CHAPTER 145

ON THE SCATTERING OF CONCRETE ARMOUR UNITS OF DETACHED BREAKWATERS DUE TO WAVES

KOHNO, H*., T. UDA** and Y. YABUSAKI***

ABSTRACT

On the Fuji Coast 15 detached breakwaters and 17 wave dissipating breakwaters have been constructed to prevent beach erosion. By virtue of the construction of the breakwaters the retreat rate of the shoreline position has decreased. However a large number of concrete blocks have been scattered due to waves. This study investigates the actual circumstances on the scattering of the concrete armour units of the detached breakwaters through the field observations on the Fuji Coast located in Suruga Bay facing the Pacific Ocean. The change rate of the plane area of the breakwater is examined from the aerial photographs, and the relationships among the parameter, the depth at the offshore foot of the breakwater and the number of the removed concrete armour units are investigated.

I. INTRODUCTION

In recent years beach erosion is severe in Japan. They are caused partly by the construction of dams in rivers, the extraction of sand from rivers, or the influence of the construcion of the harbor structures on the coast. Countermeasure works have been conducted at many locations to improve the condition. The Fuji Coast is one of these coasts, and beach erosion has been caused by the decrease of the fluvial sediment supply from the Fuji River and the interception of longshore sand transport due to the construction of Tagono-ura Port in the middle of the coast. On the coast 15 detached breakwaters and 17 wave dissipating breakwaters, composed of concrete armour units and placed along the shoreline, have been constructed. By virtue of the construction of these breakwaters, the retreat rate of the shoreline position became small. However a large number of concrete blocks have been scattered due to waves, and sometimes fishing nets were damaged by the scattered concrete blocks. The number of the detached breakwaters have been increasing, and hence the stability of the concrete armour units is important for the maintenance of the detached breakwaters or the wave dissipating breakwaters. Nevertheless there are few studies on this kind of problem.

The aim of the study is to investigate the actual circumstances on the scattering of the concrete armour units of the detached breakwaters and the wave dissipating breakwaters by the field investigations on the Fuji Coast. The change rate of the plane area of the breakwater is examined from the aerial photographs, and the relationships

* Head, Numazu Work Office , Chubu Regional Construction Bureau, Ministry of Construction, Shizu-oka 410 Japan.

** Dr. Eng., Head, Coastal Engineering Division, Public Works Research Institute, Ministry of Construction, Ibaraki 305 Japan.

*** Numazu Work Office.

among the parameter, the depth at the offshore foot of the breakwater and the number of the removed concrete armour units are investigated. It is concluded through the study that the change rate of the plane area of the breakwater correlates well with the depth at the offshore foot and it increases with the depth. Furthermore on the detached breakwater the greater the rate of change of the depth at the offshore foot of the breakwater is, the larger the change rate of the plane area becomes. On the wave dissipating breakwater, it is found that the change rate of the plane area correlates well with the total weight of the recovered concrete blocks.

II. GEOGRAPHICAL FEATURES OF INVESTIGATED AREA

The Fuji Coast, formed by the fluvial sediment supply of the Fuji River, is located on the bottom of Suruga Bay (Fig. 1). The coast around the river mouth has been eroded since 1960s due to the decrease of the fluvial sediment supply caused by the excavation of sand in the river. Besides, the breakwater of Tagono–ura Port was built between 1959 and 1962, and littoral drift directing eastward was cut due to the presence of the breakwater, so that beach erosion and accretion began on the east and west sides of the breakwater, respectively. On the downdrift coast of the port wave dissipating breakwaters have been placed since 1974 against beach erosion, and detached breakwaters were constructed between the mouth of the Fuji River and the port. By virtue of the construction of the breakwaters, recent retreat rate of the shoreline position became small.

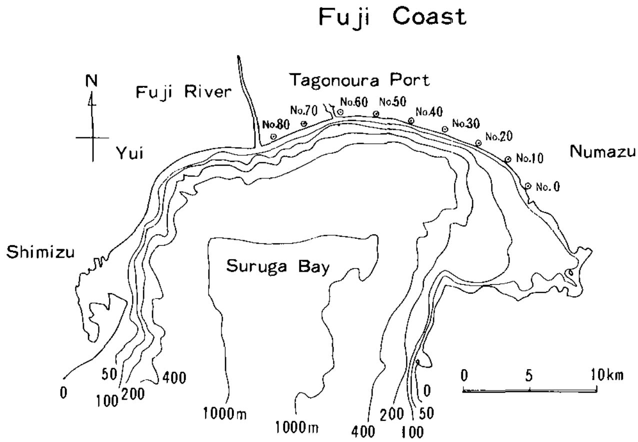

Fig.1 Location of Fuji Coast.

