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EXPERIMENTAL STUDY ON A NEW TYPE FLOATING BREAKWATER

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ABSTRACT: In the article, a new type floating breakwater is proposed based on comparing the performance of different kinds of floating breakwater that include pontoon type breakwater, scrap tire breakwater, mat float type breakwater etc. The outstanding feature of the new type breakwater is that damping at bottom of breakwater can increase wave energy dissipation and decrease coefficient of wave transmission and reflection. The relative width and relative submergence depth (the ratio of width to wave length W/L and submergence depth to wave length D/L) on the performance of the breakwater are discussed based on a series of physical model test in flume. The relationship between critical transmission coefficient (C_t=0.5) and relative width is given by experiment. In the actual design and application process, the various parameters are not independent, so the relationship between transmission coefficient and different parameters is analyzed in this paper.

Keywords: New type, floating breakwater, transmission coefficient, experiment study.

FOREWORD

Over the past two decades, interest in the study of floating breakwaters has increased owing to the advantage of lower investment and being environment friendly. Floating breakwaters can be preferable over rubble-mound or sheet-pile structures to reduce the incident wave energy under conditions include short wave period and length, small wave heights and large water depth. Floating breakwaters can accommodate for depth changes automatically, and can be used to protect a boat berthing or recreational system, and can be used at sites with large water depth or poor foundation conditions. Floating breakwater can be used for offshore oil drilling and marine aquaculture, and it has been deployed at many sites to reduce wave energy that reaches the shoreline or enters the port. In most cases, the site is located on deep water area that is at least deep enough to support boating activity. Yet there are other site with shallow water area and small scales that might also benefit from the deployment of floating breakwaters that can be constructed simply with a sufficient low cost. In recent years, floating breakwaters more and more get people's attention and recognition due to the above-mentioned advantages.

RESEARCH STATUS

The earliest documented on applications instance of floating breakwaters is the wood floating breakwaters that is built in Plymouth port, in 1811 UK. In 1944 during World War II British troops landed in Normandy by means of floating breakwaters that is named Bombardon and composed of wreck and caisson. The floating breakwater is 1.6km far from coastline, and each unit is 600m long, 7.5m wide and 7.5 high. A floating breakwater is placed in Aomori port in Japan to test their ability to withstand waves and wave absorption performance, in 1930.

Before this century, the majority of the study and application of the floating breakwater is in developed country. For the past 10 years, with the development of economic and technological in China, and a variety of floating breakwaters are designed and studied. Floating breakwaters can be divided into flexible floating breakwaters and rigid floating breakwaters according to their elastic properties. Flexible floating breakwaters can appear elastic deformation under wave action with smaller wave reflection than that of normal rigid floating, the major types of flexible floating breakwater is floating raft, waste tire type, thin film etc. The rigid floating breakwater can't appear elastic deformation under wave action, the major types of rigid floating breakwater is box, fence, pontoon etc. Hales (1981), McCartney (1985) and Mani (1991) classified floating breakwater types according to their geometrical configuration and functional similarities. Structure width in the direction of wave propagation provides one means of classification, wide-beam floating breakwater and narrow-beam floating breakwater. Mooring configurations may also be used to classify the floating breakwater. One type is rigid vertical piles that extend from below the seafloor up to

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the water surface, and the other type is flexible mooring lines or chains that connect the breakwater to anchors on the seafloor.

