CHAPTER 61

SCOURING DUE TO WAVE ACTION AT THE TOE OF PERMEABLE COASTAL STRUCTURE

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ABSTRACT

In this paper, the relation between a reflection coefficient of waves and a void ratio of permeable face of a structure is firstly revealed, because of the fact that there is a close relationship between the reflection coefficient and the phenomena of scouring. Before the scouring depth is investigated, the relation of the scouring depth to subsidence is made clear. Then, it is found that the scouring depth which has great influence upon subsidence of blocks, becomes larger with the increment of the coefficient of reflection. Furthermore, a composite cross section which has an imaginary uniform slope of 20 degrees, is proposed as the stable cross section against the subsidence of blocks.

INTRODUCTION

In recent years, various armour blocks, such as Tetrapod, Hollowsquare blocks and Hexaleg blocks have been used for the constructions of a seawall, a breakwater, etc. in Japan, and they were also installed in front of the seawall to protect the overtopping of waves.

They are, however, suffered from scouring at their toe, by which the subsidence of blocks is often caused, even if the weight of blocks is sufficient against wave forces. Particularly, the phenomena of remarkable subsidence of blocks are observed along the coast of Toyama facing the Japan sea. Block structures that are installed in front of a seawall shows such an appearance of subsidence, that the subsidence to a half of an original height is observed for Tetrapod blocks, during winter season.

Therefore, the study on the phenomena of scouring at the toe of a permeable coastal structure, which has a close relation with the subsidence of blocks due to wave action, is required for the coastal structure construction.

The author investigated the scouring at the toe of permeable coastal structure on the experimental basis, and made clear the influence on the scouring depth affected by water depth at the toe, slope of seaward face and incident wave characteristics.

Furthermore, based on the experimental results, a proposed cross section of the permeable structure to be stable against the subsidence of blocks is also discussed.

VOID RATIO OF PERMEABLE FACE AND REFLECTION COEFFICIENT OF WAVES

Before the investigation on the scouring due to waves, the influence of void ratio of permeable slope on the reflection coefficient of waves which has a close relation with the scouring depth, was studied.

In this experiment, the void ratio is varied as 0 %, 3.9 %, 7.8 %, 16.8 %, and 30 % by making holes of 12 mm diameter in a wooden plate. The relative water depth at the installed position of a structure is kept constant 0.04. Wave characteristics of the model test are shown in Table-1.

Healy's theory is used to calculate the reflection coefficient of waves based on wave record in front of a seawall that are measured at 18 positions of 5 cm interval.

Fig.-1 shows a series of the experimental results, and of the previous experimental results that the author had obtained for Hexaleg blocks models, and Straub, Bowers and Herbich (1958) had got for rubble mound and wire mesh, are appended to this figure.

It is found that the coefficients change remarkably with void ratio when it is less than 20 %, but the change of the coefficients becomes small when the void ratio is greater than 20 % under any slope of permeable face.

In general, the void ratios of armour blocks lie between 40 % to 60 % as shown in Table-2. Therefore, if the scale of any kind of blocks to the incident wave height is identical, it is concluded that the reflection coefficients of wave are almost independent of the shape of the armour blocks.

EXPERIMENT ON THE SCOURING AT THE TOE OF PERMEABLE STRUCTURE

EQUIPMENT AND PROCEDURE

The permeable structure in prototype indicates the void ratio of greater than 50 % , and is installed in front of a seawall. However, in connection with the above experimental results on the influence of the void ratio upon the reflection coefficient, the following test are carried out under the condition that void ratios of model blocks are