The locations of the detached breakwaters and the wave dissipating breakwaters on the Fuji Coast are shown in Fig. 2. Figure 2 (a) is the arrangement of the detached breakwaters in Fuji region, where is adjacent to the mouth of the Fuji River on the west side and ends by the breakwater of Tagono–ura Port on the east side. The direction of littoral drift in the region is eastward[1),2)], so that the sediment supply from the Fuji River is carried eastward. The construction of 17 detached breakwaters had been done by using 50-ton concrete armour units (tetrapod) by the order of the number shown in the figure during 1978 through 1984. Similarly Fig. 2 (b) is the arrangement of the wave dissipating breakwaters in Yoshiwara region located on the east side of Tagono–ura Port. On the west side of the region the breakwater of the port was constructed during 1959 through 1962, and littoral transport directing east was obstructed, so that severe beach erosion occurred on the downdrift coast. In order to prevent the shoreline retreat, 17 wave dissipating breakwaters had been constructed by the order of the number shown in Fig. 2 (b) from west to east during 1974 through 1979. These breakwaters were useful for the preservation of the shoreline position, but the scattering of the concrete blocks is severe in recent years. Because of the severity of the scattering of the blocks, the weight of the concrete armour units composing the wave dissipating breakwaters have been increased year by year. At first, 25-ton concrete armour units were used for No. 1 through No. 4 breakwaters built in earlier years. For No. 5 and No. 6 breakwaters, 40-ton concrete armour units were used at offshore part of the breakwater to strengthen the breakwater and to prevent the subsidence of the concrete armour units. Regarding No. 7 through No.17 breakwaters, 25-ton and 40-ton blocks are mixed, and both sides of the breakwaters are strengthened by 50-ton blocks to prevent further scattering of the blocks.

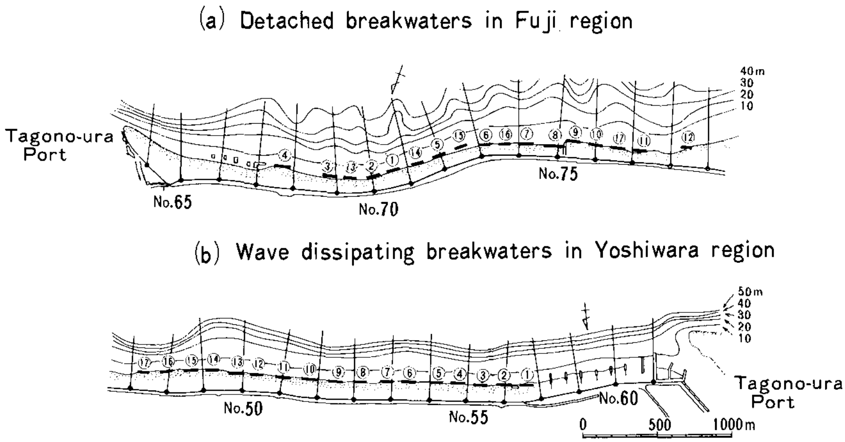

Fig.2 Locations of detached breakwaters and wave dissipating breakwaters on Fuji Coast.

The concrete armour units of the detached breakwaters are set on the sea bed directly without the rock mound in a shallower region than about 6 m, because of the difficulty of the construction of the rock mound on the steep slope beach. Similarly the armour units of the wave dissipating breakwaters are set on the shoreline without the rock mound.

Figure 3 shows the cross section of the beach passing through the center line of No.17 detached breakwater, which is useful to understand the relative location between the coastal dike and the detached breakwater. The distance between the coastal dike and the detached breakwater is around 100m in length, and there are foot protection works and wave breaking works between two structures. Since the beach slope of the Fuji Coast is very steep like as 1/3—1/10, and Suruga Bay, where the Fuji Coast is located, is facing the Pacific Ocean, the incident wave height in the typhoon season becomes so large. For the planned wave condition, significant wave height and wave period are equal to 17m and 20 sec, respectively. Because of frequent attack of high waves, the crown height of the coastal dike is high enough to attain to 17m above the mean sea level. In the sectional view of the beach shown in Fig. 3, the recent beach profiles are also shown. It is found that the sea bed off the detached breakwater was eroded between June, 1985 and February, 1986, and the maximum change of the bed reached to 1.7 m.

