HYDRAULIC MODEL TEST OF STABILITY OF AMENITY-ORIENTED BREAKWATER

Shoji Kunitomi[1], Hajime Mase[2], M. ASCE, and Tomotsuka Takayama[3]

ABSTRACT: A slit caisson breakwater has now been under construction at Takamatsu Harbor, Kagawa Prefecture, Japan, as an amenity-oriented breakwater (that is, a human friendly breakwater opened for citizen). However, wave pressures and forces acting on the slit caisson have not been evaluated. Hydraulic experiments are carried out to examine the stability of the slit caisson breakwater and uplift forces on a upper board, and to investigate a desired type of upper board of the breakwater.

INTRODUCTION

This paper examines the stability of an Amenity-Oriented Breakwater against sea waves. Here the term of amenity-oriented breakwater is defined as a human friendly breakwater opened for public.

A main function of breakwater is to protect harbors against sea waves and keep them calm. Recently, because of small amenity space near urban area, there has been an increasing demand for breakwaters to be served as a recreation space for citizen. From the view point of amenity, breakwaters should be surrounded by clear water and allow easy water exchange.

A slit caisson breakwater is now under construction at Takamatsu Harbor, Kagawa Prefecture, Japan, as an amenity-oriented breakwater. Initially, this breakwater was designed only for protecting waves. However, as one of city plans of Takamatsu City, this breakwater was determined to be opened for amenity space. However, wave pressures and forces acting on such slit caisson have not been evaluated adequately. Here, we examine the stability of slit caisson breakwater by hydraulic model tests in order to propose a desired type of upper board of the caisson.

Photo.1 shows a view of the slit caisson breakwater now being constructed at Takamatsu Harbor, and Fig.1 shows an image view of the breakwater.

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[1] Graduate Student, Disaster Prev. Res. Inst., Kyoto University, Gokasho, Uji, 611-0011, Japan
[2] Assoc. Prof., Disaster Prev. Res. Inst., Kyoto University, Gokasho, Uji, 611-0011, Japan
[3] Prof., Disaster Prev. Res. Inst., Kyoto University, Gokasho, Uji, 611-0011, Japan

Photo.1 View of slit caisson under construction

Fig.1 Image view of slit caisson

HYDRAULIC MODEL EXPERIMENTS

The breakwater will have parapets, handrails, boardwalk, footlights and stand-lights, as shown in Fig.1. One of problems is to determine what kind of boardwalk we should employ from the viewpoint of uplift forces and stability of the breakwater. We adopted three kinds of upper board for experiments: 1) boardwalk, 2) boardwalk on a slab, and 3) boardwalk on a slit slab. In actual, boardwalk is made by wood.

We carried out hydraulic experiments of sliding stability of the slit caisson and uplift forces on three kinds of the upper board due to wave motion inside the caisson. Photo.2 shows the model caisson made by transparent acrylic, and Fig.2 shows the size of cross section of the model. The model scale of the caisson is 1/30. The slit opening ratio is 30.1 % on the front side and 4.3 % on the rear side. The experimental wave flume was

Photo.2 View of model caisson

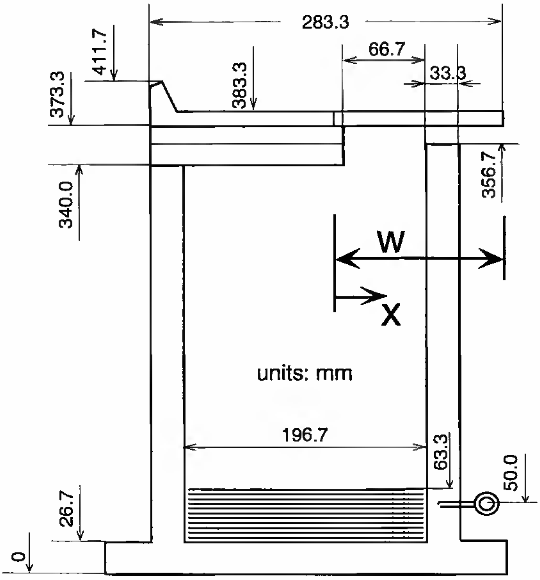


Fig.2 Size of cross section of model caisson

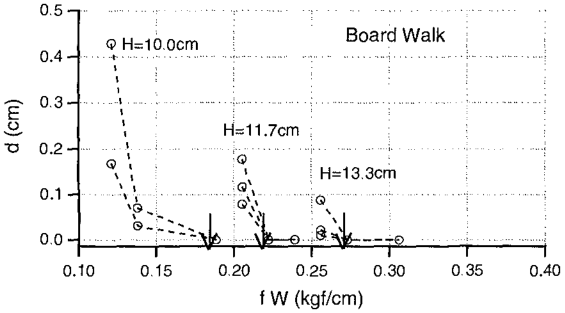
70 cm deep, 70 cm wide, and 40 m long. The model caisson was installed at 27 m far from the wave paddle.