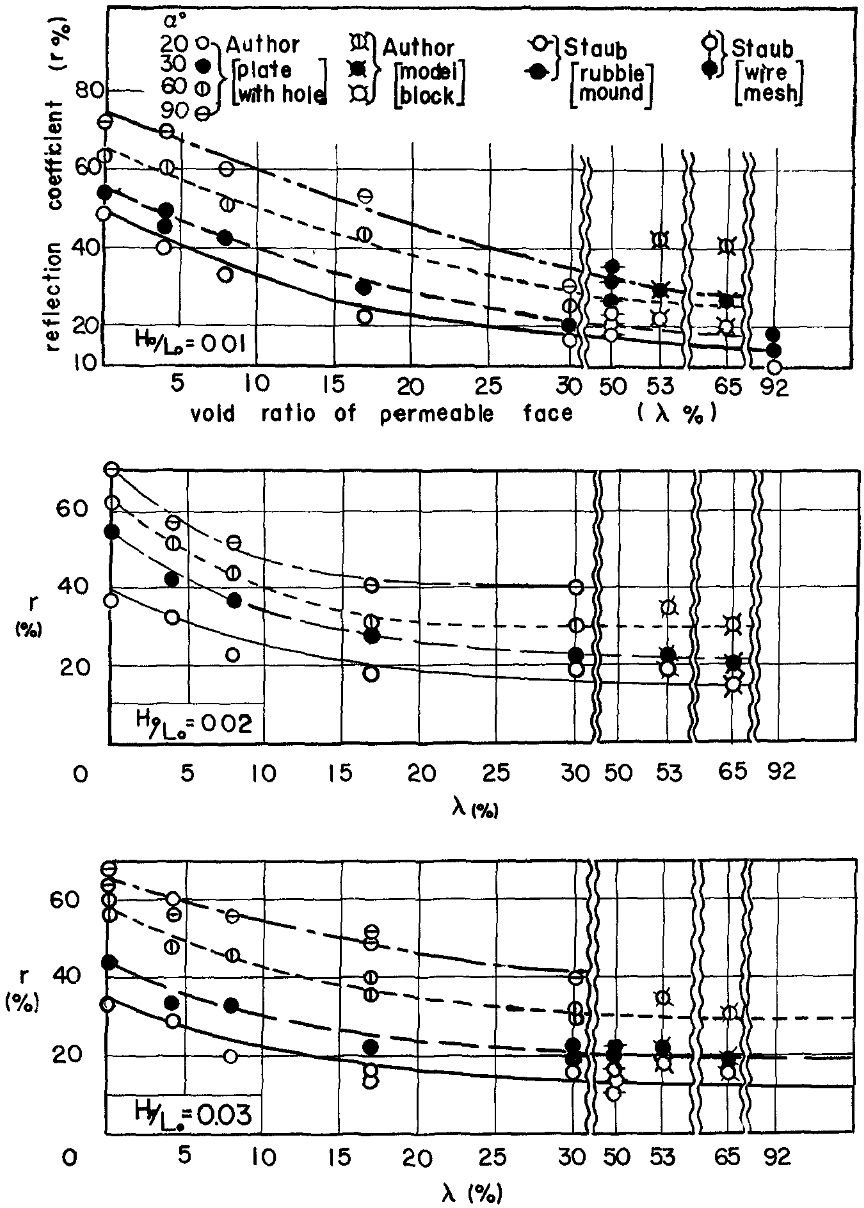

Fig. 1. Relation between void ratio of slope and reflection coefficient.

No	T (sec)	H_o (cm)	H_o/L_o	h (cm)
1	093	40	003	533
2	113	40	0.02	80
3	160	40	001	16.0

Table 1. Wave characteristics in the test on reflection coefficient.

Kinds of blocks	Rubble Mound	Tetrapod	Tribay	Hexaleg block	Hollow tetrahedron blocks	Hollow square blocks	Akmon	Bipod	Tripod
Void ratio (%)	45	52	53	40~80	66	49	60	61	53

Table 2. Value of void ratios of various armour blocks.

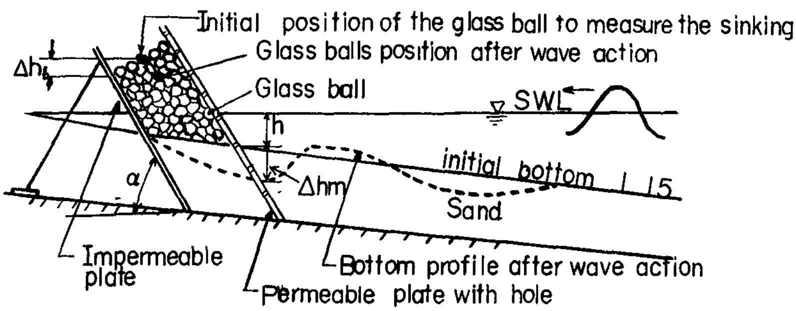

Fig. 2. Sketch of coastal structure model.

kept constant 40 % . Glass balls of 2 cm in diameter are used as block models.

