CHAPTER 93

LOCAL SCOUR AND CURRENT AROUND A POROUS BREAKWATER

By

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ABSTRACT

Scour at the foot of vertical homogeneous crib style walls which were used as models for detached breakwaters, and the rise of mean water level in the shoreside region of the breakwaters were experimentally investigated, and the experimental results were compared to some field data.

Introduction

Scour around coastal structures has been studied by many researchers. For examples, the scour at the foot of or in front of solid sea walls have been of special interest to many coastal engineers and researchers, and a quite good number of papers concerning it have already been presented.[Sawaragi and Kawasaki(1960), Sato, Tanaka and Irie(1969), Herbick, Murphy and Van Weels(1965), Herbick and Ko(1968) and many others] The scour around breakwaters due to construction of harbors at sandy coasts were investigated by Sato(1972), Sato, Tanaka and Irie(1969) and Wada, Nishimura and Nirei(1970). The scour around the pier structures in the surf zone was observed by Hotta, Uda and Sasaki(1976).

Recently, the construction of permeable detached breakwater systems of concrete blocks has become widely practiced as a counter-measure against beach erosion. Most of these breakwaters function effectively. It is, however, reported that some of them exhibit unexpected defect in their construction. Many factors are related to the construction of the breakwaters and interact with one another in complicated ways. Of these, the local scour and wave-induced currents around the breakwaters are especially considered to be very important in successful construction of the breakwaters. In relation to these problems, the scour at openings of detached breakwaters systems was studied by Toyoshima(1972) and Kawaguch and Sugie(1972), and a series of excellent

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field works on the scour at foot of the breakwaters have been carried out by the First Port Construction Bureau, The Ministry of Transport, at Nigata Coast where continuous detached breakwaters of concrete blocks about 5 km in length are situated 150m offshore.[Katayama, Irie and Kawakami(1973)] However, the problems of these breakwaters are still not fully understood, and thus, the problems still remain unsolved.

The purpose of this study is an attempt to clarify the characteristics of the local scour and wave-induced currents, and the interactions between them around permeable detached breakwaters by laboratory experiments. A difficulty in experimental study is the similarity problems between the laboratory and the field. As a means of solving this problem, some reseachers have used light specific gravity bed materials in their experiments. Horikawa and Sasaki(1970) reported in their experiments concerning a study of artificial nourishment of beaches that the Mesalite, which is a kind of light-wieght concrete aggregate with a specific gravity of 1.65, was a good movable bed material. Due to Horikawa and Sasaki(1970)'s results, fine Mesalite was used in these experiments as a bed material.

Detached breakwaters usually have a trapezoid cross section. To simplify the scouring phenomenon, however, vertical homogeneous crib style walls were used as the model of the breakwaters in these experiments. Details about the model breakwaters will be described in succeeding section.

Experimental Facilities and Procedure

Experimental Facilities

Experiments were carried out in a rectangular glass walled wave tank 0.8 m deep, 0.5 m wide and 27 m long. At one end, the tank is equipped with a piston type wave generator. The wave height can be changed by varying the stroke of the piston arm, and the wave period can be changed by adjusting the rotation of a rotary disk. At the other end of the tank model beaches were moulded with a compound slope, 1/10 and 1/40.

Measurements and Observations

Wave heights were measured by hook point gauges, electric platinum wire resistance wave meter and 16 mm meno-motion cameras. The former two of these were used in the offshore zone. To take the mean water level and the envelopes of wave crest and trough, beach and wave profiles were photographed by a 35 mm camera and 16 mm memo-motion cameras each measurement time. The scouring depths and beach profiles were measured by a point gauge which ran along fixed rails on the wave tank and which was able to measure the water depth by moving up and down a rod with constant speed automatically. Manomaters were used as another way to measure the mean water levels, and their results were compared with the results gained from the 16 mm cameras.

Bed Materials and Model Beaches

Two bed materials were used in these experiments. One was the Mesalite mentioned above and the other was a fine natural sand, specific gravity, 2.65. These were used to discover how the scouring patterns and beach changes differ with different bed materials. Grain size distribution curves of the two bed materials are shown Figure 1. As an initial beach slope, a compound slope with 1/10 and 1/40 was used. This initial slope was chosen to produce a wide surf zone similar to these of natural beaches in rough sea conditions within the limited wave tank length.