The design wave height and period are 1.9 m and 5.5 s, respectively, as a fifty-years return period wave in the field. We carried out experiments by using regular and random waves. In the case of regular waves, the wave period was fixed as 1.1 s. Wave heights were changed from 6 cm to 13 cm so as to include the design wave height of 6.3 cm in the experiment. The water depth was set constant at 38 cm corresponding to the high water level. Concerning random waves, the significant wave height and period were 6.3 cm, and 1.1 s, respectively. The water depth was 38 cm (high water level) and 41 cm (highest high water level).

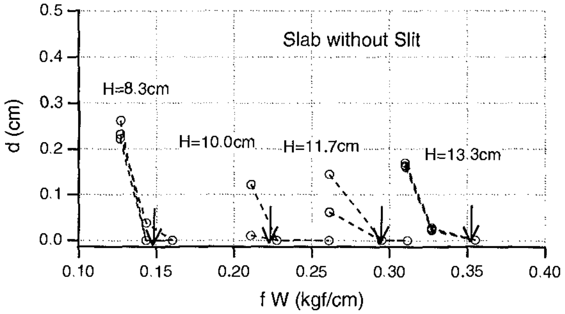
EXPERIMENTAL RESULTS AND DISCUSSION

Regular Wave Tests

Figure 3 shows the results of sliding stability tests for the caisson with three kinds of upper board against a parameter of wave height. The friction factor between the caisson and rubble mound was measured and found to be 0.51 on average. The displacements of the caisson under wave action were measured by two displacement gages installed at back side of the caisson. The vertical axis of the figure indicates the mean displacement per one wave. The horizontal axis indicates the sliding resistance force defined as the product of friction factor and caisson weight in water. From the results, we can obtain

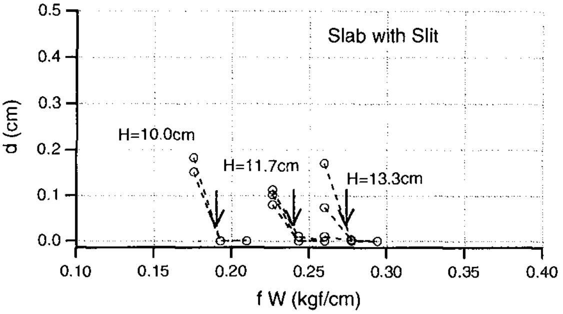


(a) Board walk



(b) Slab without slit

Fig.3 Relation between sliding resistance force and caisson displacement



(c) Slab with slit

Fig.3 Continued

the critical resistance force for different wave height conditions as shown by arrows in the figures.

Figure 4 summarizes the non-dimensional critical resistance forces. The horizontal axis is the non-dimensional wave height normalized by the design wave height and the vertical axis is the critical resistance force nondimensioned by w_0Hd (w_0: the weight of water per unit volume; H: the wave height; d: the water depth). The circles, triangles and squares denote the results for the cases of the slab without slit, the slit slab, and the

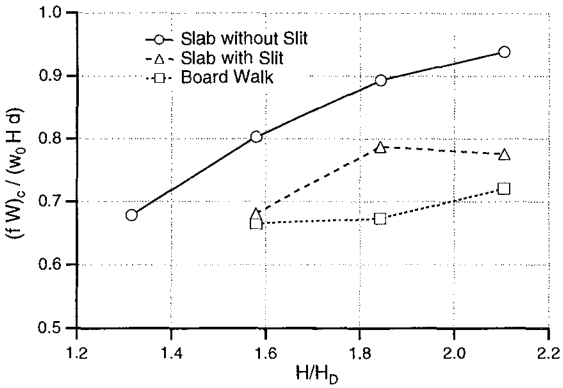


Fig.4 Critical sliding resistance force and caisson displacement

boardwalk, respectively. This figure shows that the critical resistance force becomes smaller as the slit opening ratio of the upper slab becomes larger.

