CHAPTER 37

STUDY ON SCOURING AT THE FOOT OF COASTAL STRUCTURES

by

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ABSTRACT

This paper presents the results of two-dimensional model experiments conducted in order to clarify the basic characteristics and to find out some preventive measures against scouring around coastal structures. The applicability of these results to the field are discussed on the basis of some results of field investigations.

The results of two-dimensional experiments presented herein show that the characteristics of waves just in front of structures and their reflection by structures are most important factors of scouring. The results of field investigations, however, indicate that in addition to those two factors, the currents caused due to waves around structures play important roles in scouring.

INTRODUCTION

Scouring around structures is one of the important factors to be considered in the design and construction of coastal structures. So far as authors know, however, there are few reports on scouring, because of the complexity of the phenomenon and the difficulty of the field observations under storm condition. Some of them are; experiments introduced the variation of the water level due to the tide by R. C. Russel & Sir C. Inglis (1953), study on the submerged breakwater by M. Homma & K. Horikawa (1961), study on scouring at the foot of an inclined sea wall by J. B. Herbich, H. D. Murphy & B. V. Welle (1965), study on scouring at the toe of permeable structures by T. Sawaragi (1966) and so on.

Therefore, authors have conducted several model experiments on the scouring around coastal structures. In this paper, are mentioned the results on the following four kinds of experiments conducted in the two-dimensional wave-tanks using natural sand.

a. Scouring at the foot of a vertical sea wall.
b. Scouring at the foot of an inclined sea wall.
c. The effectiveness of plastic filters for the prevention of scouring.
d. Scouring at the foot of a composite breakwater.

SCOURING AT THE FOOT OF A VERTICAL SEA WALL

In this experiment, the basic characteristics were investigated on scouring at the foot of a vertical sea wall installed at several points along two types of beach profile; the normal and storm beaches.

EQUIPMENT AND PROCEDURES

Equipment

Experiments were conducted in the two wave-tanks of different size shown in Fig.-1. The medium size wave-tank shown in the upper side of this figure is 40 m long, 0.5 m wide and 0.9 m deep and the large size wave-tank in the lower side is 105 m long, 3.0 m wide and 2.5 m deep. As shown in this figure, these both tanks were divided longitudinally into two or three parts with partition-walls and the two parts of 17 cm in width for the medium size wave-tank and the part of 80 cm in width for the large size wave-tank were used for the experiments.

Procedures

In these wave-tanks, at first, a model beach with the slope of one to ten was exposed to the action of test waves until the model beach reached the equilibrium state. Then, a vertical wall was installed and the same waves were acted again. Through a test-run, the beach profile and the shape of scour were measured with a point-gauge at intervals of several minutes near the beginning of the test-run and one hour near the end, until the steady state of the scouring was established after 6 to 10 hours of wave-run. Wave heights were measured with an electric-resistance wave-gauge and recorded on a pen-writing oscillograph.

For some cases, radio-active tracers which were made by adhering the radio-isotope of Au-198 on the surface of sand, were used in order to know the movement of bed materials. Distributions of radio-active tracers were measured with a scintillation-type detector.

Test cases

Table-1 shows the cases of the experiments. For each case in Table-1, the vertical wall was installed at various points of the equilibrium beach, therefore, the number of test-run was fourty-two. The test waves could be classified into two ranges of wave steepness as shown in the first column of this table, one is flat waves which make the normal beach and the other is steep waves which make the storm beach.

Table-1

Equilibrium profile	Ho/Lo	Ho (cm)	T (sec)	d (mm)	Ho/d	d/Ho	Wave tank
Normal beach	0.0062	8.7	3.0	0.69	1.3×10^2	0.0079	Medium
	0.0062	8.7	3.0	0.38	2.3×10^2	0.0044	Medium
	0.0065	26.0	5.1	0.21	1.2×10^3	0.0008	Large
Storm beach	0.033	8.7	1.3	0.69	1.3×10^2	0.0079	Medium
	0.033	8.7	1.3	0.38	2.3×10^2	0.0044	Medium
	0.051	42.4	2.3	0.21	2.0×10^3	0.0005	Large

RESULTS OF THE EXPERIMENTS

Process of scouring and distributions of the scouring depth

Variation of the scouring depth with the lapse of time was different with the position of the vertical wall and could be classified into following four types. Types of scouring;

Type-I Scouring progresses rapidly for several minutes in the beginning, then the scouring stops, and accretion occurs.

