CHAPTER 55

ON THE EFFECT OF ARMOUR BLOCK FACING ON THE QUANTITY OF WAVE OVERTOPPING

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INTRODUCTION

Japan, surrounded by sea, is constantly threatened by storm surges and beach erosions, for which protection works are being vigorously undertaken. As a measure for protection, facings of various armour blocks have come to be used for the seawalls and embankments. This is a skillful utilization of characteristic functions of armour blocks to dissipate and absorb wave energy effectively. However, systematic experiments and studies on this subject have been conducted only in very few cases.

This paper treats of the effect of the facing of armour blocks on wave overtopping by comparison of the quantity of waves topped over the vertical seawall with facing and that of without facing. Furthermore, this paper attempts to compare the results of the field observation and the experiments on the quantity of wave overtopping. Based on these data, the authors present a design criterion of the crown height of seawall with armour block facing.

EXPERIMENTAL PROCEDURE

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The experiments have been conducted by using a wave channel, 46 meters long, 1.5 meters high, and 1 meter wide. The various types of test wave were generated by a flap type wave generator. The blower of wind tunnel has a propeller fan, 1000 millimeters in diameter and a damper to adjust the wind discharge in three steps.

The beach slope was set at 1 on 10 in order to compare the present experiment with the ones conducted at University of Tokyo and others. The beach bed was made of mortal on which the seawall was erected. The model scale was selected to be 1/25 based on the Froude's Similarity Law. The cross sections of seawall used for the experiments are shown in Figs. 1 through 5 which show the respective experimental results. As for armour blocks of model, tetrapods of 240 grams in weight were used. These model blocks corresponded to the 4 tons type tetrapods in field. The wave heights were measured by a parallel wire resistance gauge and recorded by a pen-recorder. The gauge was located in the part of the channel with uniform depth. The water which topped over the seawall was gathered into the collecting tank behind the seawall and its volume was measured.

The waves used for the experiments were regular ones. The prototype wave conditions were 6 sec., 7 sec., and 9 sec. in periods, and 3.0 meters in the equivalent deep water wave height. The steepness of the wave in deep water was in the range of 0.02 and 0.05, which was commonly observed in field.

RESULTS AND DISCUSSION

The symbols used in this paper are as follows :

- T : wave period (second)
- Ho : equivalent deep water wave height (meter)
- Lo : deep water wave length (meter)
- h : water depth at the toe of seawall (meter)
- $\frac{HoLo}{2\pi}$: quantity of water moving onshore per wave and per unit width in deep water
- Q : quantity of wave overtopping per wave and per unit

width of the seawall

$\frac{2\pi Q}{(HoLo)}$: dimensionless quantity of wave overtopping

hc : crown height of the seawall from the still water level (meter)

ht : crown height of the armour block facing from the still water level (meter)

Figures 1 through 5 show the relation between the relative crown height hc/Ho and the dimensionless quantity of wave overtopping 2πQ/(HoLo). In each case the quantity of wave overtopping decreases as hc/Ho increases, however its tendency is stronger in case of the seawalls with facings than in the case of the vertical walls. Especially, in case of the relative water depth h/Ho = 1.0, it is evident that the seawall with facing provides a stronger tendency of decrease of quantity of wave overtopping (see Figs. 3-a and b). This shows that the effect of the facing on dissipation of wave energy is remarkable.