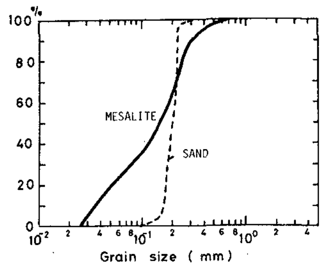


Figure 1 Grain size distribution curves.

Model Breakwaters

It would seem that scouring patterns and beach changes would be affected by the hydraulic properties of the breakwaters. From this reason, four kinds of vertical homogeneous crib style walls were experimentally investigated. Two thicknesses of model breakwaters and three kinds of filler were used. The characteristics of the model breakwaters are shown in Table 1.

Table 1

symbol of the walls	thickness of the walls	filler materials
W_1	2 cm	gravel 5-8 mm
W_2	2 cm	gravel 10-13 mm
W_3	2 cm	glass ball 18 mm
W_4	5 cm	glass ball 18 mm

Experimental Conditions

Only one type of wave was used in this experiment. The wave characteristics were as follows;

wave period, T, = 1.1 second
deep water wave height, H_o, = 10.8 cm
wave steepness, H_o/L_o, = 0.057

The deep water wave height was calculated from the shallow water wave height which was decided by means of Hely's method from wave data taken at constant water depth of the tank, 0.45 meters.

Experimental Procedure

After moulding the model beaches carefully,the walls were installed. First at 50, 100, 130 and the at 250 cm from the shoreline. After a wall was installed, the waves were started. At the time of each measurement, the waves were first observed, then the wave generator was stopped, and the scouring depths and beach profiles were measured by using the point gauge. A first series of experiments was finished, the Mesalite bed was removed, and it was replaced by the fine natural sand for the next set of experiments. Each test was run until wave number t/T, was over 70,000, where t was experimental duration. This number was decided on the basis of the following consideration; that is, we assumed that if storm wave periods would be within from 6 to 8 seconds, and storms would not continue over three day, the number of waves which would attack the breakwaters during a single storm would be roughly about 70,000.

Experimental Results and Discussion

Relationshop between local scour and beach change(sea bottom topogrphy change)

One difficulty in the study of local scours is that both beach change and local scour exist together. That is, the local scour is superimposed on the bottom topography, and their changes are complicatedly interacted. Figure 2 shows an example of the local scour around a pier structure surveyed by the Authors, and P shows positions of piers. In this case, we can easily recognize that local scour is superimposed on the natural beach profile, and that the pier will not influence major changes in the beach profile because it is understood that the disturbance of wave motion around pier is small. It is, however, not hard to imagine that the existence of a system of detached breakwaters on beaches will greatly influence wave motion, and it is difficult to predict the beach changes accompanying the change of the wave motions at the present time. In fact, this prediction is an important problem with which we are confronted right now and which must be solved. As of right now, the correlationship between local scour and beach change from this study has not become clear.

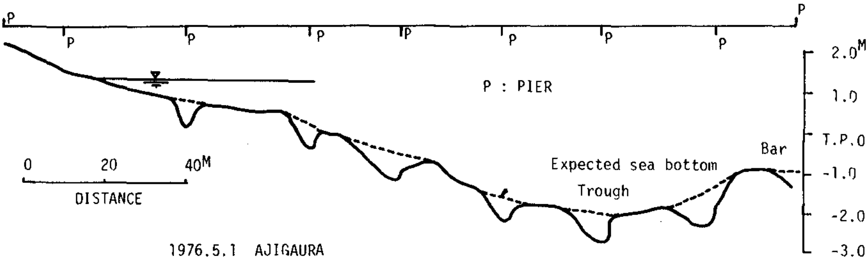


Figure 2 An example of local scour around pier structure.

Scouring Process

The authors defined the scouring depth at the foot of the walls as the vertical distance from the sand surface of the initial slope to the scoured bottom. Figure 3 shows the processes of scouring depth. According to Sawaragi and Kawasaki(1960) the scouring process at the foot of vertical solid walls could be classified as 4 types depending on the position in which wall was situated. Sato, Tanaka and Irie (1969) classified it as 5 types. However, in the case of permeable vertical walls, it is hard to find a tendency by which the scouring process can be classified according to the differences in the positions of the walls, bed materials or hydraulic preperties of the walls.