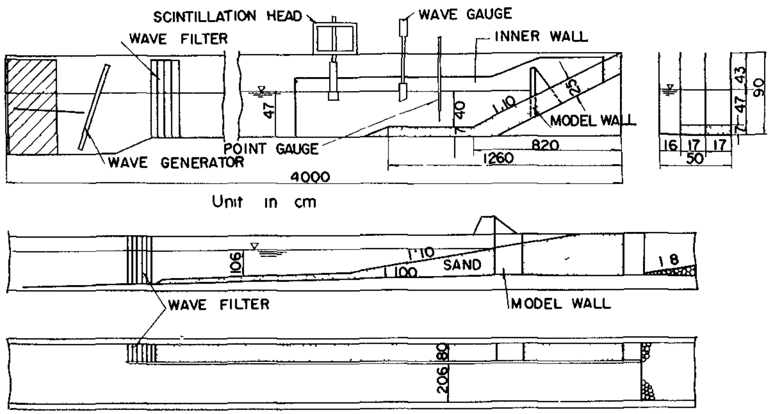

Fig. 1. wave-tanks

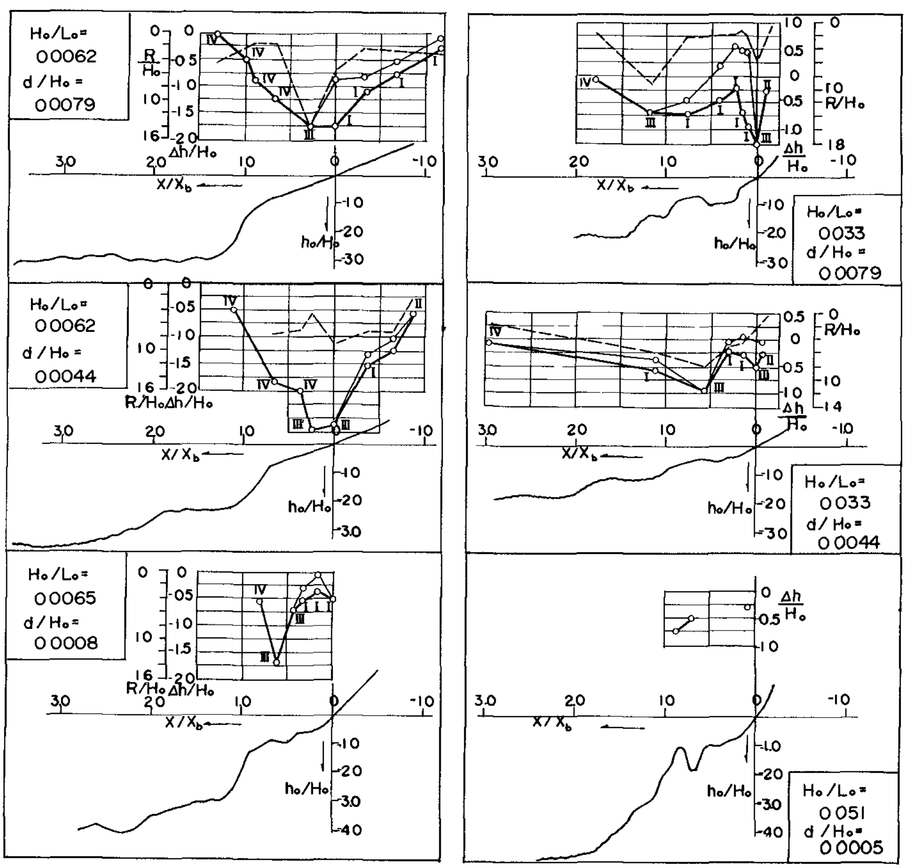

Fig. 2. The distributions of the maximum and the final scouring depth along the beach profiles.

Type-II	The stable condition is achieved after the initial rapid scouring.
Type-III	The additional slow scouring occurs following the initial rapid scouring.
Type-IV	Slow scouring continues from the beginning of the test-run.

Fig.-2 shows the distributions of the non-dimensional scouring depth ($\Delta h/Ho$), and the wave run-up height (R/Ho) along the beach profile; the left figures are for the normal beach and the right figures are for the storm beach. In these figures, the broken lines show the wave run-up height on the vertical wall, the thick lines indicate the maximum scouring depth during each test-run and the thin lines represent the final scouring depth. Therefore, the difference between the latter two lines corresponds to the amount of refilling. The abscissas of these figures are the distance from the shore-line (X) non-dimensionalized with the distance between the shore-line and the breaking point of waves (Xb). These factors such as R, Δh, Xb, X and so on are defined in Fig.-3 and Ho indicates the height of deep water waves. The breaking point of wave was defined as the point at which the front of wave crest became vertical.

Fig.-2 shows that;

i) For the normal beach, the maximum scouring depth appears to be the largest at the point a little shoreward of the final wave breaking point and the distributions along the beach profile are of V shape.

ii) For the storm beach, the distributions of the maximum scouring depth have two peaks and are of W shape; the one peak near the first breaking point and the other near the final breaking point.

iii) The largest maximum scouring depth for both the normal and storm beaches appears in type-III of scouring. For the normal beach, type-IV of scouring is found in the region seaward of type-III of scouring and type-I of scouring in the region shoreward of type-III. On the other hand, for the storm beach, type-IV of scouring appears in the region seaward of the offshore-side peak of the maximum scouring depth, type-II of scouring in the region shoreward of the shore-side peak and type-I of scouring in the region between the two peaks.

Mechanism of the four types of scouring.

Fig.-4 shows variations of the beach profiles for the typical examples of the above mentioned four types of scouring. In this figures, the dash-dot lines show the mean elevations of wave crests or troughs. Variation of the scouring depth with lapse of time for these examples are as shown in Fig.-5.

In the example of type-I of scouring shown in the top of Fig.-4, the vertical wall was installed at the shore-line and radio-active tracers were injected at the toe of the wall.

Since waves after breaking act directly on the wall in the beginning of the test-run, the foot of the vertical wall was scoured rapidly in the same mechanism as scouring by water jet, and the region just seaward of the step was accreted remarkably. Because the amount of this accretion on the seaward

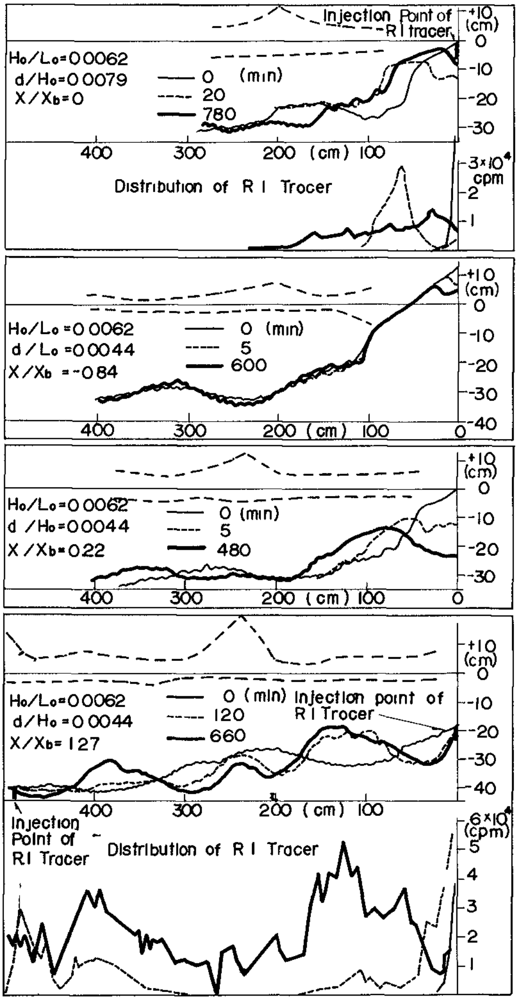

Fig. 4. Variations of the beach profiles of the typical examples of the four types of scouring, and distribution of R. I. tracers.