(1) Rigid floating breakwater

Most researches have been involved in the hydrodynamics of floating breakwaters with rectangular cross-section to investigate their performance based on numerical model or experimental. Floating box is generally made of reinforced concrete, steel or made of scrap ship with a rectangular shape, and this type of floating breakwater reduces the wave transmission coefficient by decreasing reflected wave energy. A rectangular box floating breakwater was built in 1976 in Japan. Gesraha (2006) investigated the reflection and transmission of incident waves interacting with 2D rectangular breakwater with two thin sideboards protruding vertically downward. The advantages and disadvantages of different types of breakwaters were studied, and conducted studies show that practical size designs offer protection restricted to wave heights under 1.5m and periods under 4s (Cox and Beach, 2006). Aiming to increase these operational limits, reinforced-concrete-pontoon-type and double floating breakwater appeared, and that could suppose an efficient improvement in the hydrodynamic behavior (Dong et al., 2008). The sheltering effect of floating box that was used in the Dutch Baiona port was studied by experiment (E.Pena, 2010). Stiassnie and Drimer(2003) examined the suitability of freely floating porous box in shallow water and showed that the drift forces were reduced significantly. S.G Patil (2011) investigated the wave transmission coefficient of horizontally interlaced multilayer moored floating pipe breakwater (HIMMFPB). The detail of the HIMMFPB is shown in Fig.2. The experimental study carried out by Kamat (2010) shows hydrodynamic characteristics of horizontally interlaced three and five layer floating breakwater systems, in which the wave transmission is less for five payer systems. Wu (2002) analyzed some factors influencing the wave attenuation effectiveness of pipe-type floating breakwater, and the minimum wave transmission coefficient of the floating breakwater can reach 0.22 under unfavorable incident wave conditions by improving the structure.

Nomenclature	Description
Model A (Baiona Port FB)	Baiona Port FB
Model B	Width reduction (10%) regarding model A
Model C	Lateral fin prolongation (50%) regarding model A
Model D (Catamaran typology)	Two parallel module rows, with different separations

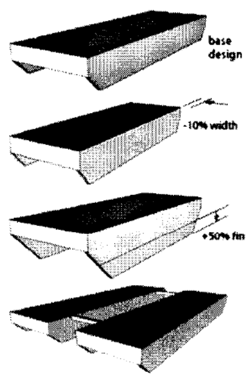

Fig. 1 Different types of Baiona port floating breakwater

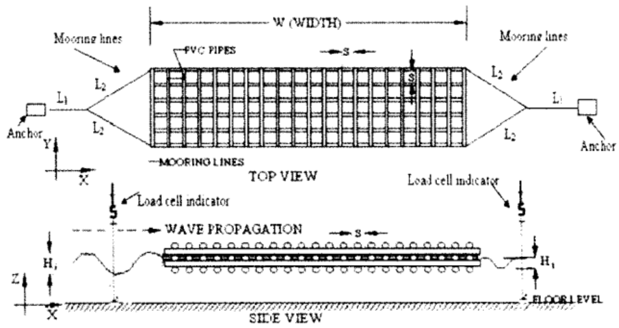

Fig. 2 HIMMFPB model layout

(2) Flexible floating breakwater

Floating raft and waste tire floating breakwaters are the common types of flexible floating breakwaters. Raft floating breakwater is composed of inflatable nylon bag and glass fiber. This type of floating breakwaters reduces wave transmission coefficient by friction between the floating breakwater and water and elastic deformation that can absorb the incident wave energy. Raft floating breakwater can be used as wave dissipation, but also applies to oil spill site recovery operations that have been studied in the University of Rhode Island. Dong (2006) studied on the board-net floating breakwater, and the results show that the proposed floating breakwater has good wave dissipation capacity, but its design parameter should be considered according to the wave and current condition in the vicinity of the breakwater. Zhang (2010) had research on the scrap tire floating breakwaters. Based on the hydro-elastic similarity theory, a physical model with small scale was designed and the experimental results show the nice performance of wave attenuation. When the breakwater width is more than 0.6 wave length, wave transmission coefficient is less than 0.5, and the breakwater play a good effect in dissipating waves. From the existing research results, the flexible floating breakwaters have high requirement about the width to achieve the better function of wave dissipation.