Only the subsidence of blocks according to the scouring at the toe is investigated without regard to tumbling of blocks due to wave action in this test. Therefore, the coastal structure model as shown in Fig.-2 is used. A plate having holes of the void ratio 30 % is set in front of glass balls, and an impermeable plate in substitution for a seawall is used.

Test are conducted under the combination of such conditions that α is 20°, 30°, 45° and 60° and that the water depth at the toe is changed as 2 cm, 4 cm and 6 cm. The characteristics of wave in model are indicated in Table-3.

The scouring depth changes its magnitude during wave action. It does not always increase with time, but sometime decreases by filling action of sand drifts during the process of scouring. The maximum scouring depth Δh_m is so closely related to the amount of subsidence of blocks that the measurement of beach profile is conducted at 5, 10, 15, 25, 35, 45 and 60 min. after wave operation. The hypersonic sounding equipment is used to measure the beach profile, and its range of measurement is from 2.5 cm to 50 cm of water depth.

RELATIONSHIP BETWEEN AMOUNT OF SUBSIDENCE OF BLOCKS AND SCOURING DEPTH

Before the scouring depth is investigated, it must be confirmed whether the subsidence of blocks is dominated by the scouring at the toe or not. Therefore, the relationship between the amount of subsidence of blocks and the scouring depth has to be made clear.

Fig.-3 shows the relationship between the amount of subsidence of blocks Δh_b and the maximum scouring depth Δh_m. H_0 in Fig.-3 indicates the wave height in deep water. The amount of subsidence of blocks for the slope (α) of seaward face of greater than 30 degrees may be influenced apparently by the scouring depth as shown by the chain line in Fig.-3. On the other hand, when α is equal to 20 degrees, the amount of subsidence of the blocks are small as compared with the scouring depth. From the test results, it may be estimated that the slope of seaward face of 20 degrees indicates the stable slope against the wave action.

RELATIONSHIP BETWEEN SCOURING DEPTH AND REFLECTION COEFFICIENT

A change of the seaward slope of structure and of an initial water depth at its toe bring about the changes

No	T (sec)	Ho (cm)	Ho/Lo
1	185	8	0015
2	160	8	002
3	131	8	003

Table 3. Wave characteristics in the test on scouring depth.

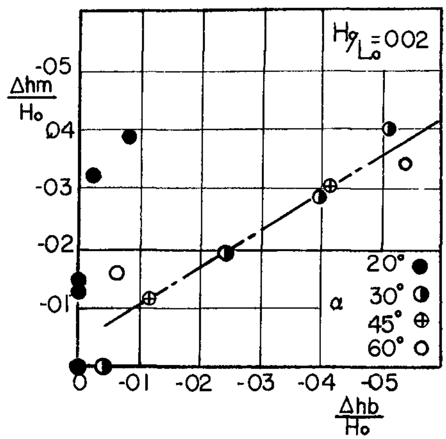

Fig. 3. Relationship between amount of subsidence of blocks and maximum scouring depth.

of the reflection coefficients. Therefore, the author manifests the influences of the seaward slope and of the initial water depth on the scouring depth through the change of the reflection coefficients.

Ira.A.Jr. Hunt (1961) had proposed that in the design of seawall a reflection coefficient should be made as small as possible in order to protect the overtopping of waves. The author investigated whether the Hunt's conception is able to be applied to the relation of the scouring depth to the reflection coefficient.

Fig.-4 shows the relation between the reflection coefficients and the scouring depth. From this figure, it is found that the scouring depth becomes larger proportionally to the increment of the coefficient, when the coefficient is greater than 25%. When the coefficient is less than 25%, the scouring depth becomes remarkably small, and in some cases, the final topography at the toe makes accumulation. (The state that Δh_m is equal to 0 in Fig.-4 shows the accumulation.)

Fig.-5 shows the relation between the scouring depth and the initial water depth at the toe of structure. Consequently, it is found that the structure installed at a shallow position is not necessarily stable against the scouring.

The quantitative scouring depth is not, however, obtained from the scouring depth in Figs.-4 and 5, because it is also related with the ratio of a sand grain size to a wave height.