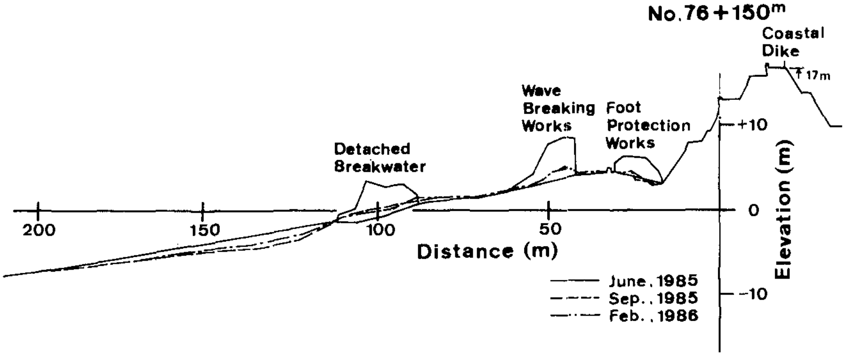

Fig.3 Cross section of the beach passing through the center line of No.17 detached breakwater.

III. SCATTERING OF CONCRETE ARMOUR UNITS OF DETACHED BREAKWATERS

For the investigation on the scattering of concrete armour units, the change of the plane area of the breakwater was examined first. The plane shape of the breakwater was traced from the aerial photographs, whose scale is 1/2500, and the change of the shape was determined by the subsequent photographs. Furthermore, the shoreline positions around the breakwaters were also examined, and the relation between the shoreline change and the scattering of the blocks were investigated. The results of the investigation are summarized in Fig. 4. The change of the shape of the detached breakwaters is expressed in an order from east to west. Each breakwater was constructed on the date shown in the figure. Tidal levels in the subsequent photographs differ from each other, but the correction of the shoreline change due to the change of the tide level was not considered, because the beach slope around the

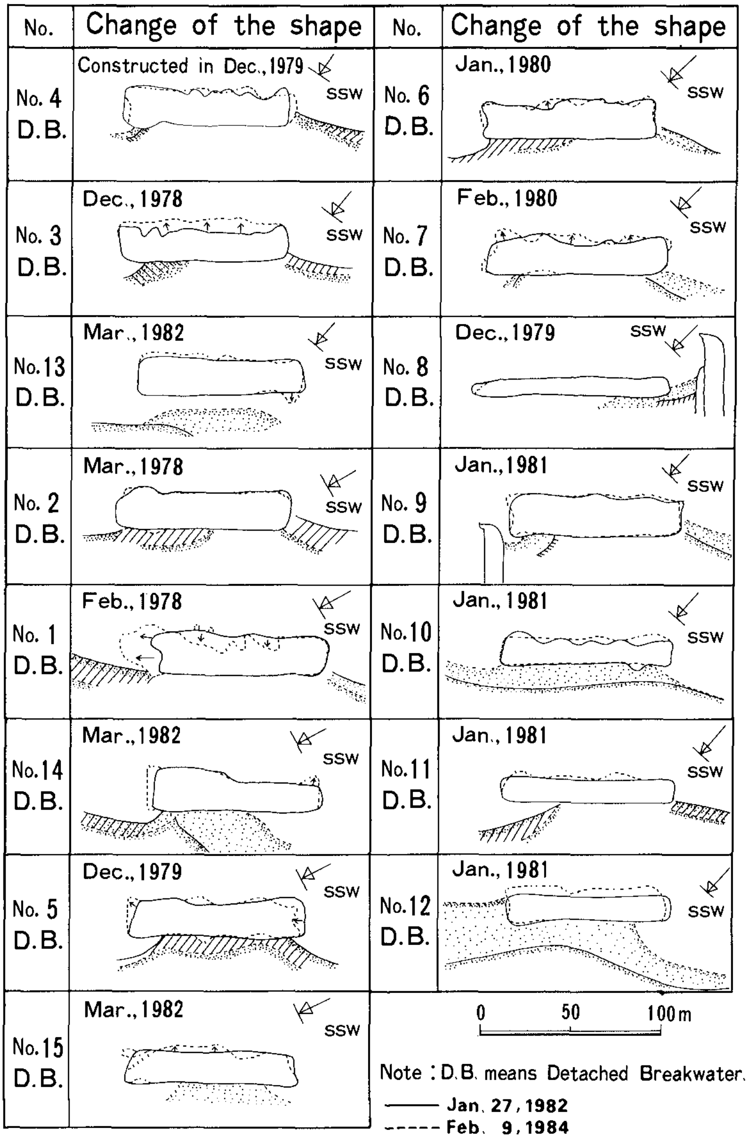

Fig.4 Traces of shapes of detached breakwaters in February, 1982 and February, 1984. Each breakwater was constructed on the dates shown in the figure.

breakwaters is very steep.