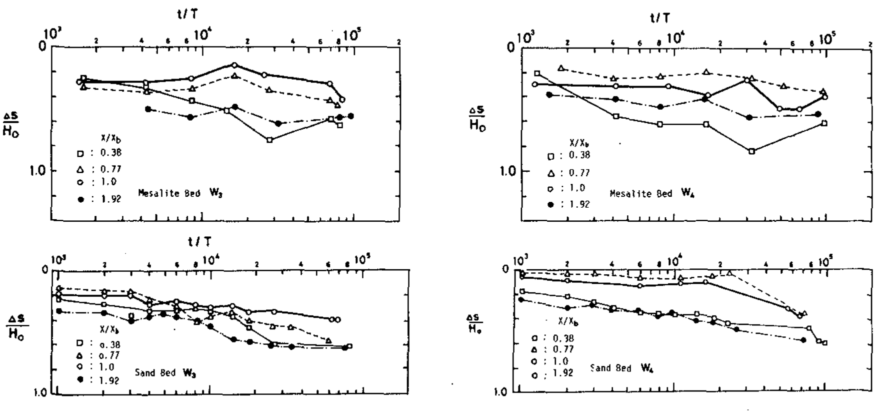


Figure 3 Scouring process.

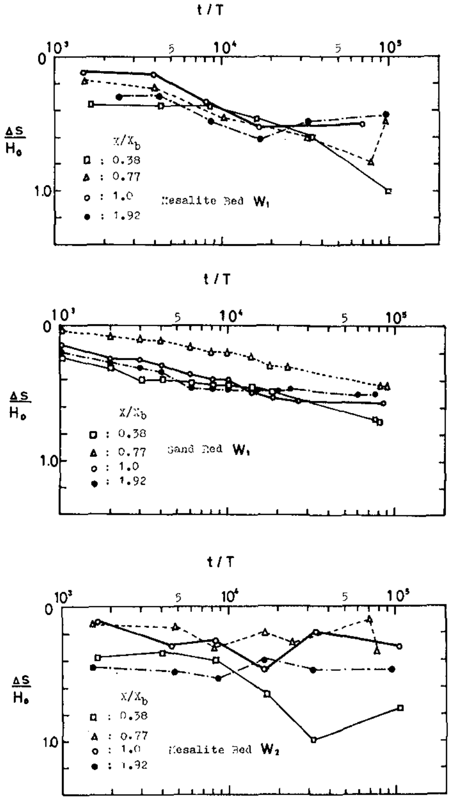


Figure 3 Scouring process.

Change of Beach Profile

Figure 4 shows examples of final beach profiles and the ratios between wave heights with walls to wave heights with no wall at each point, X,. From this figure, the following are pointed out;
(1) Influence of bed material appears on the final beach profile wnen no wall are used, that is, the retreat of shoreline of a Mesalite bed is much larger than that of the sand bed. When a wall is used the retreat of the shoreline is small. However this retreat does not necessarily mean that the beach in the shoreside of wall is being eroded. The retreat makes the swash zone steeper, and a swash bar is formed. After that the shoreline retains its stability.
Walls exhibit a sufficiently effective function. (2) On the offshoreside of walls, waves become much lager than when no wall was used and become partial standing waves, and the loops and nodes of