(3) Wave dissipation effect of floating breakwater

The objective of floating breakwaters is to reduce the height of wave transmitted H_t passed the structure. It is expected that the wave transmission coefficient C_t is small enough in shelter of the floating breakwater. The wave transmission coefficient is defined by the following equation:

$$C_t = H_t / H_i \tag{1}$$

Where, H_i is incident wave height and H_t is the transmitted wave height. If viscous effect is ignored, the incident wave energy is divided into two parts, transmitted wave energy and reflected wave energy. According to the wave theory, the total energy per unit length is proportional to the squared wave height. So the relationship of wave height and coefficients is as follows:

$$C_r = H_r / H_i \tag{2}$$

$$H_i^2 = H_r^2 + H_t^2 \tag{3}$$

$$C_r^2 + C_t^2 = 1 \tag{4}$$

Where, H_r is reflected wave height and C_r is reflected coefficient of floating breakwater. Under actual sea and test conditions, due to the effect of friction, wave breaking, wave absorption and attenuation of floating body, the sum of transmitted and reflected coefficient is less than 1.

Many research results show that the main factors affecting the wave transmission coefficient including the form of structure, the relative width of floating breakwater (the ratio of width and incident wave length W/L), the floating breakwater into the water depth (the ratio of the height of breakwater in water and water depth, D/L) and wave steepness (H/L). The curves of three different structural forms floating breakwaters transmission coefficient and relative width are shown in Fig.3. Shown as Fig.3, if the wave transmission coefficient of pontoon and box floating breakwater less than 0.5, W/L must greater than 0.3; on the other hand, when $W/L \geq 0.5$, the transmission coefficient does not vary with increasing width significantly reduced, and it is difficult to less than 0.2. When the relative width is bigger than 1, the transmission coefficient of raft floating breakwater is less than 0.5.

LABORATORY EXPERIMENTS

Model Design and Instrumentation

The model layout is shown in Fig.4. The PVC pipe with 300mm diameter is used to make the floating breakwater, and the main design parameter is shown as follows: the cross-sectional shape is concave diamond, and the length, width and height is 98cm, 24cm and19.5cm, respectively. Length 20cm nylon rope is installed in the bottom of the floating breakwater to increase the damping. The internal space is filled with foam, in addition to necessary counterweight. Two mooring lines are placed on wave-ward side and lee-ward side of concave-diamond floating breakwater, respectively.

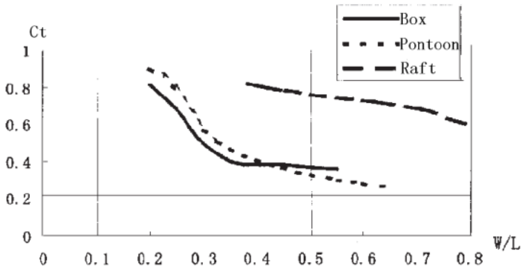

Fig. 3 Transmission coefficient curve of different floating breakwaters

The experiments were carried out in a wave flume in Tianjin Research Institute for Water Transport Engineering (TIWTE). The flume is 65m long, 1.0m width and 1.3m high, and its effective working depth is 1.0m. It has a rigid concrete bed and the sides are lined with glass panels for the entire length of flume for observation of the experiment inside the flume. Waves were generated by a wave generator. The wave generator is hydraulically driven and can generate both regular and random waves with simultaneous absorption of short waves reflected from the far end of the flume. Two wave height sensors were placed in front and behind of floating breakwater, respectively, and the wave height sensor is TK2008 type capacitance sensor with an accuracy of 0.1mm. Each set of tests was carried out at least three times, and the number of repetitions would be increased, when the difference of tests phenomenon and measurement between the results of the three tests.

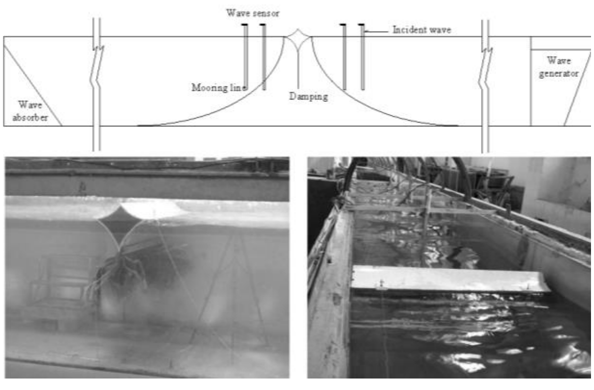

Fig. 4 Model layout in the flume and picture in flume

Wave Simulated and Test Arrangement

Order to study the relationship between wave transmission coefficient of floating breakwater and relative width of floating breakwaters and wave height and period (wave steepness), wave dissipation effect of floating breakwater were tested, when wave with different height and period acted on the floating breakwater. Model test water depth was 0.4m, 0.5m and 0.6m that on behalf of different design water level. Irregular significant wave height is 0.02m ~ 0.08m, and the significant wave period is 0.5s ~ 1.2s. JONSWAP spectrum was used to simulate the irregular wave in experiment, and the analytical formula is as follows:

