CHAPTER 83

DESIGN OF A DETACHED BREAKWATER SYSTEM

by

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ABSTRUCT

Beach erosion is one of the serious problem in Japan. As a countermeasure against beach erosion, many preventive works, such as sea walls and groins, have been constructed during the past 20 or more years. However, as the result of field investigations, it has become clear that sea walls and groins are not always effective on beach erosion prevention, and inversely, in some cases, they accelerate the beach erosion.

Based on the above cognition, the author has proposed and tried to apply the detached breakwater system as a measure against beach erosion for the last 8 years. This is for the purpose of developping the sand deposition behined the breakwater. Therefore several experimental works of the detached breakwater system were carried out under the guidance of the present author, and most of these tests were successful.

The design method of this system was composed by the author on the basis of the result of field investigations, which have been conducted for more than 8 years.

The numerous construction works of detached breakwaters have been carried out in accordance with the design method proposed in this paper, and the effectiveness of detached breakwaters has been proved on the several coasts in Japan where severe beach erosion occurs.

EXPERIMENTL WORKS OF THE DETACHED BREAKWATER SYSTEM

The oldest document on beach erosion in Japan was written in 833. Since the 1950's, beach erosion has been increasingly severe in many coastal areas, not only on sandy beaches, but also on soft-rocky coasts. The deterioration of rivers as a source of sediment supply to the coast, and the construction of shore protection works and harbor facilities have brought the erosion of the coast line all over the Japanese Islands.

Many groins have been construoted on many coasts, and the number of groins amounts to more than 8,000 at present. More than half of them are still effective, but the remainders are ineffective. The reason of such ineffectiveness must be as follows. Before 1940's unilatteral littoral drift caused most of the beach erosion, but recentry, the straightly coming waves, the direction of which is almost perpendicular to the shore line, have been causing the severe beach erosion.

Owing to the above consideration, the author tried to apply the detached breakwater system as a measure against beach erosion. A detached breakwater system consists of a group of breakwaters, constructed in parallel with the shore line, and is normally located in the surf zone. The primary function of the detached breakwater is to diffract and dissipate the incoming wave energy.

The first experimental work of this system was carried out on Ishizaki coast near Hakodate city Hokkaido Island. Before 1960, there were wide sandy beaches with 1 or 2 meters thickness of sand on the rocky sea bed. After finishing the sea wall construction works, which were carried out early in the 1960's, the sandy beaches have vanished.

Then, the author proposed to construct detached breakwaters there, and built trially the first one the nearshore of the rocky bed in 1966. Soon after the completion of the work, the tombolo was formed in front of sea wall, and it grew larger gradualy.

More than 10 breakwaters have been succeedingly constructed during the following several years, and they were all effective. According to later investigations, it has become clear that the deposit sand was carried from offshore sea bed at a depth of about 4 meters, where a kind of seaweeds was newly found. The seaweeds can grew only on the rocky bed. The length of a breakwater is about 60 meters, and it was built by the 2 layer pile of the 3.5 ton hexa-leg-blocks. The tombolos generated by the detached breakwater system exist even now, and the yield of seaweeds is on the increase.