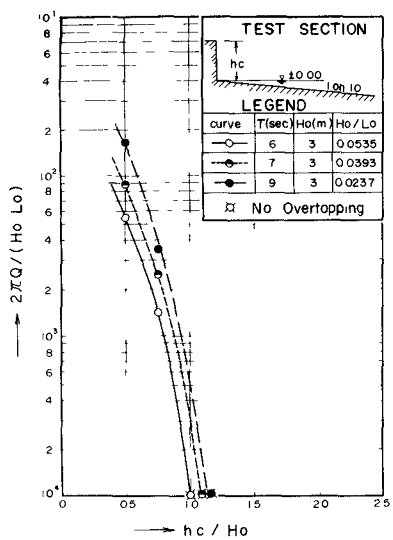


Fig. 1-a, h/Ho = 0

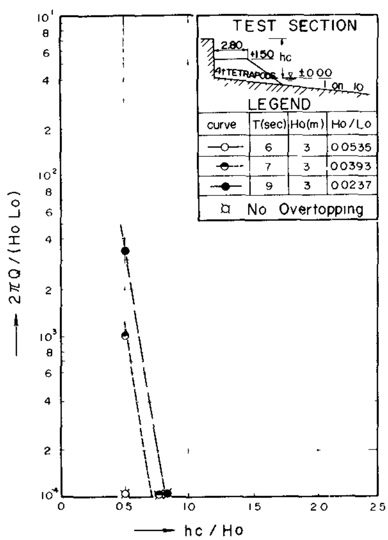
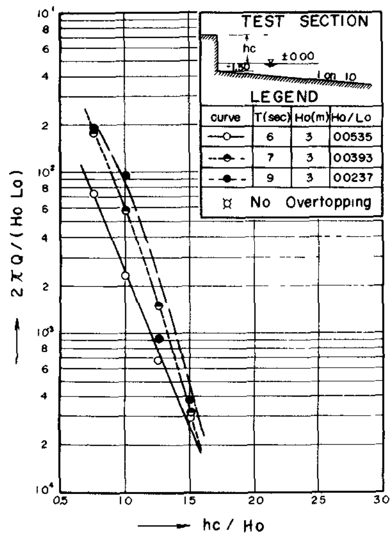


Fig. 1-b, h/Ho = 0

Relation between 2πQ/(HoLo) and hc/Ho with a parameter of Ho/Lo



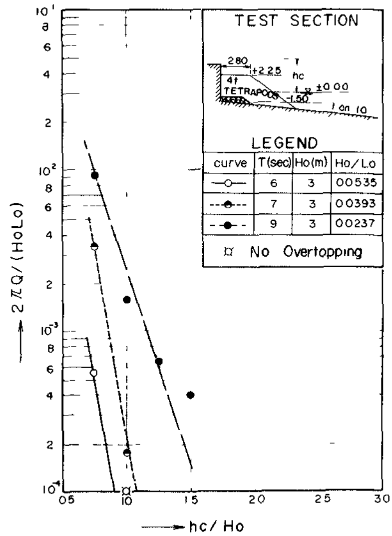
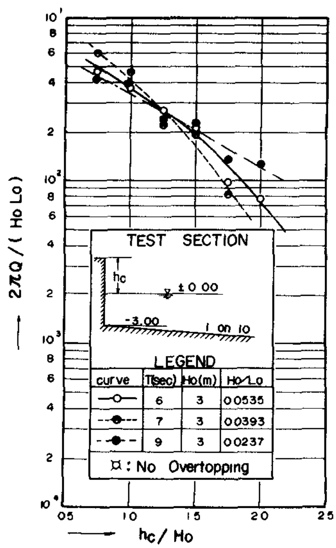


Fig. 2-a, h/Ho = 0.5 Fig. 2-b, h/Ho = 0.5

Relation between 2πQ/(HoLo) and hc/Ho with a parameter of Ho/Lo



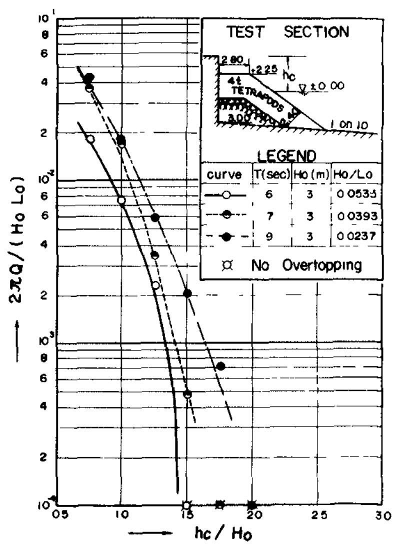
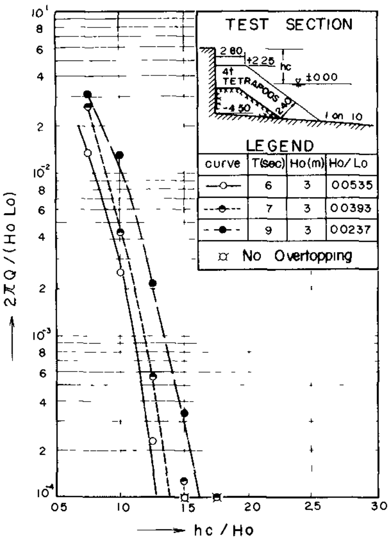