Figure 5 shows the modification factor against the wave height. Here the modification factor is defined as the ratio of measured critical resistance force to the predicted one by Goda's formula (1985). This figure shows that, in the case of the slab without slit, the modification factor becomes largest, and its value is about 1.0 at H/H_D=1.85 (corresponding to the maximum wave height of random waves). The maximum modification factor is about 0.9 for the slit slab, and about 0.8 for the boardwalk. By formu-

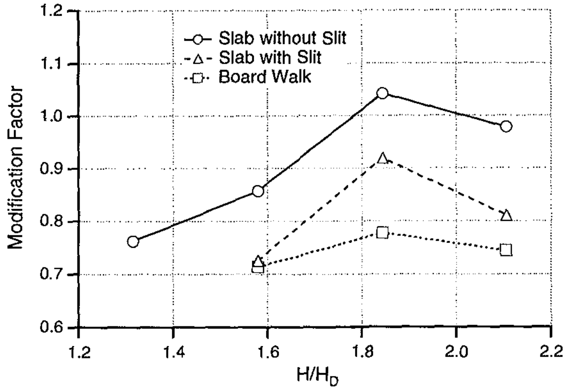


Fig.5 Critical sliding resistance force and caisson displacement

lating the modification factor for the slit caissons generally, we can estimate the resistance force by utilizing the Goda's formula (1985).

After the sliding stability tests, we measured wave pressures and uplift forces on upper boards by using five wave pressure gages and by utilizing strain gages.

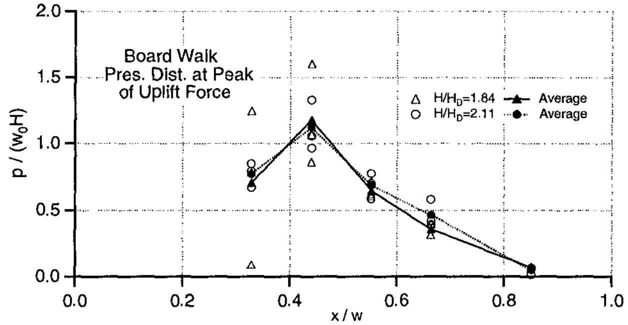
Figure 6 shows the spatial distribution of wave pressures on upper board. The x is the distance from the edge of the slab, and w is the width of the slab, shown in Fig.2. The vertical axis is wave pressure normalized by w_0H. Normalized wave pressures become the maximum around x/w=0.45 ~ 0.5 (in front of the rear wall of caisson). Wave pressures decrease to be zero towards the rear end of the caisson. We also see that wave pressures depend on the incident wave heights for the case of the slab.

Figure 7 shows the normalized uplift force per unit length against normalized wave height. The uplift force coincides with the integrated value of wave pressures as a whole. Figure 7 shows that uplift force is proportional to the wave height in the rage of this experimental condition. Besides, we can see that uplift force on the slab without slit is larger than that on boardwalk. From the viewpoint of hydrodynamics, employment of boardwalk is preferable for small resistance sliding force and small uplift force. However, it is dangerous to walk on the boardwalk when the water splashes out of slits at wave attack on the boardwalk, and how to set wooden boardwalk to the caisson against local wave pressure, shown in Fig.6, is a remaining problem.

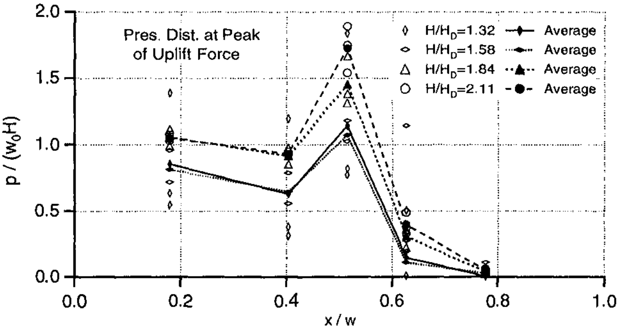
Random Wave Tests

Total record time was 20 minutes. We analyzed 700 individual waves excluding first 100 waves from the start of wave making. Figure 8 shows the measured and target wave spectra which are represented by solid and dash lines respectively. Random waves were well generated in the flume.

From random wave experiments, we obtained the critical sliding forces as 0.21 kgf/cm for the boardwalk, 0.25 kgf/cm for the slab, 0.21 kgf/cm for the slit slab. These critical sliding resistance force correspond to those by regular waves of H/H_D=1.58. This means that we can estimate the sliding resistance force of random waves from regular wave experiments by employing the regular wave smaller than the maximum wave (H/H_D=1.8).