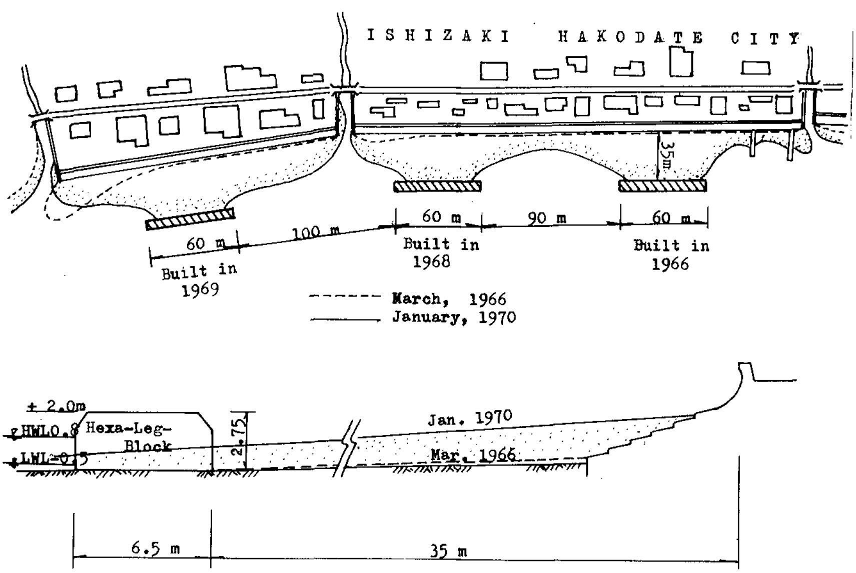

Fig. 1 The detached breakwaters on Ishizaki coast.

Pl. 1 The detached breakwaters on Ishizaki coast and the model of the hexa-leg-blocks

The second experimental work of this system was carried out on West-Niigata coast, which is one of the most famous places in the sense of severe beach erosion in Japan. The coast has been eroded since 1890, and the eroded distance amounts to more than 300 meters. Therefore, its regression speed was about 6 to 10 meters per year. The first breakwater construction was initiated in 1966, and the additional three breakwaters have succeedingly constructed in later 2 years.

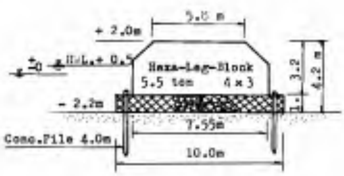

Fig. 2 The structure of the breakwater on West-Niigata coast

The length of the first breakwater is 400 meters. The structure was constructed on the sandy sea bed at the depth of about 2.5 meters, and was about 120 meters offshore from the shore line. The breakwater consists of 2 layer pile of hexa-leg-blocks and rubble mound covered with steel wire cage.

Since it was under construction, the tombolo was formed behind the breakwater, and the maximum advanced distance of shore line was about 80 meters. However, 2 years later after the completion, the body of breakwater sunk about 1.8 meters, and the tombolo reduced the size. Reinforcement works for rising the crown height of breakwater were carried out, and the tombolo advanced again.

Further experimental works have been carried out in the following several years, and most of them have been successful as the countermeasure against beach erosion.

Then the author intended to establish a design criterion for the detached breakwater system. At first, the author analysed the collected data of 86 samples of existing detached breakwaters.

STATISTICAL STUDY OF EXISTING DETACHED BREAKWATER

In 1969, the author has done a statistical study on the existing detached breakwaters. At that time, there were 86 places where breakwaters had been constructed, and the number of the breakwaters was 217 in total, in which the breakwaters at 18 places constructed under the author's supervision were included. The following factors were investigated.

1. Classification of breakwater type (continuous, single, or group breakwaters)
2. Relationship between breakwater length and distance from shore line
3. Relationship between breakwater length and water depth
4. Relationship between distance from shore line and openning between the neighboring two breakwaters
5. Structure type and crown height above still water level
6. Relationship between sinking and foundation works
7. Primary factor for the sand deposition and tombolo formation

(1) Classification of breakwaters

The detached breakwaters were classified into several according to the length of breakwaters. Table 1 is the result of classification.

Table 1 Classification of existing detached breakwaters

Classification		Number of places	Number of breakwaters	Total length
Continuous breakwaters		10	10	12,743 m
Island type or group breakwaters	Single breakwaters	34	34	4,093
	2 breakwaters	18	36	4,189
	3 breakwaters	9	27	3,952
	4 breakwaters or more	15	110	8,243
Total		86	217	33,220 m

According to this table,

1) The number of places for continuous type is only 10 (12%), but the total length of them amounts to 38% of all, and the mean length of a breakwater exceeds 1,200 meters.
2) The number of places for single type amounts to 40%, but the mean length of a breakwater is only 120 meters.
3) Group breakwater, concist of 4 or more breakwaters, amounts to only 17% of the total number of places, but the number of breakwaters amounts to 51% of all, and the mean length of a breakwater is 75 meters.