Fig. 3-a, h/Ho = 1 Fig. 3-b, h/Ho = 1

Relation between 2πQ/(HoLo) and hc/Ho with a parameter of Ho/Lo



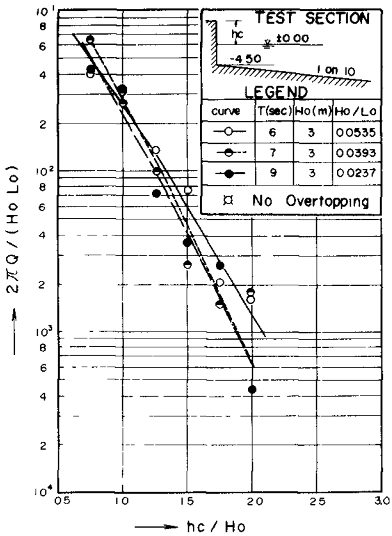
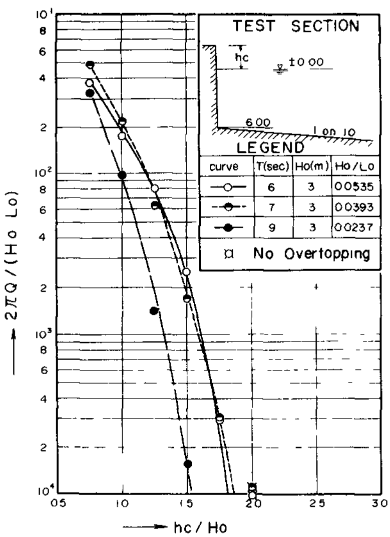


Fig. 4-a, h/Ho = 1.5 Fig. 4-b, h/Ho = 1.5

Relation between 2πQ/(HoLo) and hc/Ho with a parameter of Ho/Lo



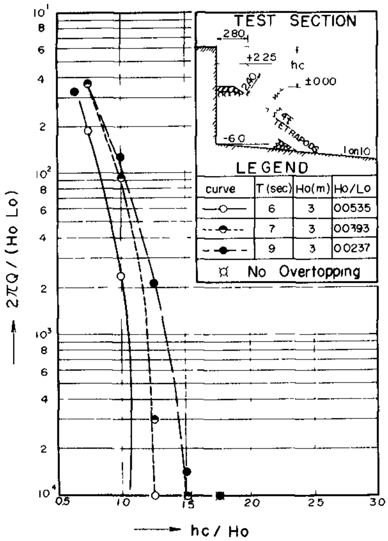
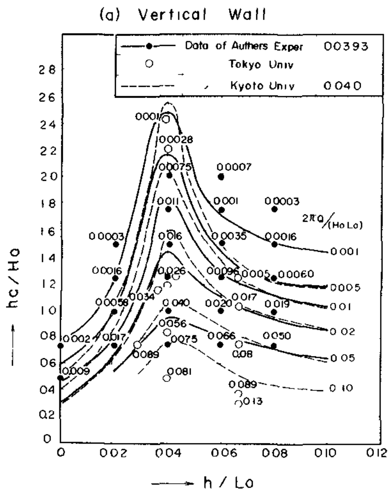


Fig. 5-a, h/Ho = 2 Fig. 5-b, h/Ho = 2

Relation between 2πQ/(HoLo) and hc/Ho with a parameter of Ho/Lo



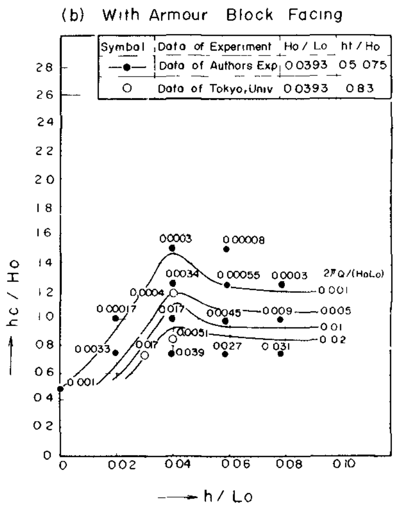


Fig. 6-a Fig. 6-b

Relation between hc/Ho and h/Lo with a parameter of 2πQ/(HoLo)