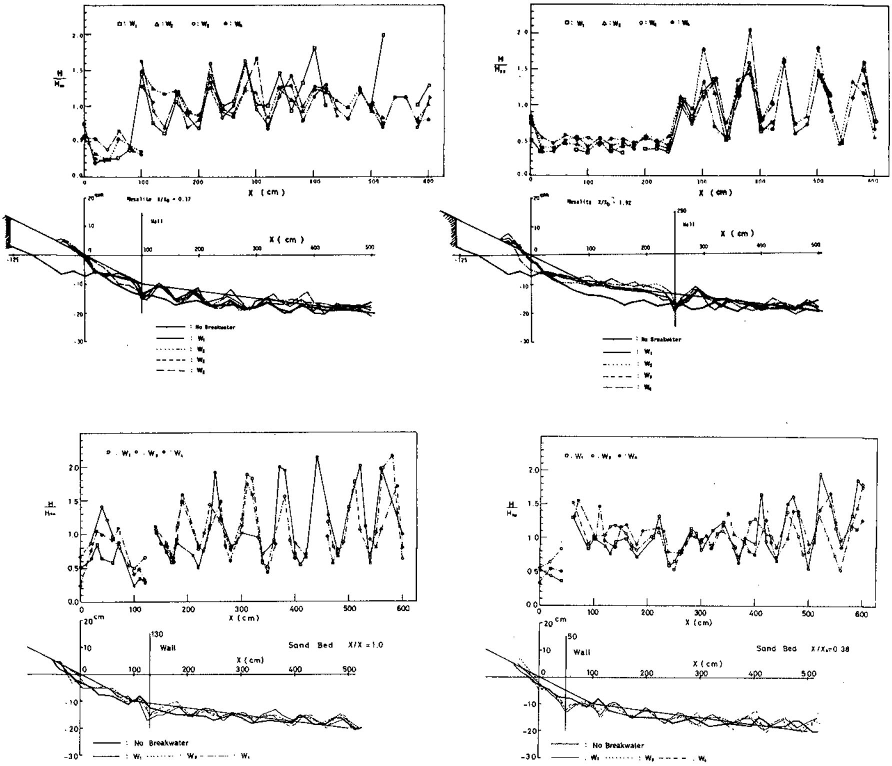


Figure 4 Beach profiles and ratios between wave height with walls to wave height no wall.

the standing waves closely correspond to the troughs and crests on the beach profile. This result agrees with that on scour in front of solid seawalls obtained by Herbich and Ko(1968).

The configuration of beach profiles in front of walls suggests that large sea bottom changes on natural beaches will occur in front of detached breakwaters.

The Maximum Scouring Depth

In Figure 5, the ratios of scouring depths to deep water weve height, $\Delta S/H_o$, are plotted against the relative positions of the walls, X/X_b, where X is the distance from the shoreline to the positions at which the walls are situated, and Xb is the distance from the shoreline to break-point. As seen from Figure 5, the scouring depths are largest at $X/X_b = 0.38$ and are small in the neighborhood of the break-point regardless of the bed materials and hydraulic properties of walls. It is not clear why the scouring depths are the largest at $X/X_b = 0.38$. However, it may depend on beach change. As seen in Figure 6 and Figure 4, the initial beach slope of this position, $X/X_b = 0.38$, was steeper, and the bed material moved largely offshore. That is, one may say that the local scour overlapped on the lowering of initial slope due to beach change. Might the local scour be $\Delta S'$ in Figure 6 ?
In any cases, the scouring depth is not greater than the order of the deep water wave height.

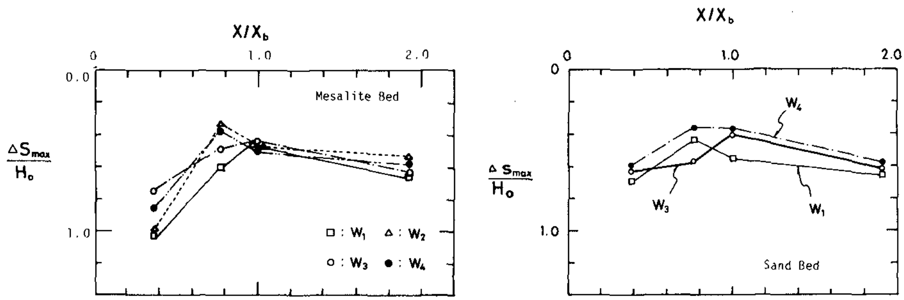


Figure 5 The maximum scouring depth.

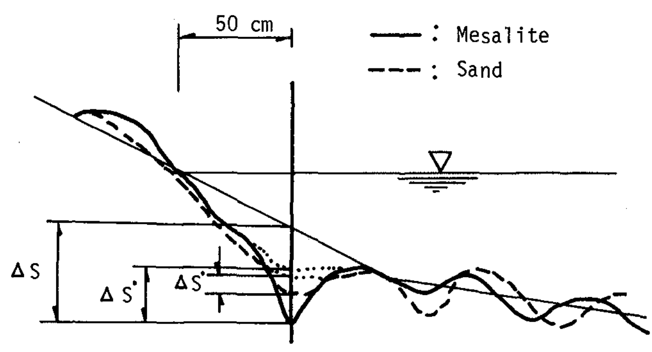
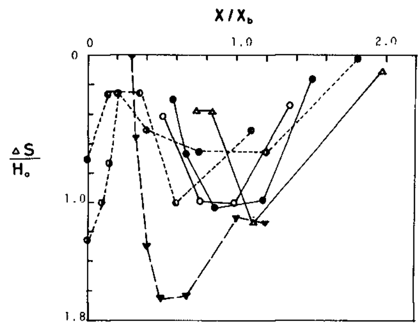


Figure 6 Examples of beach progile at X/X_b =0.38

Figure 7 shows the relationship between $\Delta S/H_o$ and X/X_b in the case of solid walls. In this case, the maximum scouring occurs when the walls are situated at the break-point or a little inside the break-point. On this point, there is a remarkable difference between solid and porous walls. Conversely, the fact that maximum scouring depth is not greater than the deep water wave height under stormy conditions is the same for each.