(2) Continuous breakwater

According to the field investigations about the continuous breakwaters,the following facts can be found:

1) Most of the breakwaters have been constructed before 1960.
2) They have never formed tombolos.
3) For the purpose of the sand deposition, the continuous breakwater are not always better than the island type breakwaters.
4) For the purpose of dissipating wave energy, the continuous breakwaters are better than the island type.

(3) Relationship between breakwater length and distance from shore line

Fig. 3 shows the relationship stated above. It is impossible to find out any correlation between breakwater length and distance from the shore line.

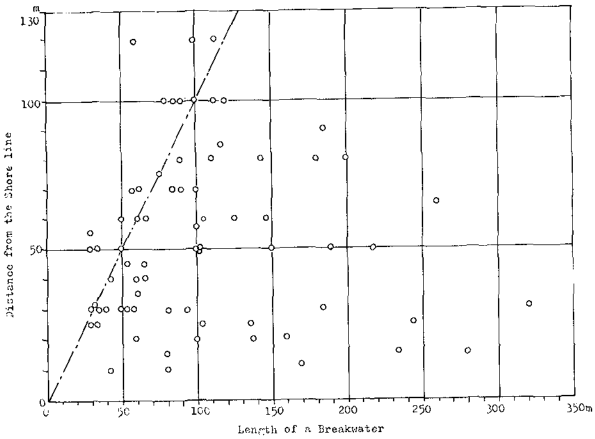

Fig.3 Breakwater length and distance from shore line

(4) Relationship between breakwater length and water depth

Fig.4 shows that it is also impossible to find out a clear correlation between the breakwater length and the depth where the breakwaters are constructed.

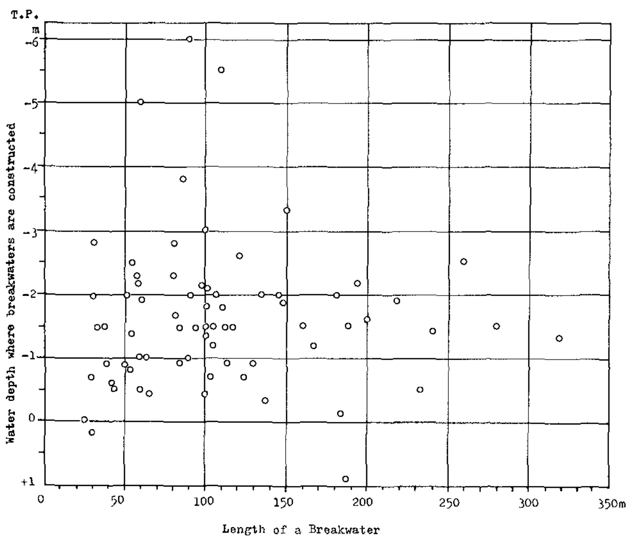

Fig.4 Breakwater length and water depth

Most of the breakwater were constructed at the water depth within the range of 1 m to 2 m below T.P.(Tokyo Peil).

(5) Relationship between distance from shore line and openning

Fig. 5 shows that most of the openning between the neighboring two breakwaters are less than 50 m, and they have no relationship with the distance from the shore line.

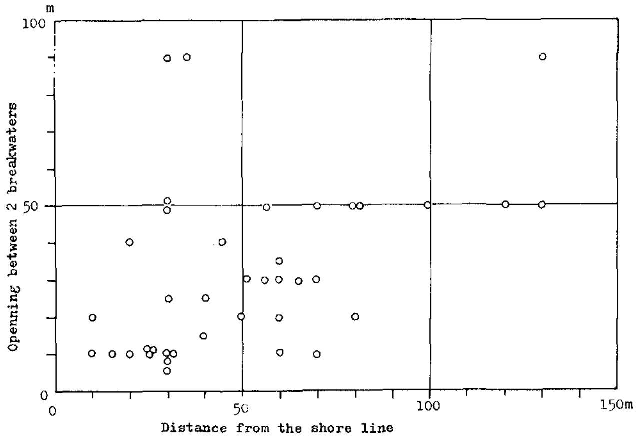

Fig. 5 Distance from the shore line and openning

(6) Crown height of breakwater

Fig. 6 shows that most of breakwater have the crown height of 1 to 2 m above the high water level.