During the examination period of change of the form of the detached breakwaters between February, 1982 and February, 1984, high waves of Hmax= 9.85m and H 1/3=7.26m attacked the coast in September, 1982. Large change of the form are observed in No. 3, No. 1, No. 5, No. 15, No. 7 and No. 12 detached breakwaters during the period, and particularly the change of No. 1 breakwater is large. Regarding the general features of the form change of the detached breakwaters, large changes are observed at the offshore side and the east end of the breakwaters. Three causes are considered. First, wave force is large at the offshore side of the breakwater, so that the blocks are apt to be scattered by strong wave force. Second, the east end of the breakwater may be scoured, since the predominant direction of littoral transport is eastward. Thirdly, wave force acts on the blocks obliquely, because wave incidence prevails between S and SSW in storm wave condition on the coast and this wave incidence makes a considerably large angle with the longshore direction of the breakwaters.

The direction of the detached breakwater, θ, measured counterclockwise from South, the offshore distance from the shoreline to some contour lines, ℓ, and the total number, M, and the total weight of recovered concrete blocks, W_T, are expressed in Fig. 5 as well as the arrangement of the detached breakwaters. The abscissa is the number of the survey lines of 250m intervals. The directions of the breakwaters, defined by the angle between the normal of the breakwater and South, at No. 2 through No.15 detached breakwaters differ from those at the other breakwaters over 20 degrees, since the directions of coastline themselves change to a great extent as shown in Fig. 2. The offshore distances from the shoreline to 10, 20 and 30m deep contour lines have such a distinctive feature that they are short between No. 2 through No.15 detached breakwaters. In other words, the bottom slope of the detached breakwater is steep at locations between No. 2 and No.15 breakwaters compared with the other locations. Under such a condition the incident waves are considered to attack the breakwaters without large attenuation of wave energy, so that the scattering of the blocks should be severe at these locations.

On the Fuji Coast the recovery works of the scattered concrete blocks, obstructing the local fishery, have been conducted at offshore zone up to about 10m deep off the detached breakwaters and the wave dissipating breakwaters since 1981. The total number and the total weight of the recovered blocks in Fig. 5 are the summation during the period from October, 1982 to February, 1984. The location where many scattered blocks were recovered agrees well with the one where the normal to the detached breakwater makes a large angle with South, the offshore distances to some contour lines are short, and hence the beach slope is very steep.

Next, the change rate of the plane area of the breakwater (Y), the depth at the offshore foot of the breakwater (h), and the change of the depth ($\triangle$h) from February 1982 to February, 1984 are expressed in Fig. 6. Y is equal to the change of the plane area during the period divided by the area measured in February, 1982. h is obtained in the central section of the breakwater, and in addition $\triangle$h is positive when the water depth increases. In the calculation of the plane area of the breakwaters there are two cases in which the change of the shape of the breakwater protrudes against the original form and it is depressed to the original one. Here, the change of the plane area is defined by the addition of both changes. The change rate of the plane area of the breakwater, Y, has a fairly large variations alongshore, and its maximum is 0.34 at No. 1 breakwater. It is found that Y is in good correlation with the depth at the offshore foot, h in February, 1984 except the data at No. 12 breakwater, where is close to the river mouth of the Fuji River. Generally the change rate of the plane area, Y increases with the depth at the offshore foot of the breakwaters. To the contrary, it is not in good correlation with h in February, 1982.

On the changes of the depth, △h, from February 1982 to February 1984 shown in Fig. 6, the changes are considerably large, that is, maximum increase and decrease of the water depth attain to 2.2m at No. 3 breakwater and −2.2m at No.12 breakwater, respectively. There is a tendency that the depth at the offshore foot of the breakwater having larger number than No. 8, expressing the later construction than No. 8 breakwater, decreases and the depth increases at the older breakwaters than No. 8. This means that sand accumulate not only behind the breakwater, forming a tombolo, but also in the offshore zone of the newly constructed breakwaters,

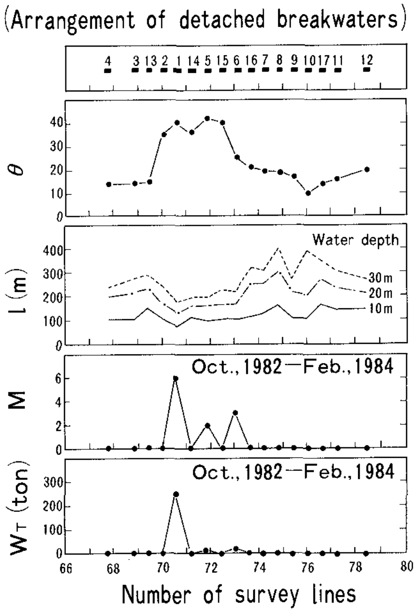

Fig.5 Spatial changes of the direction of the detached breakwater, θ, the offshore distance from the shoreline to some contour lines, ℓ, and the total number, M, and the total weight of recovered concrete blocks, W_T.