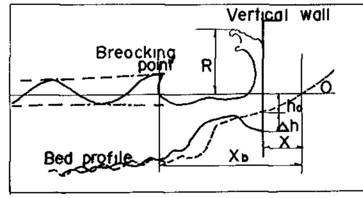

Fig. 3

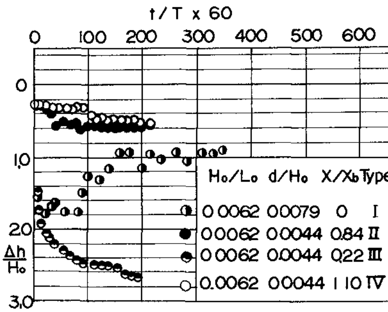

Fig. 5. Variations of the scouring depth with lapse of time for the examples shown in Fig.-4.

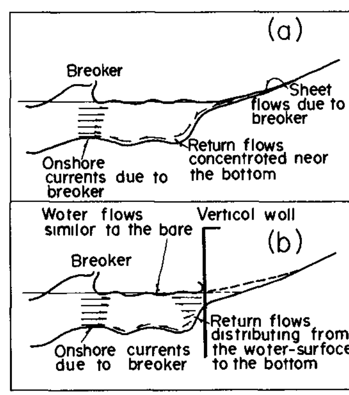

Fig. 6.

slope of the step is more than the amount of scour at the foot of the vertical wall, it is clear that sand was also supplied to this region from the offshore-zone due to the shoreward sand transport.

As illustrated in Fig.-6(a), in the equilibrium beach without the vertical wall, waves after breaking rush up on the shore to form the sheet flow, which cause return flows concentrated near the bottom. And this return flows may balance with the onshore currents near the bottom due to waves. When a vertical wall is installed as shown in Fig.-6(b), the water currents after wave breaking reflect from the vertical wall to bring out return-flows distributing from the water-surface to the bottom, because this water currents in the zone near to the breaking-point is similar to the bore. As the result, the return flows near the bottom decrease as compared with the case without the sea-wall; this decrease of return flows near the bottom results in the increase of the net onshore currents. Therefore, at the portion seaward of the step in front of the vertical wall, bed materials are transported shoreward to accumulate in front of the step from the beginning of test-run. This accumulation of sand extends toward the toe of the vertical wall gradually and refills the scouring hole. The distribution of radio-active tracers shown in Fig.-4 shows clearly the above mentioned process of refilling.

In the cases where a vertical wall was installed near the shoreward end of the foreshore, the decrease of the return flow near the bottom did not occur so much, since the sheet flow acted on the vertical wall. Therefore, the steady state was attained without the refilling. This type of scouring is type-II.

Since waves break at the two points such as near the longshore-bar and the shoreline, the energy of the water flow after breaking may be small in the cases of the storm beach. Therefore, type-II of scouring appears near the shoreline as shown in Fig.-3.

When a vertical wall is installed in the offshore zone, type-IV of scouring appears. The lowest figure of Fig.-4 shows an example of this type. In this case, the vertical wall was installed at the point of 20 cm in water depth and radio-active tracers were injected at the two points; one at the toe of the wall and the other at 500 cm seaward from the wall. As known from the variation of beach profiles and the distribution of R. I. tracers, sand seaward and shoreward of the loop of the standing wave are transported to seaward and shoreward respectively to accumulate near the node of the standing waves. Since the surface of the vertical wall corresponds to a loop of standing waves, sand at the foot of the wall are transported seaward and scouring proceed gradually.

Type-III of scouring occures in the location between type-I and type-IV of scouring, and the mechanism of scouring in this type is composed of two steps of scouring, that is, in the first step, the foot of the vertical wall is scoured rapidly by the waves after breaking in the mechanism similar to scouring by water jet and in the second step, the foot of the wall is scoured gradually due to the standing waves which are formed due to the increase of the water depth in front of the vertical wall by scouring.

Maximum scouring depth

Fig.-7 shows the relation between the largest maximum scouring depth non-dimensionalized with the height of the deep water waves $(\frac{\Delta h_M}{H_0})$ and the steepness of the deep water waves. In this figure, it is clear that the values of $\Delta h_M/H_o$ are larger for the flatter wave and for the steepness of 0.02 to 0.04, $\Delta h_M/Ho$ takes the value of nearly 1.0, that is, the largest maximum scouring depth is approximately equal to the height of the deep water waves.

On the other hand, in Fig.-8, the value of $\Delta h_M/Ho$ decreases with the ratio of the relative median diameter of the bed materials (d /Ho).

Since, wave steepness is the value of 0.02 to 0.04 under ordinary storms and the value of d /Ho is smaller than that in present experiments, the maximum scouring depth under the actual storm condition may be considered not to exceed the height of the deep water waves.

SCOURING AT THE FOOT OF AN INCLINED SEA WALL

EQUIPMENT AND PROCEDURES

Equipment and procedures

Experiments were conducted in the medium size wave-tank shown in Fig.-1 and their procedures were the same as the experiments on the vertical wall mentioned above.

Experimental conditions and test cases

Wave conditions and bed materials of this experiment were the same as the matters listed in the fifth line of the Table-1, and the model beach was of storm beach. Inclination of the wall surface was varied at three values of 90, 60 and 30 degrees from the horizontal line. The model wall was made of wooden plates and was driven into the sea-bed.

RESULTS OF THE EXPERIMENTS

Fig.-9 indicates the distribution of the maximum and the final scouring depth along the beach profile. Except a few cases, the process of scouring could be classified into the before mentioned four types of scouring. For example, in the case of X/Xb = 0.96, no scouring appear, but accretion occurs from the beginning of test-run. This new type of scouring was defined as type-V of scouring. Those types of scouring are shown with Greek figures in Fig.-9.

The graphs shown in the upper side of Fig.-9 represent the relation between the scouring depth and the angle of inclination of the wall. The thick lines indicate the maximum scouring depth and the thin lines the final scouring depth.

From the lower figure, it is clear that although the distribution of the maximum scouring depth for 90^o sea wall is of W shape as the above mentioned experiments on the vertical wall, the distribution for 30^o sea wall is of V shape having a peak near the longshore-bar. And the different types of scouring appear at the same point due to the difference of the inclination of the wall.