Figures 6 show the relation between hc/Ho and the relative water depth h/Lo with a parameter of 2πQ/(HoLo). For the purpose of comparison, the results of experiment at Universities of Tokyo and Kyoto are also shown. In these figures, the results of wave overtopping (2πQ/(HoLo)) obtained in the present experiments are shown with solid lines, while the results of experiments at Kyoto University with dotted lines. Comparing the solid and dotted lines, it is shown that they nearly correspond except in the vicinity of h/Lo = 0.04.

Figures 7 and 8 show the relation between 2πQ/(HoLo) and h/Ho with a parameter of hc/Ho. From these figures it is evident that whether it is a vertical wall or a wall with facing, the quantity of wave overtopping reaches a maximum near the wave breaking point. Figure 7 also shows that the quantity of wave overtopping does not decrease much as the crown height increases at the wave breaking point.

Figure 9 shows the varations of the quantity of wave overtopping according to the change of crown height of facing. But the crown width of facing is kept constant. Figure 9 may be regarded as a useful data to design an economical crown height of seawall and of armour block facing in order to prevent wave overtopping effectively.

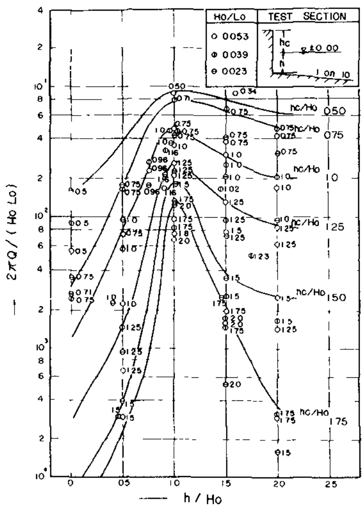


Fig. 7

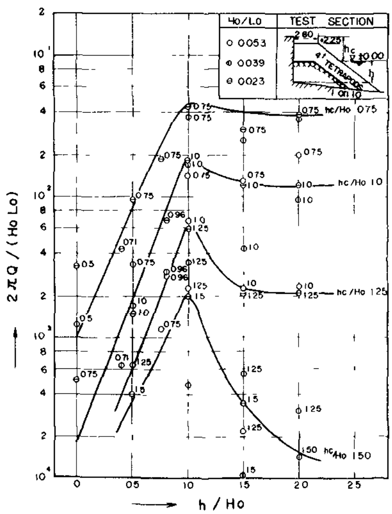


Fig. 8

Figures 7 and 8 Relation between 2πQ/(HoLo) and h/Ho with a parameter of hc/Ho.

Fig. 9 Rate of wave overtopping by the variation of crown height of armour block facing.

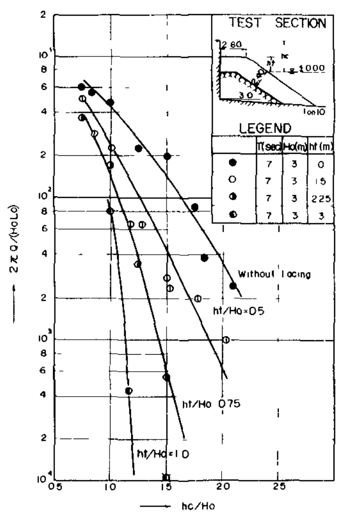


Fig. 9

FIELD OBSERVATION

1) FIELD OBSERVATION AT SAKATA COAST

When the results of experiments are applied to the field, the similarity of the model test to the field is important. To ascertain this, one of the authors has compared the results of field observation conducted by the Ministry of Construction at Sakata Coast with the results of experiments by using regular waves (model scale is 1/20).