$$S(f)=\beta_j H_{1/3}^2 T_p^{-4} f^{-5}\exp\left[-\frac{5}{4}(T_p f)^{-4}\right]\times r^{\exp\left[-(f/f_p-1)^2/2\sigma^2\right]} \qquad (5)$$

Where:

$$\beta_j=\frac{0.06238}{0.230+0.0336r-0.185(1.9+r)^{-1}}\left[1.094-0.01915\ln r\right] \qquad (6)$$

$$T_p=T/\left[1-0.532(r+2.5)^{-0.569}\right] \qquad (7)$$

$$\sigma=\begin{cases}0.07 & f\le f_p\\ 0.09 & f>f_p\end{cases} \qquad (8)$$

Where: r is peak factor of wave spectrum; f_p is peak frequency of wave spectrum, $S(f)$ is synthetically spectral density (m^2.s), $H_{1/3}$ is significant wave height, f is frequency, $\overline{T}$ is average wave period.

TEST RESULT ANALYSIS

Effect of Wave Height and Period

Wave transmission coefficients of floating breakwaters were studied when wave with different height and period acted on the floating breakwater, with different water depth. In order to facilitate analysis the result, Figure 5 shows the wave transmission coefficient as the function of incident wave height and period, under the different water depth condition. It can be seen from the test results under the same wave height conditions, the bigger wave period the bigger transmission coefficient; under the same wave period condition, the transmission coefficient is not a single increase with wave height. From the critical value of wave transmission coefficient, $C_t \ge 0.5$, breakwater wave dissipation effect is relatively poor when the wave period is greater than or equal to 0.7s; $C_t \le 0.5$, breakwater wave dissipation effect is relatively good when the wave period is less than or equal to 0.6s. The wave period is a key factor affecting the floating breakwater transmission coefficient. Wave period determines the wave length and relative width of the floating breakwater, so the relative width of the floating breakwater is a key factor affecting the transmission coefficient too. The next section, the effect on transmission coefficient of relative width will be studied.

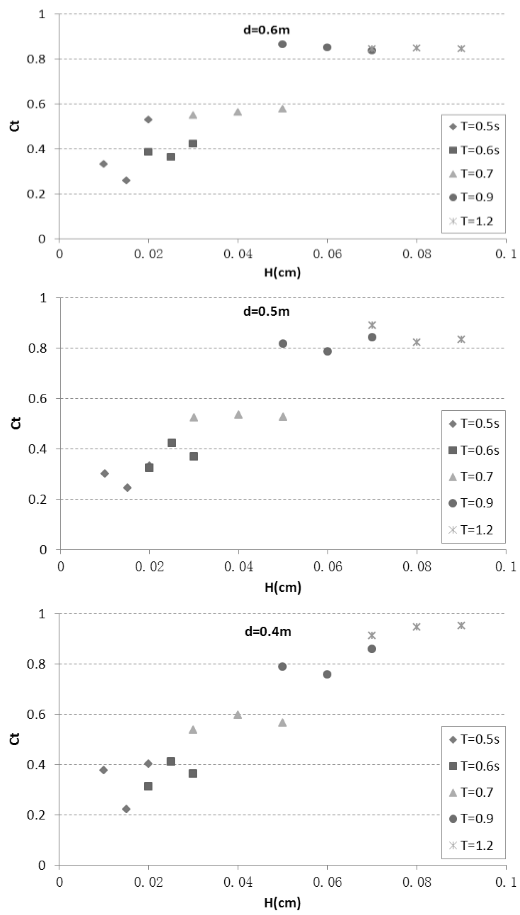

Fig. 5 The relationship between C_t and wave height and period

Effect of Relative Width and Relative Water Depth

Wave transmission is affected by incident wave height, period, water depth and itself width, etc. According to these factors, the function of transmission coefficient is shown as follows:

$$C_t=H_t/H_i=fun(L/H_i,d/H_i,D/H_i,W/H_i) \qquad (9)$$

Where: L is wave length, and it is the function of wave period and d water depth; D is breakwater height underwater; W is breakwater width.