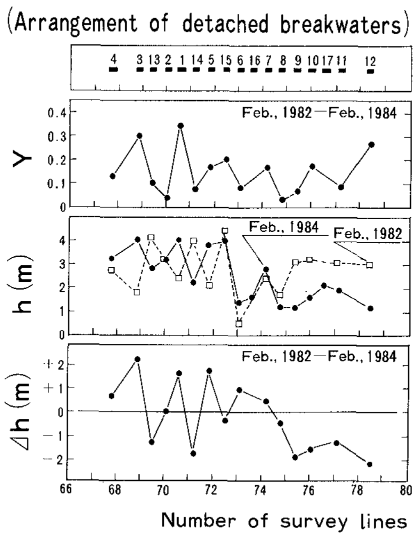

Fig.6 Spatial changes of the change rate of the plane area of the breakwater, Y, the depth at the offshore foot of the breakwater, h, and the change of the depth, △h, from February, 1982 to February, 1984.

although the cause is not clearly understood.

Regarding the relation between the change of the depth at the offshore foot of the breakwater, △h, and the change rate of the plane area, Y, fairly good correlation can be found. In other words, the change rate tends to increase with the positive change of the depth except No.12 breakwater located close to the river mouth.

The relations among the change rate of the plane area, the depth at the offshore foot and the change of the depth are investigated directly. Figure 7 expresses the relationship between Y and h. The relation is given by the equation

$$Y = 0.019h^2 \qquad (1)$$

where Y is a dimensionless variable and h is the depth in meter unit. The change rate of the plane area increases with the square of the depth at the offshore foot of the breakwater. The relation is considered to be obtained because wave height depends on the water depth strongly near the surf zone where the detached breakwaters are located, and in addition wave force acting on the concrete armour units depends on the wave height at that depth.

The relation between Y and △h is shown in Fig. 8. Two broken lines in the figure are drawn in order to confine almost the lower and upper limits of the data except that at No. 12 breakwater. It is known from the relation that Y also increases as △h becomes large. Namely, this means that the scattering of the concrete blocks becomes severe with the increase of the depth at the offshore foot of the breakwater.

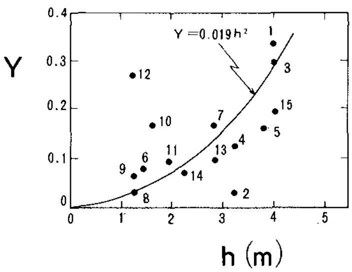

Fig.7 Relationship between the change rate of the plane area of the breakwater, Y, and the depth at the offshore foot of the breakwater, h.

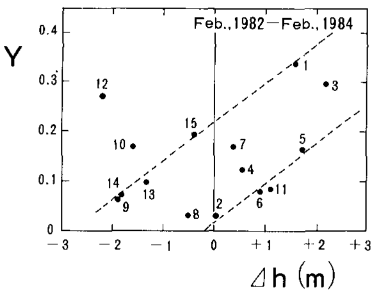

Fig.8 Relationship between the change rate of the plane area of the breakwater, Y, and the change of the depth at the offshore foot, △h.

Finally, pictures taken to know the setting condition of the concrete armour units at the offshore foot of the breakwater are shown in Pictures 1 and 2, where No.17 detached breakwater is selected as an example. These underwater photographs were taken at the east end of the breakwater as shown by the circle sign in Fig. 9 on February 20, 1984. The water depth is around 4 m deep. There does not exist the local scouring hole, and bed materials mainly consist of gravels in the vicinity of the breakwater. Far from the location there extends sandy bed and sand ripples develop. For the reference length for the decision of the ripple scale and diameters of gravels, it can be used that the radius of tip of the leg of 50-ton concrete armour units is equal to 0.455m and in addition the length of the leg is about 1.8 m long. Comparing these scales with the gravels, it is found that the maximum scale of the bed materials are around 10-20 cm.

Picture 1 Underwater picture taken at the offshore foot of No.17 detached breakwater (1).

Picture 2 Underwater picture taken at the offshore foot of No.17 detached breakwater (2).

Owing to the grain size test of the bed materials on the Fuji Coast, generally coarse materials having the median diameter of 10-20 mm are found at the foreshore, and then the diameter of the materials decreases with the water depth. The median diameter in the offshore zone deeper than 6 m becomes less than 1 mm. These features of the grain size distribution of the bed materials agree considerably well with the ones observed in Pictures 1 and 2 .