Sakata Coast faces on Japan Sea and is constantly attacked by violent waves caused by monsoon in winter (see Fig. 10). Observation of offshore waves was accomplished by the use of a wave recorder of underwater pressure type, while the measurements of the quantity of wave overtopping and the height of wave run-up were performed by the facilities shown in Fig. 11 and Photo. 1. Water topped over the seawall striked against the plate for reception 10 meters in width, and was gathered into the collecting tank through the guideway. Observations were conducted twice at 9 a.m. and 3 p.m. The quantity of wave overtopping for 10 minutes was measured at each time.

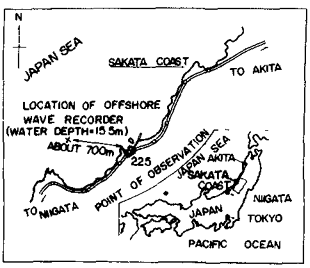


Fig. 10 Location map of Sakata Coast.

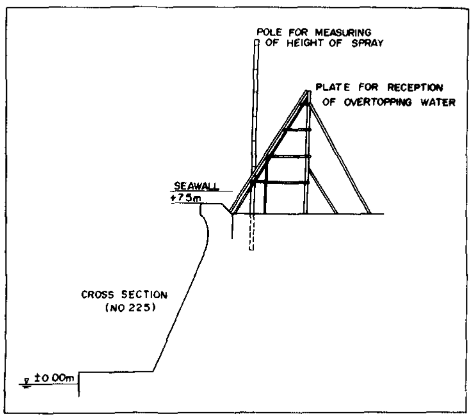


Fig. 11 Facilities of field observation of wave overtopping at Sakata Coast.

The comparison of the values of the field and laboratory observations is shown in Fig. 12. The plotted data of the field observation show the relation between the significant wave heights recorded in 10 minutes and the average quantity of wave overtopping. The solid lines in the figure show the envelopes of the experimental values for wind velocity of zero and 25m/sec. The wind velocity of 25m/sec is the prototype wind velocity which was calculated on the basis of the Froude's Similarity Law. A considerable difference is noted between the experimental values of no wind and wind of 25m/sec. This is due to the fact that the curved-face wall is highly effective in case of no wind and most of jumping waves are bounced back seaward. The observed values are sandwiched in between two envelopes of experimental data of no wind and wind of 25m/sec. Taking into consideration that the wind velocity in field was less than 12m/sec, it is safe to say that the observed values of quantity of wave overtopping in the field are roughly in agreement with the

Photo. 1 Facilities of fiels observation of wave overtopping at Sakata Coast.

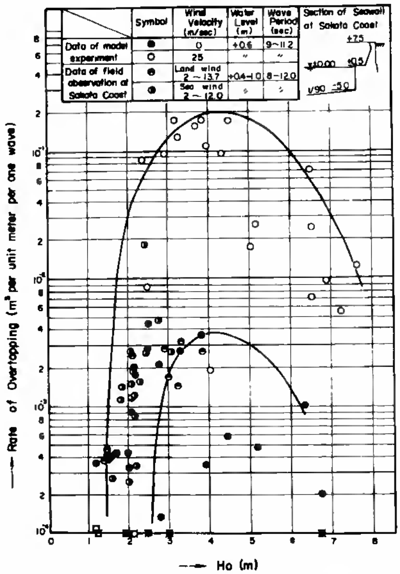


Fig. 12 Comparison between field and experimental data on the quantity of wave overtopping.

experimental values obtained by using regular waves with wind.

2) FIELD OBSERVATION AT OITA AND BEPPU COAST

Table 1 is the records of the water level and waves when Typhoon No. 9 (6309) attacked Oita Coast (see Fig. 13) on August 9, 1963. The conditions of wave overtopping over the seawall at Oita Coast during the typhoon is shown in Photo. 2.

Table 1 Records of the water level and waves when Typhoon No. 9 attacked Oita Coast.

Time	Wind velocity	Water level	H1/3	T1/3	H1/10	T1/10	Hmax	Tmax
13:30	21.7m/sec	+2.18m	3.27 m	7.0 sec	3.86 m	7.0 sec	4.10 m	7.0 sec

Ho1/3 = 3.55m (equivalent significant wave height in deep water)

Photo. 2 Conditions of wave overtopping at Oita Coast.