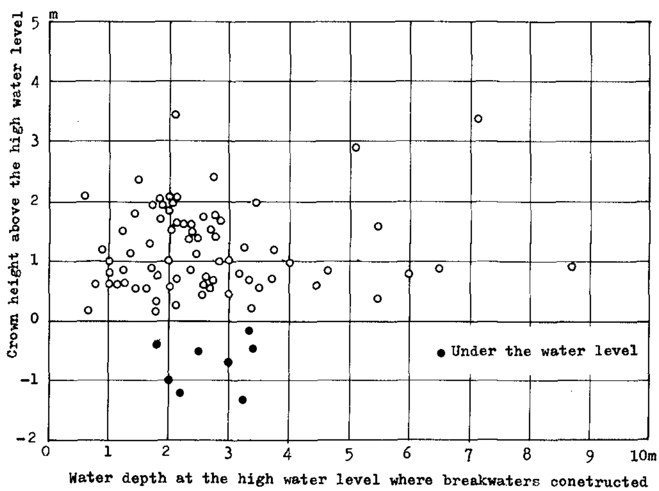

Fig. 6 Crown height of breakwaters above the high water level

(7) Structure type of breakwater

Table 2 shows the structure type of breakwaters classified for each age when breakwaters construction started.

Table 2 The structure type of detached breakwaters

Construction start / Structure		before 1955		1956-1965		after 1966		total	
		place	length	place	length	place	length	place	length
permeable	tetrapods	2	2,750m	6	2,931m	9	4,005m	17	9,686m
	hexa-leg blocks	-	-	2	725	16	5,392	18	6,117
	hollow triangle	-	-	1	250	1	120	2	370
	akmon	-	-	-	-	1	279	1	279
	another blocks	-	-	-	-	2	248	2	248
	total	2	2,750m	9	3,906m	29	10,044m	40	16,700m
unpermeable	concrete blocks	7	4,594	4	1,950	1	238	12	6,782
	cellular blocks	2	485	-	-	3	187	5	672
	composit type	2	2,230	3	800	3	1,260	8	4,290
	rubble mound	3	1,040	4	887	5	1,320	12	3,247
	stone facing	6	871	2	367	1	291	9	1,529
	total	20	9,220m	13	4,004m	13	3,296m	46	16,520m
all total		22	11,970m	22	7,910m	42	13,340m	86	33,200m

According to this table, it is recognized that the structure type of of breakwaters has been changed with the age and the difficulty to get construction materials. Very recentry, after the appearance of tetrapod, many kinds of armour blocks have been used as a construction material in general. It is not clear that what type structure is most suitable for detached breakwaters, but the author pressumes that the permeable type has some merrit and generally better than un-permeable type.

(8) Sinking and Foundation

Most of the breakwaters have been sinking more or less, except those constructed on the rocky sea bed. Several measures for prevention of sinking have been applied, however the effective foundation has not yet been found.

(9) Factors for getting good sand deposition and tombolo formation

The function of the existing 86 samples of detached breakwaters are devided into two groups, one is for wave dissipation and another is for sand deposition and tombolo formation.

Table 3 shows the purpose and function of detached breakwaters.

Table 3 Purpose and function of existing 86 breakwaters

Purpose	Number of place	Function for sand deposition			
		nothing	small	effective	tombolo
Wave dissipation	48	36	5	7	1*
Sand deposition	38	6	5	27	19*
Total	86	42	10	34	20*

* : Number of place where tombolos were formed are included in "effective".

In spite of that the breakwaters were constructed with wave dissipation purpose, the breakwaters are effective at 12 places for sand deposition. Inversely, in spite of that the breakwaters were constructed with sand deposition purpose, the breakwaters at 11 places are ineffective.
In order to find out the factors for getting good sand deposition and tombolo formation, the author investigated the relationship among the breakwater length, distance from shore line, the crown height of breakwater, and water depth where the breakwaters were constructed.
Fig. 7 shows the correlation among these factors for island type breakwaters (except continuous type breakwaters) in non-dimension. However, as shown in this figure, any clear factor for sand deposition and tombolo formation can not be found.