In the graphs in the upper side of this figure, the scouring depth

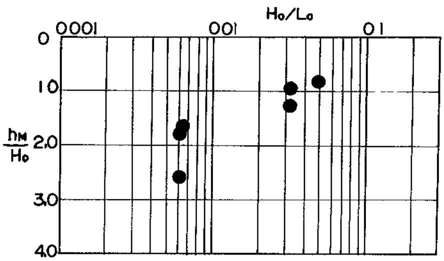

Fig. 7. Relation between the largest maximum scouring depth and the wave steepness.

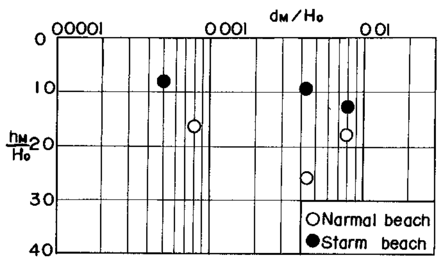

Fig. 8. Relation between the largest maximum scouring depth and the median diameter of sand.

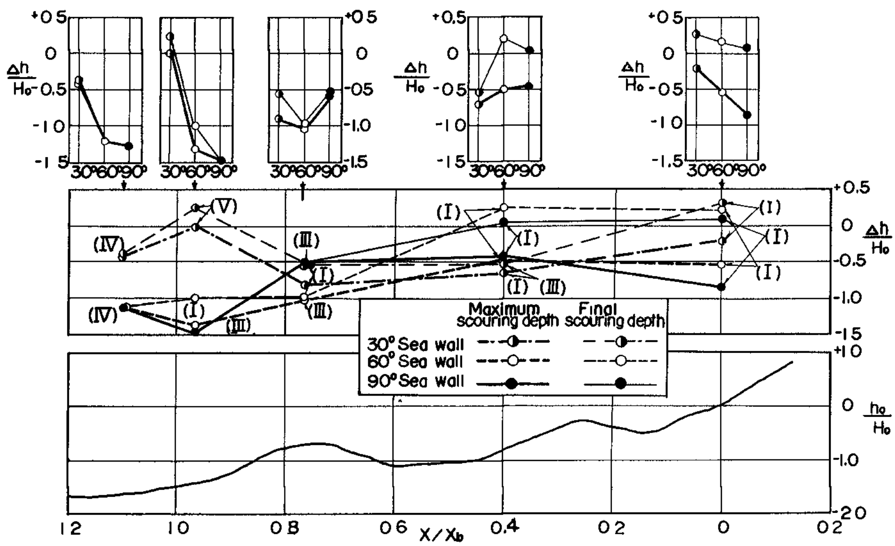

Fig. 9. Distribution of the scouring depth along the beach profile and the relation between the scouring depth and the inclination of the wall.

decreases with the angle of inclination of the wall in the regions around the shoreline and seaward of the longshore-bar, although the difference are small between the scouring depth of 90° sea wall and 60° sea wall in the region seaward of the longshore-bar. The tendency, however, can not be found at the crest and trough of the longshore-bar.

As known from this figure, the amount of refilling decreased with the angle of the inclination of the wall at the point of X/Xb = 0 and X/Xb = 0.4. The reason of this fact may be similar to the matter mentioned about Fig.-6. That is, in the case of the inclined wall, the decrease of the return-flow near the bottom would be little in comparison with the case of the vertical wall, because the water-flow after wave-breaking rushed up on the surface of the wall having the characteristics of the sheet flow.

In the seaward region of the longshore-bar, the standing waves due to the reflection of wave from the surface of the wall was formed. As seen in Fig.-10 showing the distributions of the mean elevations of the wave crest or trough in front of the sea wall installed at the point of X/Xb = 0.96, the positions of the nodes and loops of the standing waves are shifted remarkably in the case of 30° sea wall. When the distance of this shifting was close to a quarter of the wave length, the foot of the wall was accreted from the beginning of test-run without scouring. This type is type-V.

By the results of these experiments it may be concluded that the inclined sea-wall is effective for the prevention of the scouring except the region near the longshore-bar, while the effectiveness of 60° sea wall is small in the offshore zone.

THE EFFECTIVENESS OF PLASTIC FILTERS FOR THE PREVENTION OF SCOURING

Use of plastic fiber cloths as filters for prevention of scouring at the feet of coastal structures was reported by R. J. Barrent and others in the 10th Conf. on Coastal Engineering in Tokyo. Authors examined experimentally the effect of these plastic filters for the prevention of scour taking the two cases of the armor-stone revetment and the wave-absorbing structure.

EQUIPMENT AND PROCEDURES

Equipment and procedures

The experiments were conducted in the medium size wave-tank without partition-walls shown in Fig.-1. The cross sections of modeles of the armor-stone revetment and the wave-absorbing structure are shown in Fig.-11 and Fig.-12. The models shown in these figures correspond to 1/20 in scale of the structures in the field.

In the experiment on the armor-stone revetment, the models were built on the flat bed of sand having the median diameter of 0.2 mm and for the wave-absorbing structure, models were built on the equilibrium beach which was formed by acting test-waves on the initial beach of sand of 0.14 mm in median diameter having the slope of 1/10.

The permeability of plastic filters tested in these experiments is shown in Table-2.

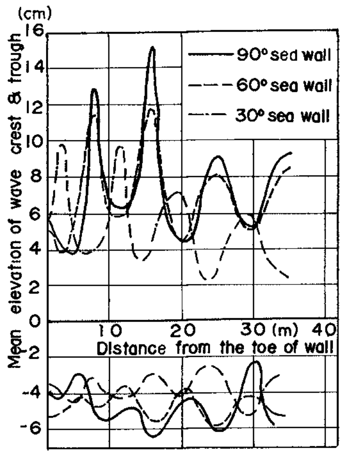

Fig. 10. Distributions of the mean elevation of the wave crest or trough.

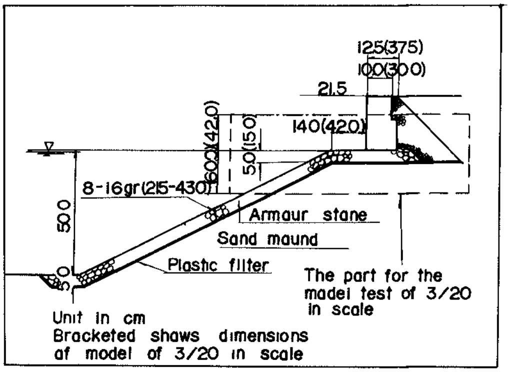

Fig. 11. Cross section of the model of the armour-stone revetment.