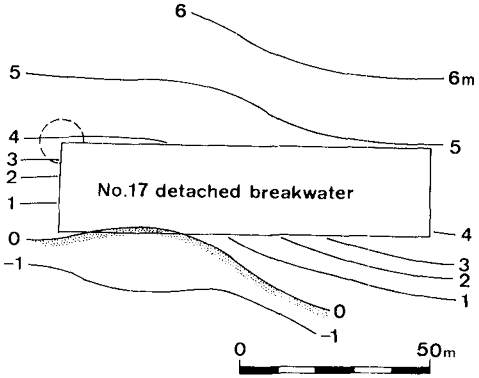

Fig.9 Bottom contours around No.17 detached breakwater measured on February 20, 1984.

IV. SCATTERING OF CONCRETE ARMOUR UNITS OF WAVE DISSIPATING BREAKWATERS

Regarding the wave dissipating breakwaters, the same kind of the investigation was carried out as the detached breakwaters by using the aerial photographs. The arrangement of the wave dissipating breakwaters, the direction of the normal to the breakwater, θ , the offshore distance to some contour lines from the shoreline, ℓ , the change rate of the plane area, Y and the depth at the offshore foot of the breakwater, h are expressed in Fig. 10. The total number and the total weight of the concrete blocks recovered between October, 1981 through February, 1984 are also shown. The abscissa is the number of the survey lines of 250 m intervals. The direction of the coastline where the wave dissipating breakwaters were placed is almost uniform as shown in Fig. 2. The direction of the normal to the breakwater, measured counterclockwise from South, does not vary so much alongshore, since the breakwaters are set along the straight shoreline. According to the offshore distances to 10-30m deep contour lines, the bottom slope is steep in the zone deeper than 20m, because the interval of the distances is relatively narrow. The change rate of the plane area, Y, was calculated from the photographs obtained in December, 1979 and February, 1982. The maximum wave height in the period is Hmax=8.6 m, H1/3=3.5m measured in October, 1981. It is found that Y correlates well with h measured in December, 1979, although its correspondence with the depth in February, 1982 is not dominant. The depth at the offshore foot, h, was particularly large at four locations of No. 6, No. 7, No. 10 and No. 11 breakwaters in 1979, but then increased as a whole in February, 1982 because of beach erosion.

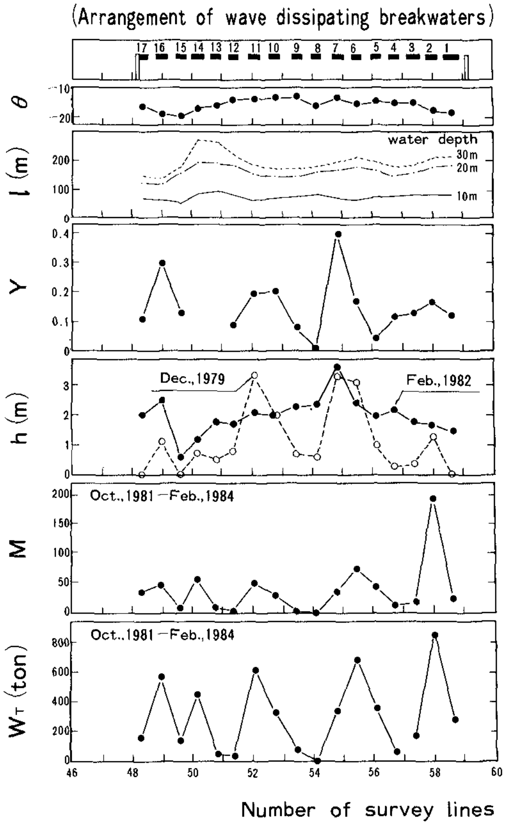

Fig.10 Spatial changes of the direction of the normal to the breakwater, θ, the offshore distance to some contour lines from the shoreline, ℓ, the change rate of the plane area, Y, the depth at the offshore foot of the breakwater, h, the total number, M, and the total weight of the scattered concrete blocks, W_T.

Next, the total number and the total weight of the scattered concrete blocks shown in Fig. 10 are studied. It is understood that there is a good correlation among Y, M and W_T. The total number and the total weight of the scattered blocks increase with Y. The change rate of the plane area of the wave dissipating breakwater determined from the aerial photographs becomes a good parameter for judging the extent of the scattering of the concrete blocks.

Since the longshore distributions of the depth at the offshore foot and the actual

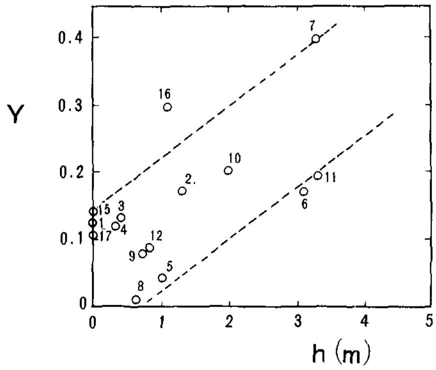

Fig. 11 Relationship between the change rate of the plane area of the breakwater, Y, and the depth at the offshore foot of the breakwater, h.