CONSIDERATION FOR THE STABILITY OF BLOCKS AGAINST THE SUBSIDENCE

In case of the seaward slope of greater than 30 degrees, the stability of armour blocks against the scouring and subsidence is discussed through the reflection coefficient. But in case of the seaward slope of smaller than 20 degrees, the armour blocks becomes stable against the subsidence without any relation with the scouring. The fact that the slope of seaward face of 20 degrees indicates a stable slope against the wave action, is confirmed by the experimental results which Prof. S. Nagai and Mr. A. Takata have carried out.

Table-4 indicates stable slopes due to wave action for various block models obtained by Prof. Nagai and Mr. Takata. It is understood that final slopes change from the initial slope of 45 degrees and 34 degrees to approximately 20 degrees.

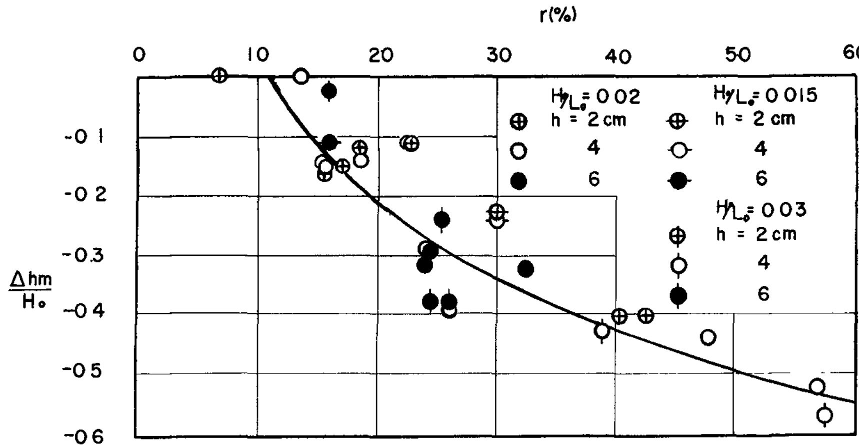

Fig. 4. Relationship between reflection coefficient and scouring depth.

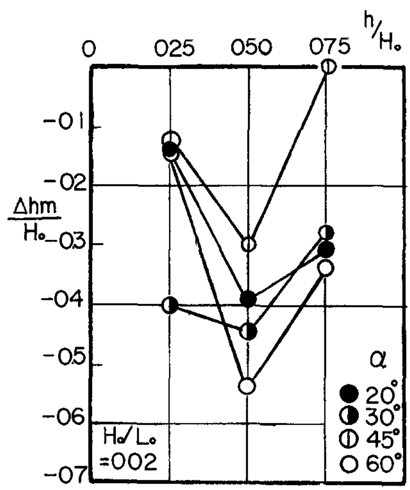

Fig. 5. Influence of initial water depth at the toe of structure on scouring depth.

Kinds of blocks	Wave choroteristics (Conversicen to prototype)	Initiol face slope	(60min) Stable slope
Tetropod (60t)	H=4 1 m T=9 0 sec	34°	1 32(17° 50′)
Hollowsquare blocks (5.0t)	H=4 1 m T=9 0 sec	〃	1 29(19° 20′)
Hollow tetrohedron blocks (6.0t)	H=4 1 m T=9 0 sec	〃	1 4.3(13° 4′)
Tetrapod (60t)	H=4 1 m T= 90 sec	〃	1 25(21° 49′)
Hollow squore blocks (50t)	H=4 1 m T=9Q sec	〃	1 15(33° 40′)
Hollow tetrohedron blocks (60t)	H=4 1 m T=9 0 sec	〃	1 32(17° 20′)
× Initiol beach slope 1 · 10			
Tetropod (60t)	H=3 7m T=1 05 sec L=1 04m	45°	1' 24(22°30′) 60 min 1 3.2(17°4′) 180 min
Hollowsquare blocks	H=4m T=1 05 sec	34°	1 2.8(20° 25′) 60 min
Tetrapod	H= 5m T=1 0.5 sec	〃	1 15(33°40′) 30 min
Hollow tetrohedron bloks	H= 5m T=1 05 sec L= 1 04m	〃	1 · 2.3(23°25′) 30 min
Hollowsquoreblocks	H=4 0m T=1 0 5 sec	〃	1 19(28°) 30 min
Tetropod	H= 50~52m T= 10 5 sec L= 1 04m	〃	1 2.5(21° 43′) 30 min
Hollowsquareblocks + Rubble mound	H=5 0m T=1 0.5 sec L= 1 04m	〃	1 25(21° 43′) 30 min
× Initiol beoch slope (1 16)+(1 3)+(1 10)			

Table 4. Stable slopes against wave action for various block models (by S. Nagai and A. Takata).