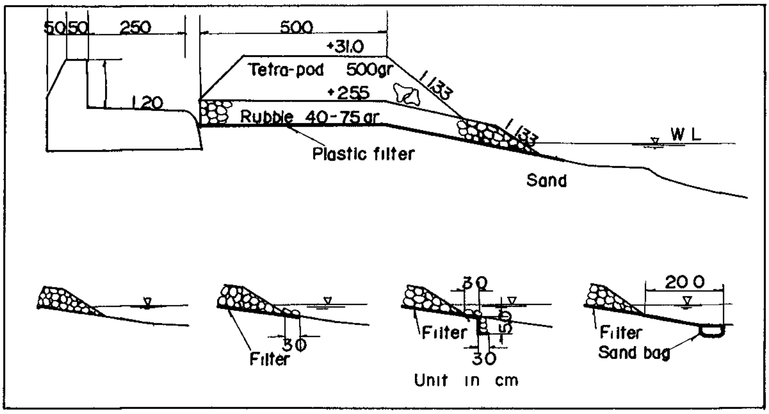

Fig. 12. Cross section of the model of the wave-absorbing structure.

Table-2. Permeability of plastic filters

Experiment	Armor-stone revetment	Wave-absorber
Mesh of filter	a-14 mesh	a-16 mesh
Permeability (m/sec)	1.1×10^{-2}	5.72×10^{-3}

EXPERIMENTAL CONDITIONS AND TEST CASES

In the experiments on the armor-stone revetment, the three types of sublayers; sand mound only, sand mound covered with rubbles only and sand mound covered with rubbles and plastic filters were tested. The test cases and the conditions are shown in Table-3.

Table-3

Case No.	Scale	Wave height	Wave period	Type of sublayer
a	1/20	5 cm	0.9 sec	Sand mound only
b	1/20	5	0.9	Sand mound covered with rubbles
c	1/20	5	0.9	With plastic filters
A	3/20	15	2.2	Sand mound only
B	3/20	15	2.2	Sand mound covered with rubbles
C	3/20	15	2.2	With plastic filters

In case-A, B and C listed in Table-3 the part enclosed by dash-dot line in Fig.-11 was tested in the scale of 3/20 in order to examine the scale effect of experiments.

RESULTS OF EXPERIMENTS

On the armor-stone revetment

Fig.-13 shows the variation of the front surface of the mound of revetment for case-A, B and C. In case-A the foot of the upper structures was scoured very remarkably and the upper structure was on the point of falling. In the case-B where sand mound covered with rubbles, the shoulder of the mound was scoured and the upper structure was inclined remarkably. And in the case-C with plastic filters the scouring was hardly seen except a slight scouring at the shoulder of the mound.

Fig.-14 shows the variation of the scouring depth, non-dimensionalized by the height of the deep water wave, at the foot of the upper structure with the lapse of time. In this figure, it is clear that the case-C with plastic filters is very effective for the prevention of the scouring.

On the wave-absorbing structure

Fig.-15 shows the variation of the front surface of the wave-absorbing structure and the sea bed. The thin and thick lines represent the initial state and the state after 240 minutes of wave-run respectively. And the thickest solid lines indicate the filters.

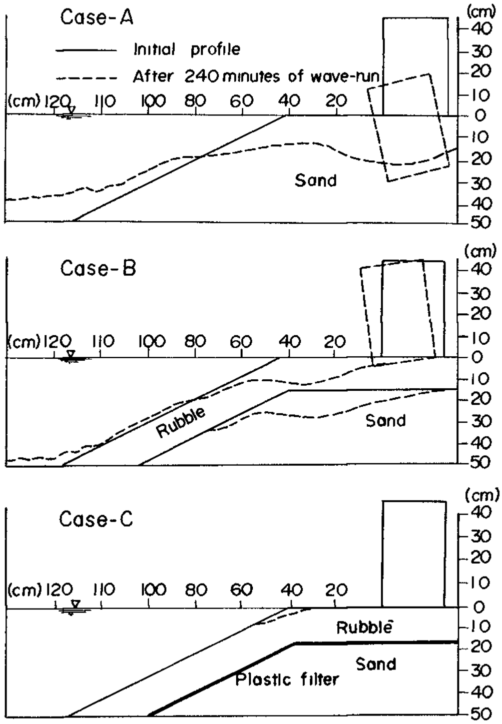

Fig. 13. Variations of the cross-section of the armour stone revetment.

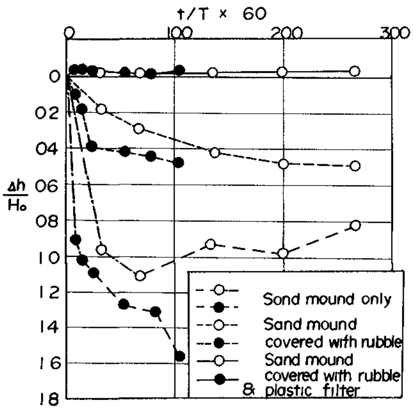

Fig. 14. Variation of the scouring depth at the foot of the upper structure of the revetment.

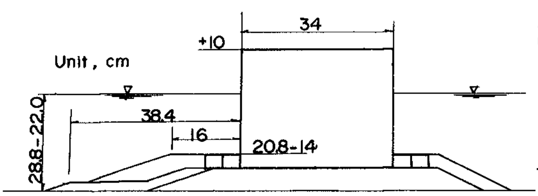

Fig. 16. Cross-section of the model of the composite breakwater.