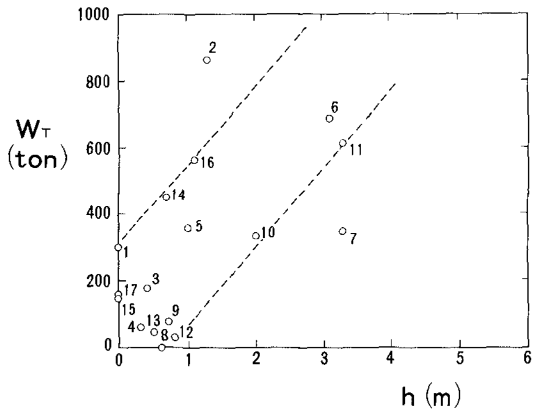

Fig. 12 Relation between the total weight of the concrete blocks, W_T, and the depth at the offshore foot, h.

conditions of scattering of the concrete blocks have already been known, the relations among the parameters are studied. The relation between the rate of change of the plane area of the wave dissipating breakwaters, Y, and the depth at the offshore foot of the breakwater, h, measured in December, 1979 is expressed in Fig. 11. There are considerably large scatter in the relation, so that lower and upper limits, enveloping the almost whole data, are shown by the broken lines to decide the mean relation. It is found that a relation stands between the rate of change of the plane area, Y, and the depth at the offshore foot, h, except No.16 wave dissipating breakwater.

$$0.077h - 0.052 < Y < 0.077h + 0.143 \qquad (2)$$

where Y is dimensionless parameter and h is the depth in meter unit. On an average, the change rate of the plane area of the wave dissipating breakwater, Y, is proportional to the depth at the offshore foot of the breakwater, h. Similarly, Figure 12 expresses the relationship between the total weight of the recoverd concrete blocks, W_T, and the depth at the offshore foot of the breakwater, h. There are some scatters in the relation, but almost all data can be confined within two broken lines except No. 2 and No. 7 breakwaters. It should be noted that the total weight of the scattered concrete blocks increases with the greater foot depth.

Finally the weight and the number of the recovered concrete blocks by the sweeping operation of the sea bed are counted at 0.5m deep intervals as shown in Fig.13. In the figure the recovered weight of the detached breakwaters and the wave dissipating breakwaters are shown differently by open and solid circles, respectively. Solid line represents the summed number of the recovered concrete blocks at every 1 m deep interval. It can be concluded from the figure that almost all scattered concrete blocks concentrate on the depths between 6 and 8 m deep. The reason is due to the abrupt change of the beach slope. Taking survey line No.75 for an example, beach slope between the foreshore and 5 m deep contour is steep enough as 1/9, and on the other hand between 5 and 10 m deep contours the slope becomes relatively mild like as 1/25. It may be concluded that it is difficult for the scattered concrete blocks to stop on the steep slope between the foreshore and 5 m deep contour, and that scattered blocks are apt to gather on the bed of relatively mild slope.

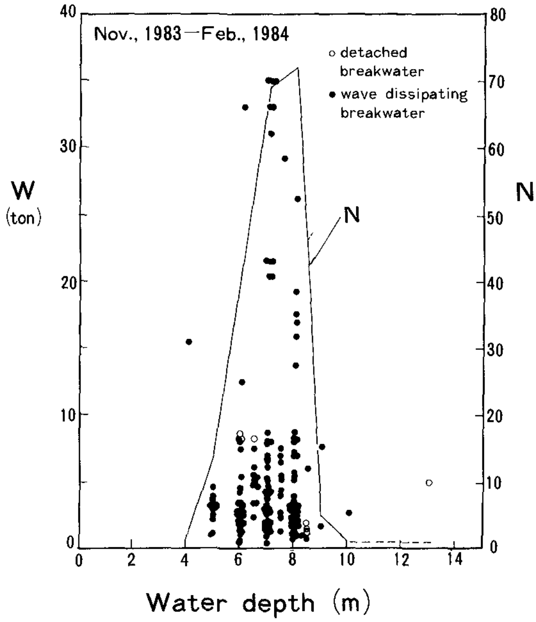

Fig.13 Vertical distributions of the weight and the number of the recovered concrete blocks.