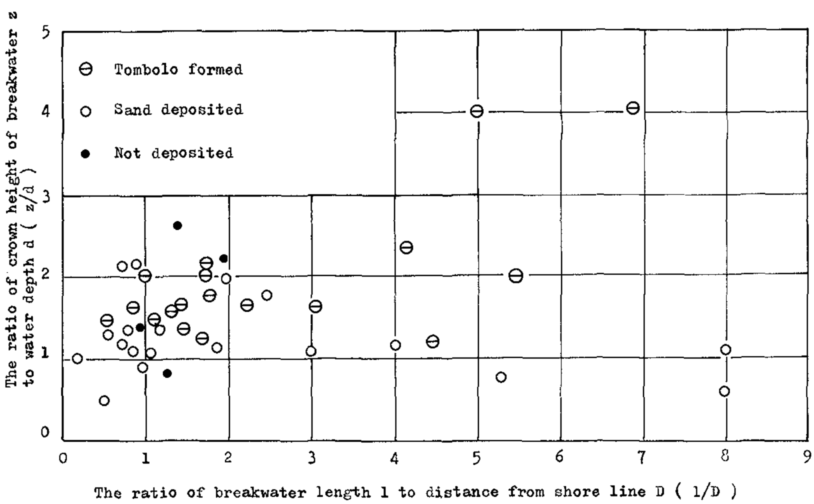

Fig. 7 Effect of breakwater location on sand deposition

DESIGN CRITERION OF THE DETACHED BREAKWATER SYSTEM

Since the statistical studies stated above could not find any clear factor for sand deposition, the author tried to make a tentative design criterion according to the results of investigation of statistical analyses and of the experience obtained through the experimental works described above.

First of all, the author proposed to classify the breakwater system into the following four systems according to the water depth of the breakwater location.

1. The shore line system
2. The shallow water depth system
3. The median water depth system
4. The deep water depth system

(1) The shore line system

This type is normally to built the breakwaters near the shore line, and to be used in the following cases:

1. the place where the beach slope being steep,
2. sand deposition to be created being possibly sufficient even in a small scale,
3. the main object being to prevent score in front of sea wall,
4. to maintain the existing shore line as it is.

As for the type to be employed in such cases, the group island type shall be preferable because of following effects,

1. flowing the sand through the openning of breakwaters,
2. intercepting the littoral drift along the shore line caused by diffraction waves.

The length of a breakwater must be 2 or 3 times wave length, that is 40 to 60 meters, and the openning between the neighboring two breakwaters must be equall to one wave length, that is about 20 meters. As to the structure type, a 2 layer pile of armour blocks is effective, wherein the foundation works are not particularly needed. The inherent problems of this system may be the occurrence of a large scale scoure in front of the breakwaters, especially in the case of constructing a breakwater on the coasts confronting the open ocean.

(2) The shallow water depth system

Breakwaters of the shallow water depth system are constructed at a water depth of less than 1 meter on a relatively gentle beach or on a beach where a big tidal range is expected, and the construction works are principally conducted by the use of the track-and crane method.

Deposition of sand is ensured by this system even though the amount of collected sand is not enough in many cases.

As for the type to be used in this case, the group island type breakwaters shall be preferable by the same reason as described in the shore line system. When a continuous breakwater is applied, jetties should be constructed behind the breakwater at an appropriate interval.

The length of a breakwater must be equall to 3 to 5 times the wave length, that is 60 to 100 meters, and the openning between the neighboring two breakwaters must be equall to one wave length, that is about 20 meters. In addition, the length of a breakwater should not be longer than 10 times the wave length in the case of island type.

Though the distance from the shore line is most naturally determined by the water depth of the breakwater location, too long distance is not profitable.