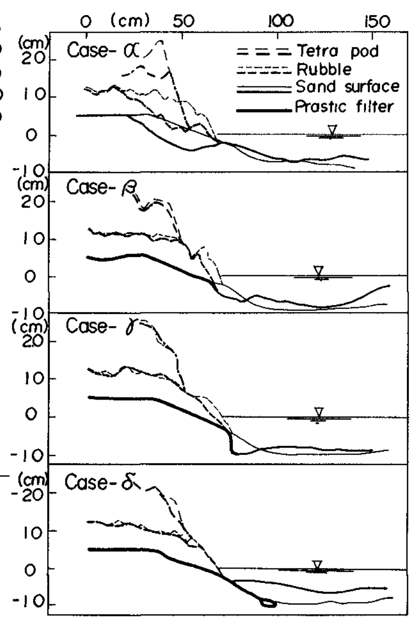

Fig. 15. Variation of the cross-section of the wave absorbing structure.

In the case (α) without filters, the sand base of rubbles was washed away and the structure sank remarkably. In the other case with filters, those sinking of structure due to scouring of the base did not occur, but the toe of the rubbles was scoured in the case (β) and (γ). In the case (δ) which produced the best result, filters were protruded seaward long enough until the water depth at the edge of filters became deep. But this device tested in the case (δ) might have a problem of the difficulty of construction and the durability of filters at the part protruded. Therefore, further studies would be performed on the scouring at the toe of the rubble mound.

SCOURING AT THE FOOT OF A COMPOSITE BREAKWATER

EQUIPMENT AND PROCEDURES

Equipment and procedures

The experiments were conducted in the medium size wave-tank without the partition-walls shown in Fig.-1. The cross section of the model breakwater is shown in Fig.-16. The models were made on the flat bed of sand of 0.2 mm in median diameter.

During the tests, test-waves were acted on the model intermittently every 30 seconds, that is, the wave generator was operated for 30 seconds and stopped for 2 minutes until waves entirely decayed out, in order to prevent reflected-waves from attacking the structure.

Experimental conditions and test cases

The test cases and conditions are shown in Table-4, where only the water depth was different among case-1 to 3.

Table-4

Case No.	Wave height	Wave period	Water depth
1	11.5 cm	1.98 sec	28.8 cm
2	11.5	1.98	26.0
3	11.5	1.98	22.0
4	7.7	1.41	22.0

RESULTS OF THE EXPERIMENT

Fig.-17 shows final bed profiles after three hours of wave action and distributions of the wave height. The vertical dash-dot lines shown in this figure indicate the position of loops of standing waves formed by the reflection of waves from the breakwater. As known from this figure, the sea beds were erroded under the loops of standing waves and were accreted under the nods as mentioned concerning to type-IV of scouring in the preceding experiments on the vertical wall. As the result, the sea beds formed sinusoidal patterns roughly having the wave length of a half length of the incident waves.

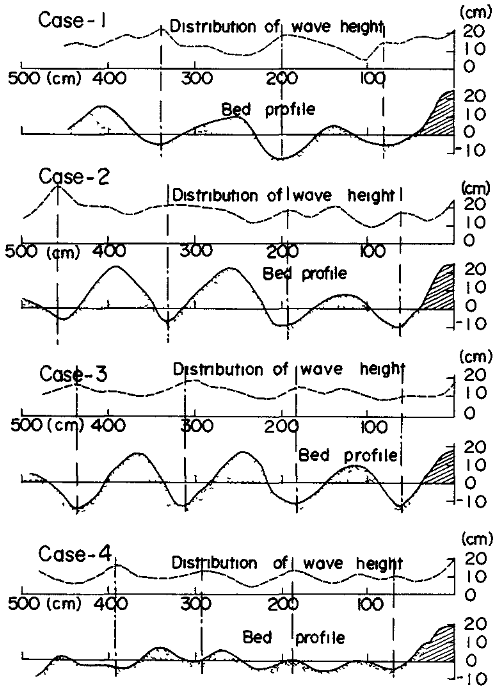

Fig. 17. The equilibrium profile of bed in front of the composite breakwater.

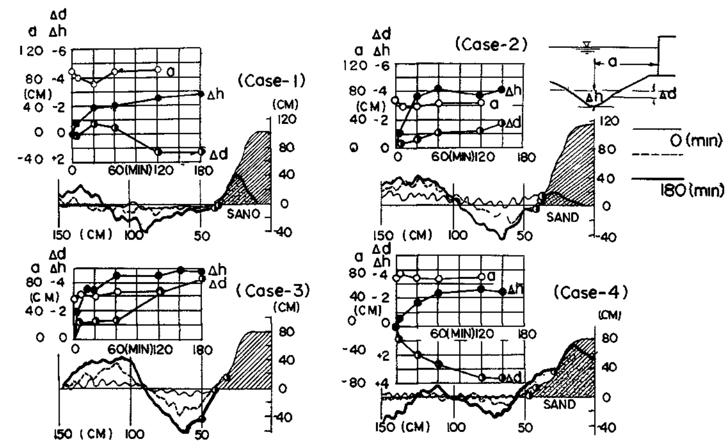

Fig. 18. Variation of the shape of the scouring hole at the toe of the composite breakwater.

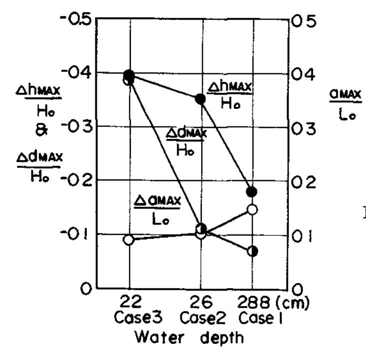

Fig. 19. Relation among $\Delta h_{max}/H_o$, $\Delta d_{max}/H_o$, d/L_o and the water depth

While the distance between the vertical surface of the breakwater and the vertical dash-dot lines nearest to the breakwater is less than the interval distance among each loop. Therefore, the patterns of distribution of the wave height and of sea bed profile are seen as if the hypothetical surfaces of reflection located at the position of the vertical dash-dot lines nearest to the breakwater.

The hypothetical surface of wave reflection approaches toward the breakwater with the decrease of the water depth in case-1 to 3.

Fig.-18 shows the variation of profiles of scouring holes at the foot of the breakwater. In this figure, the black dots indicate the toe of the rubble mound. And the final profile of sand intruding among rubbles is also represented in this figure. The graphs shown in this figure show the time variation of the scouring depth (Δh), the amount of the sliding of rubble due to scouring (Δd) and the distance (d) between the deepest point of the scouring hole and the vertical surface of the breakwater.