Parts of the factor would be fixed during the experiment, and the function of transmission coefficient changes to as follows:

$$C_t=fun(D/L,W/L) \qquad (10)$$

Then we will just change relative water depth and width one by one. Figure 6 shows the wave transmission coefficient as the function of relative water depth and relative width, and the relationship between transmission coefficient and relative water depth and relative width is shown as follows:

$$C_t = 1.1426e^{-2.659(W/L)} \quad (11)$$

$$C_t = 1.1426e^{-1.237(D/L)} \quad (12)$$

It can be seen from the formula and figure, the smaller transmission coefficient and the bigger W/L . $W/L=0.3$ is a critical value, when it bigger than 0.3 the transmission coefficient less than 0.5, and when it smaller than 0.3 the transmission coefficient bigger than 0.5. In order to ensure the shielded effect of floating breakwaters, the relative width should remain above 0.3. On the other hand, the bigger D/L and the smaller transmission coefficient, $D/L=0.6$ is a critical value. When D/L is less than 0.6, the transmission coefficient is bigger than 0.5.

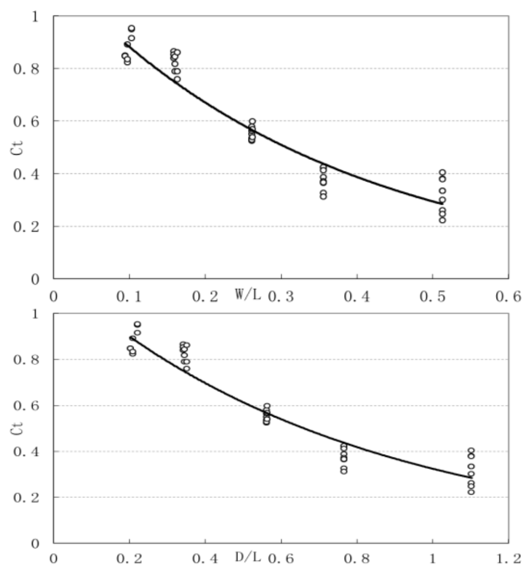

Fig. 6 The relationship between C_t and W/L and D/L

CONCLUSIONS AND RECOMMENDATIONS

Basis on the investigation of research on floating breakwaters, the research progress and application prospects are known, and the effect of wave dissipation and structure types of floating breakwaters were compared. Then concave-diamond floating breakwater was designed and experimental studied in flume. The experiment was carried on, under different wave and water depth conditions. Then the results were analyzed, and the conclusions and recommendations are as follows:

(1) The wave period is a key factor affecting the floating breakwater transmission coefficient. Wave period determines the wave length and relative width of the floating breakwater, so the relative width of the floating breakwater is a key factor affecting the transmission coefficient too.

(2)It can be seen from the formula and figure, the smaller transmission coefficient and the bigger W/L . $W/L=0.3$ is a critical value, when it bigger than 0.3 the transmission coefficient less than 0.5, and when it smaller than 0.3 the transmission coefficient bigger than 0.5.

(3)The bigger D/L and the smaller transmission coefficient, $D/L=0.6$ is a critical value. When D/L is less than 0.6, the transmission coefficient is bigger than 0.5.

(4) The experimental research on concave-diamond floating breakwater gave the function of wave transmission coefficient, which provides a basis for the design and application of the new type floating breakwater.

(5) According to its flexible, simple, and easy disassembly, floating breakwaters are gradually favored by people, and the concave-diamond floating breakwater will be used on coastal engineering after systematic and detailed test study.

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