Figure 8 shows scouring depths with $\Delta S/h$ instead of $\Delta S/H_o$. An advantage of this expression is that one can see the percent of scouring depths for the water depth in relation to the positions of the walls. From this Figure 8 , $\Delta S/h$ is not greater than 0.6 without X/X_b = 0.38. A maximum of about 2 m scouring depths was observed at Nigata Coast where detached breakwaters were situated in water depth of 3 m about 150 m offshore.[Katayama, Irie and Kawakami(1973)] In this case, the ratio of $\Delta S/h$ was about 0.66. This figure almost agrees with the results gained in our experiments.



DATA SOURCES

H_o/L_o = 0.033 d/H_o = 0.0079 — Sato, S., N. Tanaka and I. Irie: Study on thf Scouring at the Foot of Coastal Structure, Coastal Eng. in Japan, Vol.12, 1969
= 0.033 = 0.0044

= 0.026 ● — Ichikawa,T: Scouring Disaster of the Vertical Breakwaters 13th Conference on Coastal Eng. in Japan, 1966 (Japanese)
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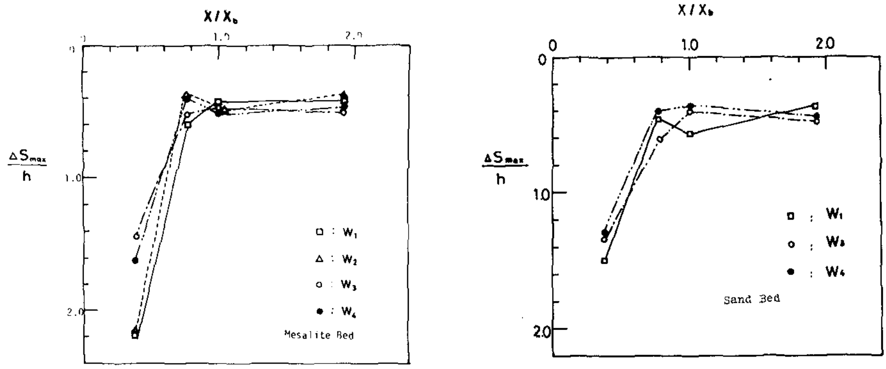
= 0.007 ▼ — Chesnutt B. Charles, and R.E. Shiller, Jr Scour of Galf Coast Beaches due to Wave Action OTC 1352

Figure 7 The maximum scouring depth of solid seawalls.



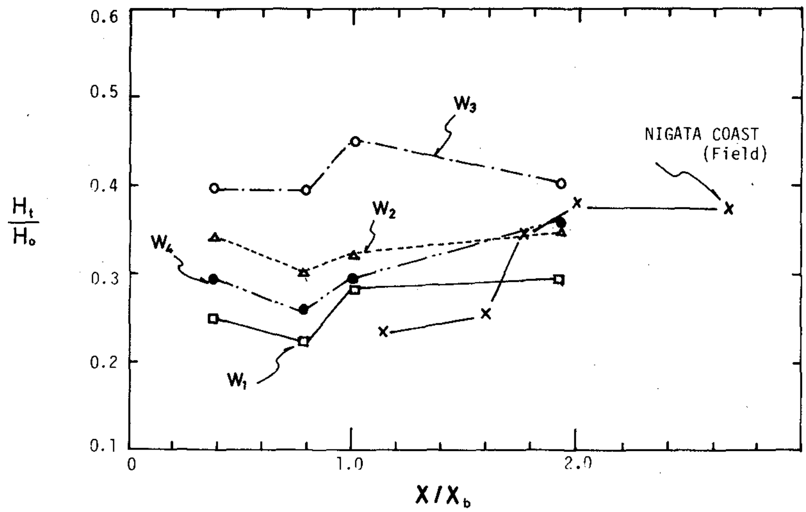
h: Initial Water Depth which the Walls are Situated

Figure 8 The ratios between the maximum scouring depth to the water depth.