The 8 mm cine-films and photographs taken at that time show the overtopping of spray. Waves come forth along the seawall and topped over it. The reclaimed land behind the seawall was extremely inundated. The experimental results for the same seawall are shown in Fig. 14. The cross section of the seawall is also shown in the same figure. The following is the results of estimation of the wave overtopping based on the water level and observed values of waves given in Table 1 :

$$Ho = 3.55 \text{ m}, \quad \text{Water level} = +2.18 \text{ m},$$
$$\text{Crown height of the seawall} = +5.5 \text{ m},$$

Therefore, $hc = 5.5 - 2.18 = 3.3$ m,

$$hc/Ho = 3.3/3.55 = 0.94$$

From Fig. 14, $2\pi Q/(HoLo) = 1 \sim 2 \times 10^{-2}$

Consequently, dimensionless quantity of wave overtopping at that time can be estimated to be $1 \sim 2 \times 10^{-2}$.

Furthermore, at Beppu Coast adjacent to Oita Coast (see Fig. 13), a great deal of damage due to the wave overtopping was reported at about the same time. The cross section of seawall is shown in Fig. 15. From Photo. 3 which shows the conditions of wave overtopping at that time, we can see that the spray jumped up expremely, and the substantial part of wave overtopped violently. We can also see that water streamed down at the backwash. At that time, the wide area of hinterland was inundated at 0.5~1.0 meter in depth on the average.

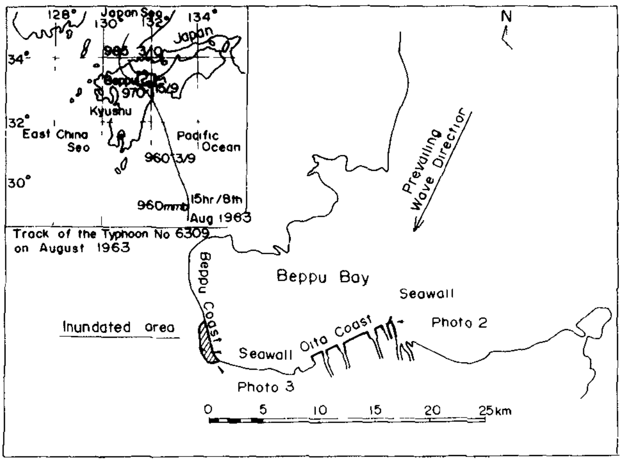


Fig. 13 Location map of Oita Coast.

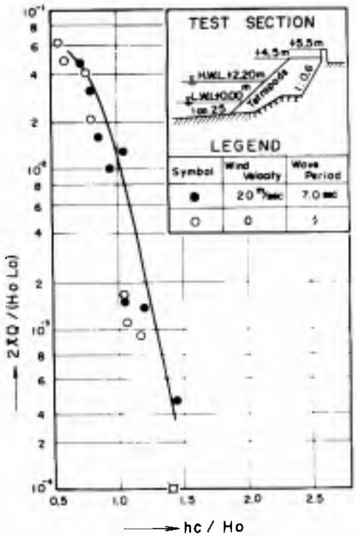


Fig. 14 Experimental results of wave overtopping at Oita Coast.

Photo. 3 Conditions of wave overtopping at Beppu Coast.

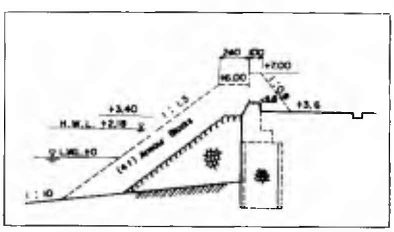


Fig. 15 Cross section of seawall at Beppu Coast. Dotted line is the section of plan to prevent the wave overtopping after the damage at Typhoon No.9.