As to the structure, an arranged pile of armour blocks is profitable, and the crown height of structure is extended to more than 1 to 1.5 meters, or a half wave height above the high water level. Possible large scale sinking of the detached breakwater may be prevented to some extent by means of proper foundation works such as mat, rip rup and like, but depending upon the foundation conditions after execution, an enforcement of armour blocks should occasionally be considered.

As a result of case study by using the data of previously done works, the following seems to be the main reasons why the sand deposition could not be achieved in this system.

1. The structure is impermeable and built in olden age.
2. The length of breakwater is too short in comparison with the distance from shore line, and the structure is located at the site of big tidal range.
3. The structure is very high and is impermeable.

In designing and executing the breakwaters, therefore, the above mentioned points should be fully considered beforehand.

(3) The median water depth system

This system is the most common one which is constructed by the use of a floating plant. The construction site should be selected in the surf zone at the water depth of 2 to 4 meters normally, and of 6 meters or more in particular case.

The purpose of this type is to reduce the wave energy and to produce the accreation of sand behind the breakwater.

For the first purpose mentioned above a long continuous breakwater is preferable, while for the second purpose an island type breakwater or a group of short breakwaters is rather preferable.

When a single island type breakwateris used, the breakwater length should be 3 to 10 times the wave length, that is about 100 to 300 meters. When a group of a breakwater is used, the length of each breakwater should be 2 to 6 times the wave length, that is 60 to 200 meters, and the openning between the neighboring two breakwaters should be one wave length, that is 20 to 50 meters.

Although the distance from the shore line has a close relationship with the depth of the breakwater location, it should be 0.3 to 1.0 times the length of breakwater as a standard. In the case of continuous breakwater, the distance should be 1 to 3 times the wave length, that is 30 to 100 meters.

As for the structure type, there is a strong tendency to use armour blocks, but in the case of that the water depth is rather deep, some other works such as rubble mound breakwater, or composit type breakwater etc. should be considered in design.

The crown height should be a half wave height, or 1.0 to 1.5 meters above the high water level, the condition of which is the same as the shallow water depth system.

The sinking of the breakwater body is one of the biggest problems here. Several countermeasure have been tried, but any definite solution has not been yet found.

Most of the cases in this system where sand could not be deposited are situated on the unsuitable conditions for the sedimentation and accumulation of sand. In other words, this situation may be explained as follows. In those cases, the water surface behind the breakwater is not calm enough to induce the sedimentation and accumulation of sand. That is to say, the water surface in the area is disturbed by the reflected waves which are generated from the sea wall owing to the fact that the water depth in front of sea wall is deep enough or the slope of sea bottom near the shore line is steep enough.

Accordingly, in order to construct a detached breakwater at a place as stated above aiming at the formation of sand deposit behind the breakwater, the execution of foot protection works at the sea wall should be considered in advance, and furthermore, if possible, beach sand replenishment works should be simultaneously executed to shallow the water depth in front of the sea wall as much as possible, for the purpose of reducing the reflection coefficient of waves at the sea wall.

(4) The deep water system

The breakwater in this type is located at the outside of the surf zone, and is similar to the normal breakwaters, the function of which is mainly to dissipate wave energy. Therefore, this type of breakwater is effective in dissipating wave energy and stabilizing the bottom configlation in the surf zone, but is not effective in bringing sand to the sheltered area from dther places.

The dimension of the breakwater determines the calmness in the sheltered area. As for the structure type, a composite type breakwater or a vertical-face breakwater is profitable from the view of construction cost, because the use of armour blocks is especially expensive in this case.

THE LATER EXPERIMENTAL WORKS ON KAIKE COAST

Following the design criterion described here, more than 20 works were executed, and all of them were successful to accomplish the main purpose.

The latest works have been executed on Kaike coast. Kaike is one of the famous hot spring resorts places along the Japan Sea, and the Kaike coast has been eroded since 1920's. The regression distance amounts to 300 meters during the last 50 years. There were many hot spring hotels along the shore line, but all of them were vanished into the sea.

First of all, several groins and sea wall were constructed as the preventive works against beach erosion. However, groins became ineffective gladually.

A large amount of armour blocks were installed in front of sea walls, but violent winter waves attacked the sea wall, and over-topped frequently . Therefore the housing area was ocassionally flooded by sea water.