Transmitted Wave heights

Figure 9 shows the ratio between the wave height transmitted to to the inside region of walls and the deep water wave height. As seen in the Figure 9, the ratio depends on the size and shape of the filler materials and the width of the wall. The larger the size of the filler, the larger H_t/H_o becomes. The greater the width of the wall, the smaller H_t/H_o becomes. H_t/H_o is smallest at $X/X_b = 0.77$ regardless of the hydraulic properties of the model breakwaters. In the same Figure, the field data observed by The First Port Construction Bureau at Nigata Coast are also plotted. In this plot, X/X_b is decided as follows: That is, because the position of the breakwaters is fixed X is constant(X = 150 m). The wave heights observed offshore at 10 m water depth were taken as the deep water wave height, H_o. Using Goda's Breaking Index[Shore Protection Manual, U.S. Army, Coastal Engineering Research Center, pp 2-121] and assuming $K_f = K_r = K_d = 1$, the water depths of the break-point were read from the Figure. Then X_b were read from the sounding map.

Field data show similar tendencies to those of the experiments.



H_t : Transmitted Wave Height

H_o : Deep Water Wave Height

Figure 9 Transmision coefficient.

Rise of the Mean Water Level inside the Wall

A rising of the mean water level was observed in the shoreside region of the breakwaters. On the contrary, a lowering of the mean water level was observed in the offshoreside region of the breakwater. This rising and lowering has a great influence on the current around the breakwaters. Figure 10 shows a dimensionless plot of η/H_o and X/X_b. It seems that the rising of the mean water level depends on the position and hydraulic properties of the model breakwaters, but these influence are not clear within this experimental works The magnitude of the rising of the mean water level is about 5 - 10 % of the deep water wave height. Field data[Katayama, Irie and Kawakame(1973)] are also plotted in the Figure 10. X/X_b in Figure 10 is decided in the same way as that described the previous section. The results of the field data are a little larger than those of the experiments. From Figure 10, it seems that the rise of mean water level in the shoreside of the wall is not beyond 10 % of the deep water wave height. The lowering of the mean water level in the offshore region from the wall fluctuated according to nodes and loops of the partial standing waves.

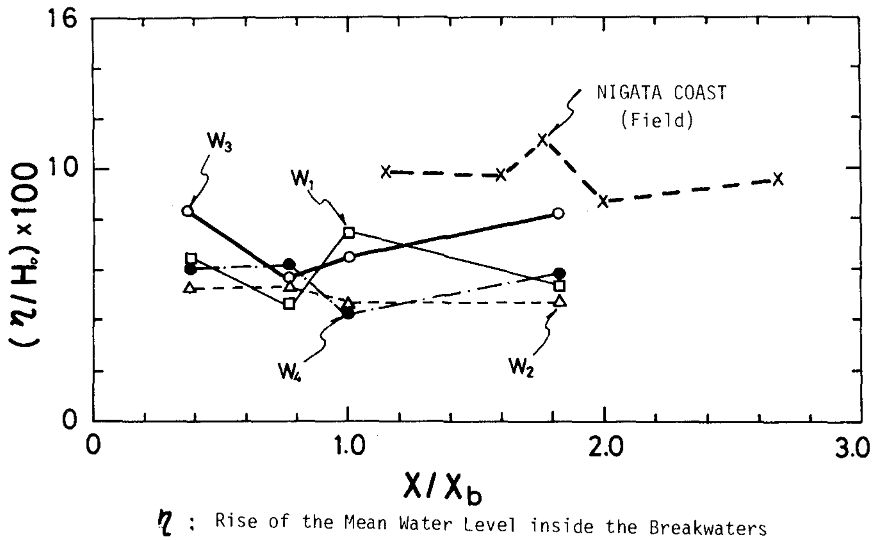
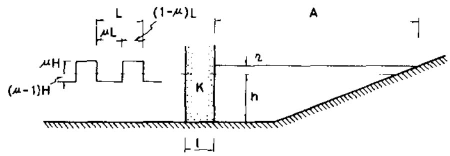


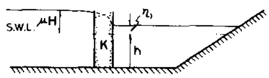
Figure 10 Rise of mean water level inside of walls.

The rising of the mean water level was analyzed. Authors assumed the wave to be shown in Figure 11. In equilibrium condition, if the Forchheimer's formula is assumed, the four equations in Figure 11 are given. From these equations, finally, the rise of mean water level, η, is approximetedly given by a equation 1. In this equation, a problem is to give μ and K (coefficient of permeability). It seems that the equation 1 will predict the rise mean water level in shoreside of the breakwaters, but it remains in discussion.