V. SUMMARY OF SCATTERING OF CONCRETE BLOCKS

The relation between the scattering of the concrete blocks and wave conditions is studied based upon the actual results of the recovery of the concrete armour units. Table 1 summarizes the results. The recovery works were carried out during October through February in each fiscal year, and in this study the data from October, 1981 to February, 1983 are summarized. The items of the data summary are the number of the scattered blocks, the total weight of the blocks, the average weight of a scattered block, the maximum weight of the blocks and the average distance of the scattering. Wave conditions observed at Tagono–ura Port or Hara Observatory on the Fuji Coast are also summarized. $\Sigma Hmax \cdot t$ and $\Sigma H1/3 \cdot t$ are the summations of the maximum wave height larger than 5 m and the significant wave height larger than 3 m, respectively, multiplied by the observation period (t= 2 hr) in place of the duration of the waves.

Table 1 Summary of scattering of concrete blocks.

		Oct.1981 –Feb. 1982	Oct. 1982 –Feb. 1983	Nov. 1983 –Feb. 1984
D. B.	M	0	7	4
	Wt (t)	–	254.7	30.7
	$\overline{W}$ (t)	–	36.3	7.7
	Wmax(t)	–	45.1	8.6
	$\overline{X}$ (m)	–	31.6	31.3
	$\overline{W} \cdot \overline{X}$	–	1147	241
W. D. B.	M	43	360	215
	Wt (t)	318.6	3640	1040
	$\overline{W}$ (t)	7.4	10.3	5.1
	Wmax(t)	24.5	46.0	35.0
	$\overline{X}$ (m)	26.1	39.9	41.7
	$\overline{W} \cdot \overline{X}$	193	409	211
	Hmax (m)	6.59	9.85	6.94
	Σ Hmax·t	25.5	305.6	78.7
	$H_{1/3}$ (m)	3.57	7.26	5.0
	$\Sigma H_{1/3} \cdot t$	20.3	223.9	46.1

D.B. : Detached breakwater, W.D.B. : Wave dissipating breakwater, M : Number of the scattered blocks, Wt : Total weight of the scattered blocks, $\overline{W}$: Average weight, Wmax : Maximum weight, $\overline{X}$: Average distance of the scattering.

The number of the scattered blocks are less than 10 on the detached breakwater, but on the wave dissipating breakwaters they reach 360 at maximun. The fact that a large number of the concrete armour units are scattered is due to the causes that the beach slope is steep and the beach has been eroded year by year at the sites where the wave dissipating breakwaters are located, and that the weight of the concrete armour units of the wave dissipating breakwaters is lighter than that of the detached breakwaters. $\overline{W_B} \cdot \overline{X}$, expressing the work done by wave force, is large on the detached breakwaters rather than on the wave dissipating breakwaters. This implies that the wave force acting the blocks of the detached breakwaters is greater than that in a case of the wave dissipating breakwaters. Regarding the comparison of the period, many blocks were scattered from October, 1982 to February, 1983, because maximum significant wave height of about 10 m attacked the breakwater. The average weight of the scattered blocks is less than 10 tons except the data obtained from October, 1982 to February, 1983 on the detached breakwater, although 50-ton blocks are used for the detached breakwaters, and 25, 40 and 50-ton blocks for the wave dissipating breakwaters. It should be noted that almost all scattered concrete blocks are broken ones. Two causes of the damage of the concrete blocks are considered. First, the blocks are damaged directly due to the wave force. Second, the engagement of the blocks is worsen and it is damaged by both dead load of the blocks itself and the wave force.

VI. CONCLUSIONS

The conclusions obtained through the study are summarized as follows.

(1) The change rate of the plane area of the breakwater calculated by the aerial photographs becomes a good parameter in order to analyse the scattering condition of the concrete armour units of the breakwaters.

(2) There exists a correlation between the change rate of the plane area of the breakwater, Y, and the depth at the offshore foot of the breakwater, h. A relation $Y = 0.019\ h^2$ stands.

(3) Y also becomes large when the rate of increase of the depth h is large.

(4) Concrete armour units of the detached breakwaters were scattered severely at locations where the depth off the breakwater is deeper compared with the average depth and the direction normal to the shoreline makes a large angle with the direction of the incident wave, because of large longshore sand transport.

(5) The change rate of the plane area of the wave dissipating breakwater correlates well with the total weight of the recovered concrete blocks. Due to the actual results of the recovery of the concrete armour units, the average weight of the scattered blocks is less than 10 tons. It is concluded that almost all scattered blocks are broken ones, judging that the initial weight of the blocks is greater than 25 tons.

REFERENCES

1) Noda, H. and H. Hashimoto:Littoral drift and shore protection facilities, Gihodo Press, 1981 (in Japanese) .

2) Kohno, H., T. Uda, Y. Yabusaki and M. Mizuno : Beach erosion on the Fuji Coast and Prediction of 3-D Beach changes, 33th Japanese Conf. on Coastal Eng ., pp.475-479, 1986 (in Japanese) .