Then the author proposed to construct detached breakwaters as

a countermeasure. During the period from 1971 to 1973, three breakwaters were constructed.
The breakwaters were located 100 meters apart from the sea wall and at the water depth of about 5 to 6 meters. Each of these breakwaters is quite effective to bring back the sand and to form a large tombolo. The thickness of deposit sand is about 5 meters at the head of tombolos, and about 2 to 3 meters in front of the sea wall.
These tombolos have become larger or smaller according to the sea condition, and they grow normally under violent wave condition in winter.
Fig. 8 & 9 show the detached breakwaters and sand deposition at Kaike coast.

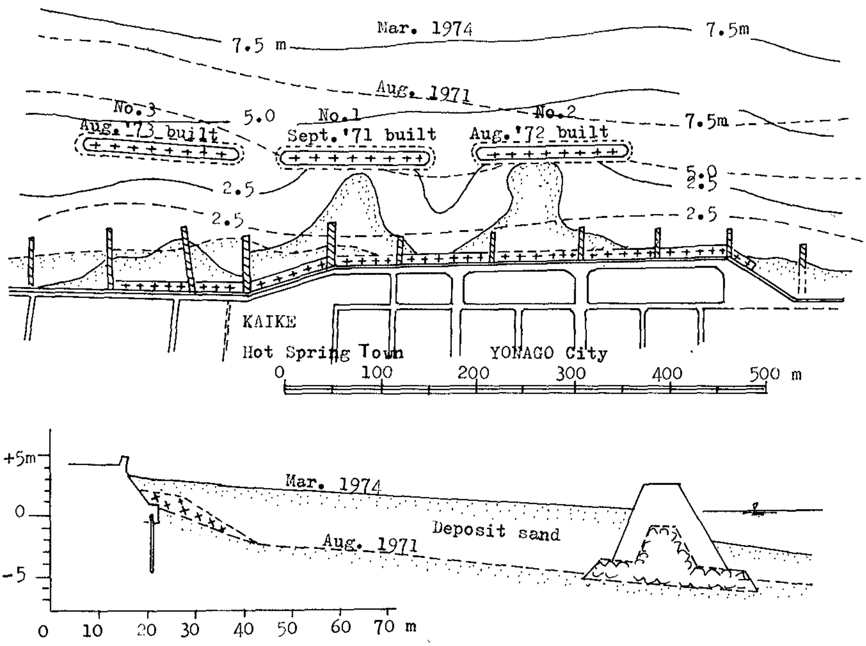

Fig. 8 The detached breakwater at Kaike coast

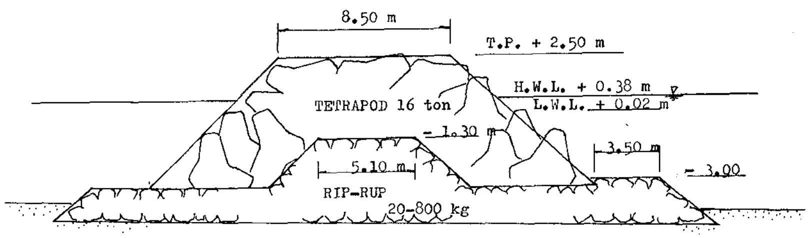

Fig. 9 The structure type of breakwater at Kaike coast

ADDITIONAL REMARK TO BE CONSIDERED IN THE DESIGN AND EXECUTION OF THE DETACHED BREAKWATER SYSTEM

In addition, the following remarks should be taken into consideration in designing and executing the detached breakwater system.

1. The detached breakwaters should, if possible, be constructed prior to the sea wall construction.
2. It is impossible to prevent completly a fatal coast erosion even by means of detached breakwater works.
3. When a breakwater is provided to form the sand deposition behind the breakwater, the measures to reduce the reflection of waves from the shore line should be taken into consideration prior to the execution of a breakwater.
4. As the shore line just beyond the openning between the neighboring two breakwaters is used to be scored, a counter-plan for shore protection should be considered before hand.