For case-1 to 3, the maximum values of Δh, Δd and d (Δh_{MAX}, Δd_{MAX} and d_{MAX}) non-dimensionalized with the height (Ho) and the length (Lo) of the deep water wave are represented against the water depth in Fig.-19.

According to these figures, the maximum scouring depth and the amount of the sliding of rubbles increase with the decrease of the water depth. But, on the other hand, the position of the deepest point of the scouring hole approaches to the breakwater and the amount of sand accumulated among rubbles decreases with the decrease of the water depth.

These facts may be considered to indicate that the position of the hypothetical surface of wave reflection acts the important reoles on scouring in addition to the effect of the water depth itself. That is, when this hypothetical surface approaches to the toe of the rubble mound, damage of the rubble mound due to scouring would become more intensitive.

THE COMPARISON BETWEEN MODEL EXPERIMENTS AND THE FIELD INVESTIGATION

In this section, the preceding results of model experiments will be compared with some data obtained from field investigation.

ON THE MAXIMUM SCOURING DEPTH

Fig.-20 shows the relation between the scouring depth and the wave height obtained in the port of Kashima. The port of Kashima is a new port being under construction on the sandy beach facing to the Pacific Ocean. The general characteristics of sand drift in this coast was reported in the 10th Conf. on Coastal Engineering in Tokyo. The scouring depth was defined as the difference between the water depth at the deepest point of the scouring hole surveyed at the tips of the rubble mound breakwater stretched perpendicularly to the shoreline and the water depth before construction at the same point. The wave height is the maximum significant wave height measured at the point of -12 m deep for two weeks before the surveying date of each scouring depth.

In this figure, almost all data distribute below the line of Δh = Ho.

Since the scouring depths were surveyed in calm days after a storm, some of them plotted in this figure would be one which had been refilled by small waves after a storm. Therefore, the maximum scouring depth under the stormy condition may be considered to be nearly equal to the maximum significant wave height during the storm. This result coincides with the characteristics of the largest maximum scouring depth obtained by the experiments on the vertical wall.

ON THE LOCATION OF INTENSITIVE SCOURING

Fig.-21 presents the relation between the scouring depth at the both sides of the breakwater and the water depth obtained in the port of Kashima. As shown in the small figure, the scouring depth was defined as the vertical distance between the deepest point and the outside of this scouring hole. And the abscissa is the water depth at the outside of the scouring hole.

In this figure, the distribution of the scouring depth has a peak at the water depth of -2 to -3 m. On the other hand, on the Kashima Coast, the longshore-bars are found around the water depth of -2.5 to -3.0 m. Therefore, although there are no data around the shoreline, the results presented in this figure may be considered to coincide with the distribution of the maximum scouring depth for the storm beach shown in preceding Fig.-4.

Fig.-22 shows examples of the sounding maps of three new ports in Japan, the port of Kashima mentioned above, the east port of Niigata and the port of Kanazawa. The latter two ports have been under construction on the coast of fine sand of 0.15-0.20 mm in median diameter facing to the Japan Sea and are attacked by large waves of 3 to 5 m in height from the north-west direction in winter, but it is very calm in summer. In these both ports, two raws of the large longshore-bars are found usually.

In these maps, some common characteristics are seen from the view point of scouring. That is, the feet of the breakwaters are scoured remarkably in the part crossing the longshore-bar and in the vicinity of the projected corner and the head of breakwaters.

Remarkable scour near the longshore-bar was also seen in the above mentioned experiments on the vertical and inclined walls. But, in the field, in addition to the agitation by wave breakers, the scouring would be accelerated by the seaward return flow along the breakwater.

Scouring around the projected corner and the tip of breakwaters would be considered to be brought by the sudden change of currents and waves in the vicinity of them. That is, sharp gradient of the energy of the turbulence may be an important factor causing the intensitive scouring around the projected corner, in addition to the intensitive turbulence itself.

From such considerations on the field data, it would be revealed that the transport of suspended materials due to the currents along the structures plays important roles for the scouring at the feet of structures, in addition to the agitation of bed materials by waves. Therefore, the further studies should be conducted about the effect of the currents for scouring.

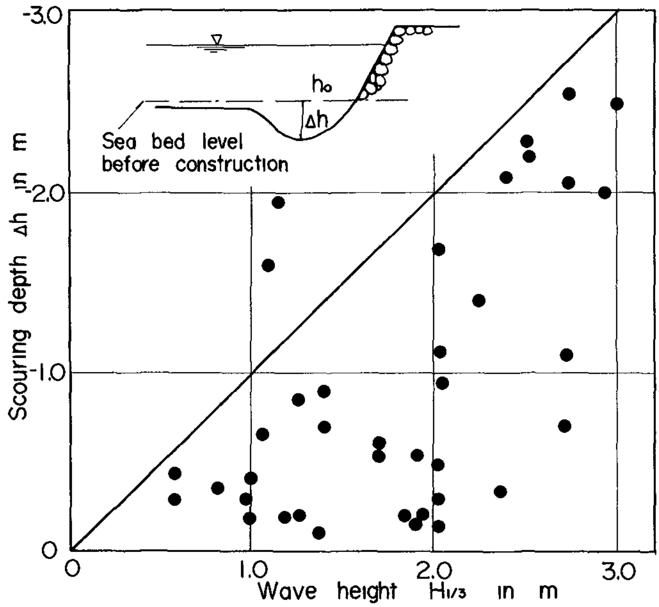

Fig. 20. Relation between the scouring depth and the wave height obtained in the port of Kashima.

