts and toothpicks - Edible shoots very common
4.5 D. membranaceus (Pai Sang, Pai Nual or Pai Sang Doy)	- All areas of Thailand, especially the Central and Northern Parts	- Bright green stem - No thorns - Diameter ≃ 3-12 cm. - Height ≈ 10-25 m. - Internode length ≃ 30 cm.	- Stems used for construction, handicrafts and paper - Popular edible shoots
5. Genus - Gigantochloa			
5.1 G. auriculata (Pai Man or Pai Poh)	- The South	- Green stem with no thorns - Diameter ≃ 8-10 cm. - Internode length ≃ 30-40 cm. - Height ≃ 10-15 m. - Dark brown shoots, weight ≃ 3-4 kg.	- Stems used for house construc-tion, handicrafts - Edible shoots
5.2 G. albociliata (Pai Rai)	- All areas of Thailand	- Green and grey stems - No thorns, covered with hair - Small, with diameter of ≃ 1.5-2.5 cm. - Found in thick clusters - Internode length ≃ 30 cm.	
5.3 G. ligulata (Pai nae or Pai Kai)	- Evergreen forest in the South	- Green stem - Diameter ≃ 2-3 cm. - Internode length ≃ 30-35 cm. - Height ≃ 3-4 cm.	- Stem used to make furniture - Edible shoots

Scientific Name	Area of Distribution	General Characteristics	Utilization
5.4 G. apus (Pai Ta Kwang)	- Evergreen forest in the South	- Green and yellow stem - Diameter ≃ 4-6 cm. - Internode length ≃ 30-40 cm. - Height ≃ 5 m.	- Stem used to make furniture - Edible shoots
5.5 G. hasskarliana (Pai Pak Man)	- All areas of Thailand	- Green and yellow stem - Internode length ≃ 20-25 cm. - Diameter ≈ 3-4 cm.	- Stem used to make fences
5.6 G. densa (Pai Pak)	- The South and Kanchanaburi Province	- Green stem with no thorns - Large, with diameter ≃ 10-13 cm. - Weight of large shoots ≃ 2-3 kg.	- Stem used to make house-utensils and paper - Edible shoots
5.7 G. compressa (Pai Kai Dum)	- Kanchanaburi and Ranong Provinces	- Dark green stem - No thorns - Large, with diameter ≃ 7-10 cm.	- Brittle, unusable stem, - Edible shoots
5.8 G. hosseusii (Pai Bong Kai)	- All areas especially Chieng Rai Province	- Bright green stem - Internode diameter ≃ 5-8 cm. with length ≃ 40-50 cm. - Height ≃ 10-13 m.	- Stem used to make handicrafts - Edible shoots
6. Genus - Melocanna M. humilis (Pai Kriep)	- Evergreen forest	- Large stem, with diamenter of 3-15 cm. - Internode length 50-120 cm., thickness 0.5 cm. - Height ≃ 10-15 m. - Large bamboo shoots	*
7. Genus - Neohouzeava	- Trad Province	- Shiny, green stem	- Stems previously used for spools

Scientific Name	Area of Distribution	General Characteristics	Utilization
8. Genus - Thyrsostachys			
8.1 T. siamensis (Pai Ruak)	- Kanchanaburi Province	- Small stem, with diameter ≈ 2.7 cm., height ≈ 5-10 m. - Found in thick clusters	- Stem used for construction and paper - Edible shoots
8.2 T. oliveri (Pai Ruak Dum)	- The North	- Dark-green stem - Internode diameter of ≈ 4-7 cm. and length ≈ 23-30 cm. - height ≈ 10-15 m.	- Strong stem used for umbrellas, ormaments, ladders and furniture - Shoots not common food.