*** DEFINITION ***



(1) WHEN THE CREST OF WAVE COME IN TOUCH WITH THE WALL



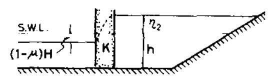
$$q_1 = \frac{K}{2l}\{(h+\mu H)^2-(h+\eta_1)^2\} \quad \text{------}(1)$$

$$\frac{d\eta_1}{dt} = \frac{q_1}{A}$$

$$= \frac{K}{2lA}(2h+\mu H+\eta_1)(\mu H-\eta_1) \quad \text{----}(2)$$

$$\therefore \quad \frac{d\eta_1}{(2h+\mu H+\eta_1)(\mu H-\eta_1)} = \frac{K}{2lA}dt$$

(2) WHEN THE TROUGH COME IN TOUCH WITH THE WALL



$$q_2 = \frac{K}{2l}[(h+\eta_2)^2-\{h-(1-\mu)H\}^2] \quad \text{--------}(1')$$

$$-\frac{d\eta_2}{dt} = \frac{q_2}{A}$$

$$= \frac{K}{2lA}\{2h-(1-\mu)H+\eta_2\}\{\eta_2+(1-\mu)H\} \quad \text{---}(2')$$

$$\therefore \quad \frac{d\eta_2}{\{2h-(1-\mu)H+\eta_2\}\{\eta_2+(1-\mu)H\}} = -\frac{K}{2lA}dt$$

$$\boxed{\eta = \frac{H^2}{h}\mu(1-\mu) - \frac{KThH}{lA}\mu(1-\mu)^2\left(1+\mu\frac{H}{h}\right)} \quad \text{--------} \ 1$$

Figure 11 Analysis of rise of mean water level.

Conclusion

In respect to transmitted wave heights and local scour, detached breakwaters function best when situated at the break-point or a little inside the break-point.

Acknowledgements

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References

Sawaragi, T. and Y. Kawasaki(1960): Scour at foot of seawalls, Disaster Prevention Research Institute Annuals, Kyoto University, Vol. 4, pp. 198-203, (in Japanese).

Sato, S., N. Tanaka and I. Irie(1969): Study on scouring at the foot of coastal structures, Coastal Eng. in Japan, Vol. 12, pp. 83-98, JSCE.

Herbick J. B., H. D. Murphy and B. Van Weels(1965): Scour of flat sand beaches due to wave action in front of seawalls, Proc. Coastal Eng. Santa Barbara Specialty Conference, pp. 703-726, ASCE.

Herbick, J. B., S. Ko(1968): Scour of sand beaches in front of seawalls, Proc. 11th Conf. on Coastal Eng., pp. 622-643, ASCE.

Sato, S and Y. Goda(1972): Coastal and Harbour Eng., pp. 339, Shokokushya Publishing Co. Ltd., Tokyo, Japan, (in Japanese).

Wada, Y., K. Nishimura and Y. Nirei(1970): Scour around breakwaters and erosion on adjacent beaches, Proc. 17th Conf. on Coastal Eng. in Japan, pp. 311-316, JSCE, (in Japanese).

Hotta, S., T. Uda and T. Sasaki(1976): Local scour around pier structures on surf zone, Proc. 23rd Conf. on Coastal Eng. in Japan, pp. 244-248, JSCE, (in Japanese).

Toyoshima, O.(1972): Coastal Engineering for practical Engineer, Erosion Section, Scour at opening on detached breakwater system, pp. 314, Morikita Publishing Co. Ltd., Tokyo, Japan, (in Japanese).

Kawaguchi, T. and M. Sugie(1972): Study of arrangement of detached breakwaters, Proc. 19th Conf. on Coastal Eng. in Japan, pp. 77, JSCE, (in Japanese).

Katayama, T., I. Irie and T. Kawasaki(1973): Field observation of effectiveness of detached breakwaters on Niigata Coast, Proc. of 20th Conf. on Coastal Eng. in Japan, pp. 519-524, JSCE, (in Japanese).

Horikawa, K. and T. Sasaki(1970): An experimental study of artificial nourishment of beaches, Proc.17th Conf. on Coastal Eng. in Japan pp. 324, JSCE, (in Japanese).