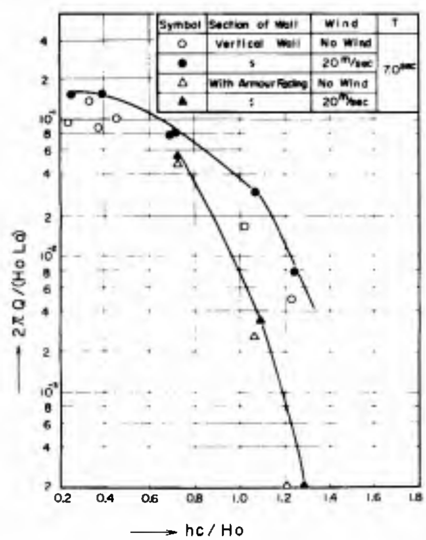


Fig. 16 Experimental results of wave overtopping at Beppu Coast.

The experimental results of wave overtopping for the same cross section is given in Fig. 16. The following is the results of estimation of the wave overtopping based on the water level and observed values of waves given in Table 1. However, the offshore wave height at Beppu Coast is 3.0 meters.

H_o = 3.0 m, T = 7.0 sec, Water level = +2.18 m,
Crown height of the seawall = +4.6 m,
h_c/H_o = 2.4/3.0 = 0.8
From Fig. 16, $2\pi Q/(H_oL_o) = 6.0 \times 10^{-2}$

ALLOWABLE QUANTITY OF WAVE OVERTOPPING

The allowable quantity of wave overtopping is determined by the relationship among the conditions of wave overtopping, the importance of structure in the hinterland, the conditions of drainage facilities, the duration of waves and others. Table 2 was made with reference to the results of experiment conducted by using regular waves with wind and to the results of field observation mentioned previously.

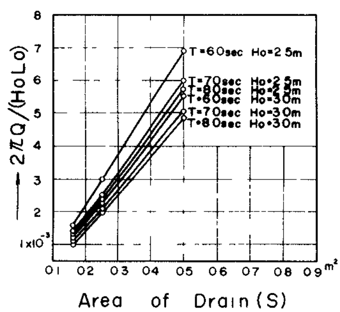
Table 2 Rate of wave overtopping and its wave conditions

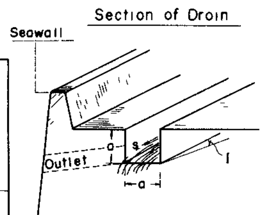
Condition of wave overtopping	Rate of wave overtopping $2\pi Q/(H_oL_o)$
Spray slightly overtops.	$0 \sim 1 \times 10^{-3}$
Considerable spray overtops or substantial part of wave overtops slightly.	$1 \times 10^{-3} \sim 5 \times 10^{-3}$
Spray overtops violently and substantial part of wave overtops considerably.	$5 \times 10^{-3} \sim 1 \times 10^{-2}$
Substantial part of wave overtops considerably.	$1 \times 10^{-2} \sim 10^{-1}$

If we take the crown height to such as extent that no spray will overtop, the seawall must be extremely high and uneconomical. On the other hand, if the crown height is as low as to permit the overtopping of the substantial part of wave, the functions of the seawall to prevent the wave overtopping get worse.

Two of the authors did a survey of the drain of the seawalls used in Japan and found that most of them have the cross section of 0.1 ~ 0.5 square meter. They trially calculated the draining capacity of such a cross section by Manning's formula and obtained the results as shown in Fig. 17. In this case, it seems that the maximum draining capacity is $2\pi Q/(HoLo) = 1 \sim 5 \times 10^{-3}$, under the conditions of T = 6 ~ 8 seconds and Ho = 3.0 m.

From these conditions, it would be supposed that the allowable quantity of wave overtopping to design the crown height of seawall can be generally determined in the range of $2\pi Q/(HoLo) = 1 \sim 5 \times 10^{-3}$.





Condition of Drain

Inclination of Drain	I=1/100
Coefficient of roughness	n=0.014
Area of Drain	s=a²
Interval of Outlet	ℓ=50m

Fig. 17 Relation between wave overtopping and the capacity of drain.

DESIGN OF CROWN HEIGHT

Arranging the data mentioned in the previous chapter, we would like to propose here one convenient criterion to design the crown height of seawall with armour block facing.