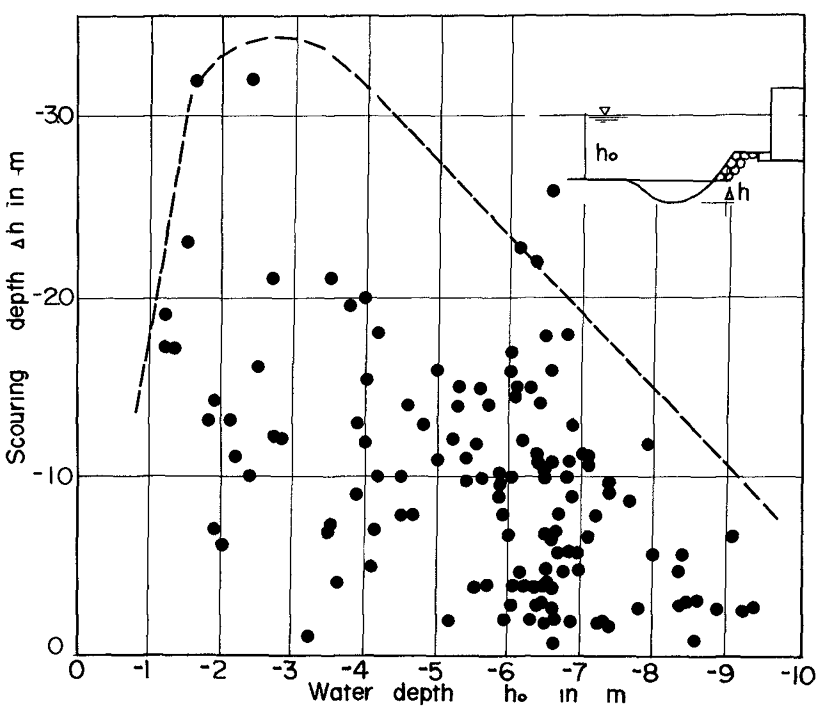

Fig. 21. Relation between the scouring depth and the water depth obtained in the port of Kashima.

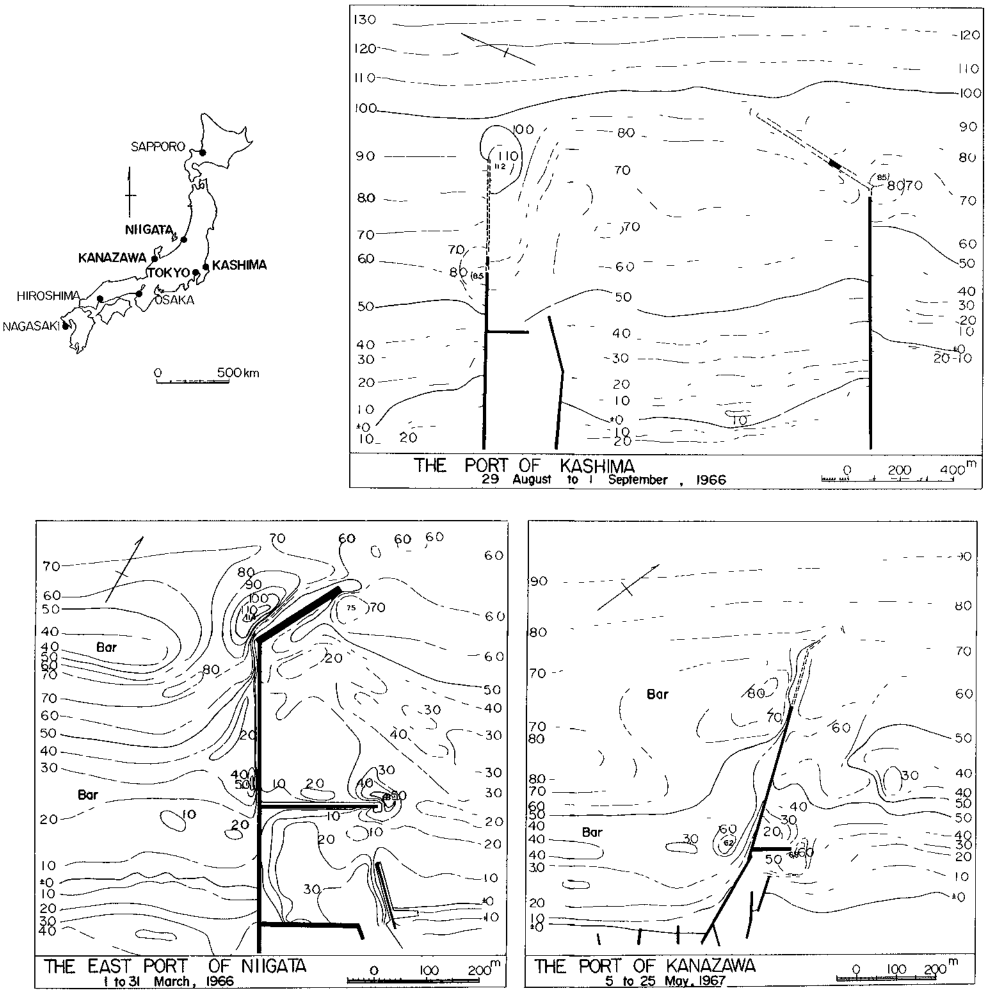

Fig. 22. Examples of sounding maps of the port of Kashima, the east port of Niigata and the port of Kanazawa.

CONCLUSION

The results mentioned above may be concluded as follows.

1) The process of scouring is classified into the following four types.

Type-I	After rapid scouring, the refilling occurs.
Type-II	The stable condition is achieved after rapid scouring.
Type-III	The additional slow scouring occurs following the initial rapid scouring.
Type-IV	The slow scouring continues from the beginning of the test-run.

2) Intensitive scouring occurs in type-III of scouring when a vertical wall installed near the plunging point of the breaker.

3) The relative largest maximum scouring depth tends to decrease with the increase of wave steepness, but it is nearly equal to the deep water wave height in case that steepness is 0.02 to 0.04, which is for ordinal storm condition.

4) An inclined wall is effective for the prevention of scouring in the region except the vicinity of the longshore-bar, although the effectiveness of 60° sea wall is small in the offshore zone.

5) Plastic filter was very effective for the prevention of scouring, but further studies would be necessary on its durability.

6) The position of the hypothetical surface of wave reflection is an important factor of scouring, in addition to the water depth itself. Damage of the rubble mound is more indtensitive when this hypothetical surface approaches to the toe of the mound.

7) The comparison of the experimental results with the data obtained in the port of Kashima shows that the matters mentioned in the second and third conclusions would be applied to the field.

8) Around breakwaters, the feet of the breakwaters are scoured remarkably in the part crossing the longshore-bar, the vicinity of the projected corner and the tip of breakwater.

9) In the field, in addition to the agitation of sea water due to wave itself, currents around the structures play important roles in scouring.

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