When the slope of seaward face is less than 20 degrees, however, the volume of structure becomes very large, and the armour blocks becomes weak. Moreover, when the seawall is already accomplished, the water depth at the toe of permeable structures in front of the seawall approaches to the one at which the scouring depth becomes large.

Therefore, the composite cross section of a permeable structure as shown in Fig.-6 is proposed; (1) the imaginary uniform slope of this section, as Dr. T.Jr. Saville (1958) proposed on the overtopping of waves, is less than 20 degrees, (2) the composite cross section must be submerged to reduce the wave reflection. The length of l as shown in Fig.-6 is calculated by Eq. (1).

$$l = \frac{h_2 + R}{\tan 20°} - s(R + h_1) - s'(h_2 - h_1) \qquad (1)$$

where R is height from the sea water level to the top of wave run up; h_1, h_2, s and s' are shown in Fig.-6.

In general, the height of an absorbing permeable structure is lower than the height of the top of wave run up. In such case, l is expressed by substituting R_c into R in Eq. (1).

$$l = \frac{h_2 + R_c}{\tan 20°} - s(R_c + h_1) - s'(h_2 - h_1) \qquad (2)$$

where R_c is the height of a permeable structure from the sea level.

It may be said that the author's proposal is verified by the following fact: an absorbing permeable structure constructed in Yui Coast, Japan, has such a cross section which has the imaginary uniform slope of 21 degrees was stable against the violent waves of 9.22 m height and 15 sec. wave period, due to Typhoon No. 24, 1965.

CONCLUSION

The scouring depth at the toe of permeable structure by which the subsidence of blocks is often caused, is qualititatively investigated through the reflection coefficient. As the results, it is suggested that the reflection coefficient provides an index for designing a slope of seaward face and an installed position of the structure.

Furthermore, an stable cross section of the

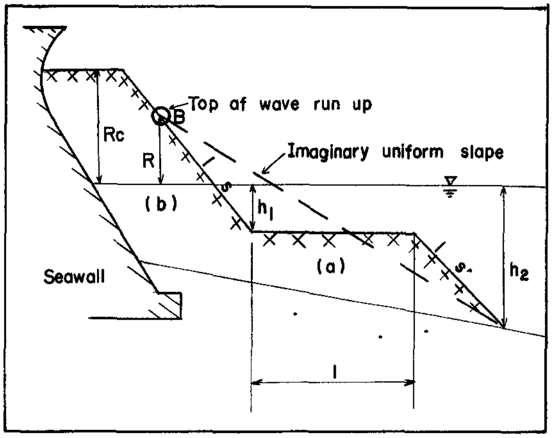

Fig. 6. Sketch of stable cross section against subsidence of blocks.

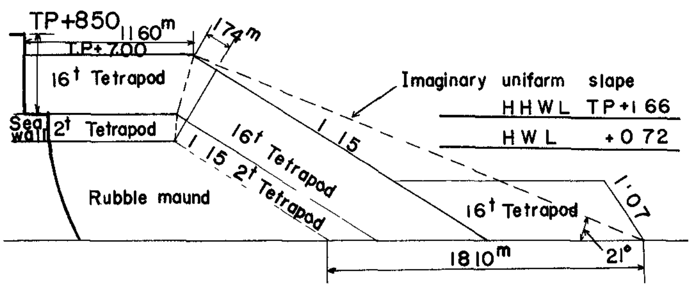

Fig. 7. Cross section of absorbing permeable structure constructed in Yui Coast.

permeable structure against the subsidence of blocks is proposed, but it has to be verified by experiments and field observations in future.

AKNOWLEGEMENT

The present studies are partly supported by the Ministry of Construction, Japan. In carring out the experimental works, the author is indebted to Mr. Hirofumi Shono, graduate student of Nagoya University.

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