(a) Boardwalk



(b) Slab without slits

Fig.6 Horizontal distribution of wave pressures on upper board

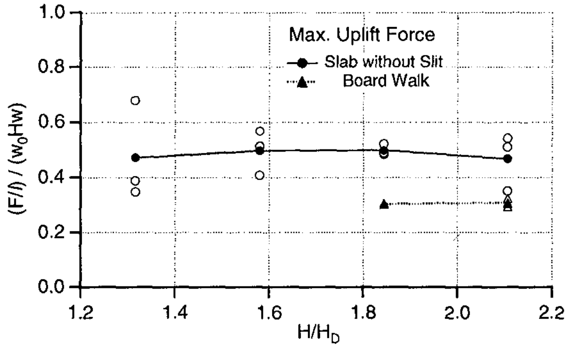


Fig.7 Horizontal distribution of wave pressures on upper board

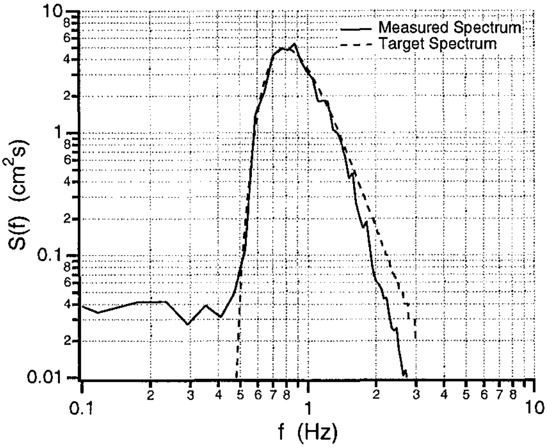


Fig.8 measured and target wave spectra

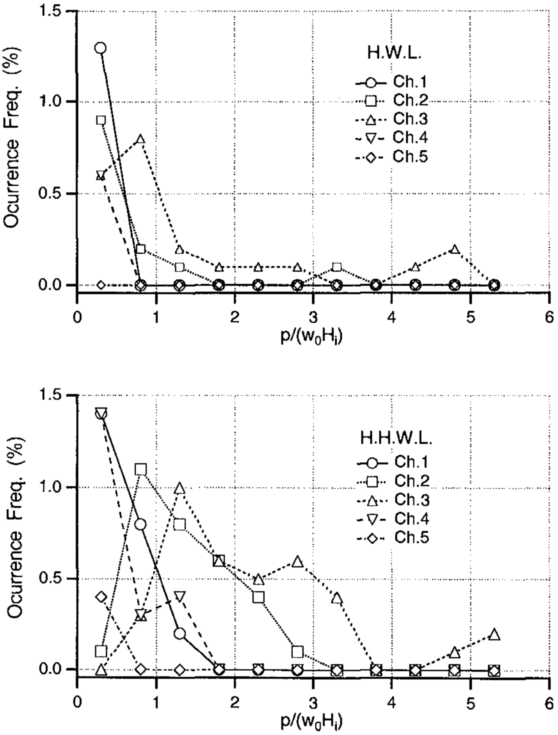


Fig.9 Horizontal distribution of occurrence frquency of wave pressures on upper board

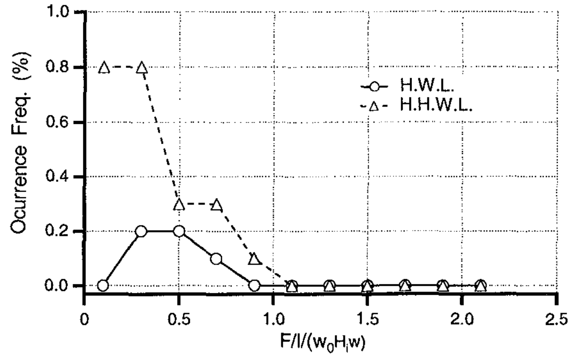


Fig.10 Horizontal distribution of occurrence frequency of wave force on upper board

Figure 9 shows the occurrence frequency of wave pressure at each pressure gage. The water depth was set at high (H.W.L.) and highest high water level (H.H.W.L.). Maximum pressure occurs at the location of Ch.3. This location is just in front of rear wall and same as in the case of regular wave experiments.

Figure 10 shows the occurrence frequency of uplift force. The occurrence frequency of uplift force at H.H.W.L. becomes larger than that at H.W.L.; however, the occurrence frequency itself is small.

CONCLUSIONS

Main results of this study are summarized as follows:

1) From experiments of regular waves, the critical sliding resistance force becomes smaller as the slit opening ratio of the upper board increase.
2) Wave pressures and uplift forces on the upper board decrese as the slit opening ratio becomes larger.
3) However, the problem is how to fix wooden boardwalk to the crown against wave pressures which locally become strong.
4) From experiments of random waves, critical resistance forces are found to be estimated from regular wave experiments by using waves of which wave height is a little smaller than the maximum wave height.
5) Besides, we can find the occurrence of large wave pressures and uplift forces is infrequent. But the boardwalk should withstand against large wave pressures even if it rarely occur.

From the results we proposed a type of upper board such as boardwalk installed on a slit slab by taking into account its leif time.

Refencres

Goda, Y. (1985): Random seas and design of naritime structures, Univ. of Tpkyo Press, Tokyo, p.323.