Figure 18 shows the required crown height of seawall with armour block facing to keep the condition of $2\pi Q/(HoLo) = 5 \times 10^{-3}$ as the allowable quantity of wave overtopping, corresponding to various water depths where the structure is built. In addition to this, the crown height of vertical wall is shown with dotted line for the reference. In the above discussion the crown height of armour block facing, ht/Ho is 0.5 ~ 0.75. Generally speaking from Fig. 18, it seems sufficient to take the crown height of seawall with armour block facing 1.3 times as high as offshore wave heights. Besides near the wave breaking point, if we take the crown height of armour block facing being equal to wave height in deep water, the quantity of wave overtopping reduces abruptly as shown in Fig. 9. Therefore, we can reduce the values of hc/Ho as shown in Fig. 18 by 20%.

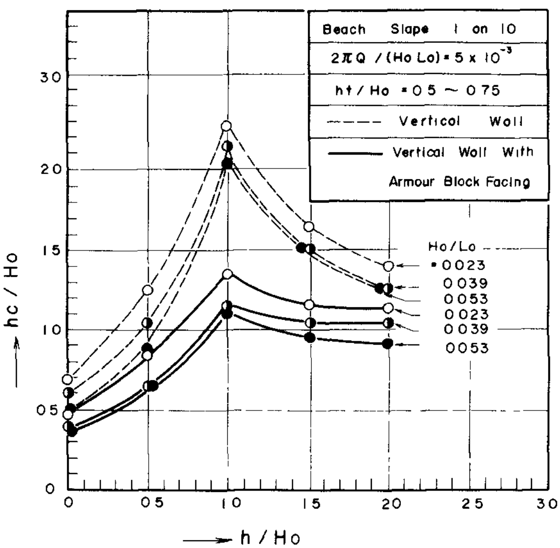


Fig. 18 Relation between hc/Ho and h/Ho.

CONCLUSION

1) As shown in Figs. 1 through 5, armour block facing is very effective for the prevention of wave overtopping. Especially the preventive function of armour block facing is remarkable at the site near the wave breaking point.

2) The observed values in field which are arranged by significant wave heights are roughly in agreement with experimental values obtained by using regular waves.

3) So far as we observed in field, it seems sufficient that we design the crown height of seawall considering the results of hydraulic experiments with regular waves with wind.

4) It would be supposed that the maximum allowable quantity of wave overtopping is : $2\pi Q/(HoLo) = 1 \sim 5 \times 10^{-3}$.

5) The crown height of seawall with armour block facing can be determined easily by using Fig. 18, in which the allowable quantity of wave overtopping is assumed to be $2\pi Q/(HoLo) = 5 \times 10^{-3}$.

6) Further investigations are required to get more accurate data in order to ascertain the above conclusions.

ACKNOWLEDGMENT

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REFERENCES

(1) Hom-ma, M. and K. Horikawa : Hydraulic Experimental Report of The Maritime Industrial Zone of Oita Prefecture. Vol. 1, 1966.

(2) Iwasaki, T. and A. Numata : Scale Effect of Model Experiment on Wave Overtopping on Seawall, J.S.C.E., 22th. Annual Convention, 1967.

(3) U.S.Army Engineer Beach Erosion Board : "Shore Protection Planning and Design", Technical Report Number 4, Beach Erosion Board, Washington D.C., 1961.

(4) Pappe, A. : Experimental Data of the Overtopping of Seawalls by Waves, Proc. of 7th. Conference on Coastal Engineering, Vol. 2, pp. 674～681, 1961.

(5) Saville, T., Jr. : Laboratory Data on Wave Run-up and Overtopping on Shore Structures, Beach Erosion Board, Tech. Memo. No. 64, 1955.

(6) Iwagaki, Y., A. Shima and M. Inoue : Effect of Wave Height and Sea Water Level on Wave Overtopping and Wave Run-up, Coastal Engineering in Japan., Vol. 8, pp. 141～151., 1965.

(7) Sibul, O. J. and E. G. Tickner : Model Study of Overtopping of Wind-Generated Waves on Levees with Slopes of 1 : 3 and 1 : 6, Beach Erosion Board, Tech. Memo. No. 80, pp. 1～27, 1956.