Experimental and calculation study on overtopping of framed seawall

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Abstract. In recent years, more and more seawalls have been used in tidal areas along coastal areas. The frame type seawall has the advantages of no water occupation, land saving and light weight. It is a difficult problem to determine the overtopping and the elevation of the embankment. In this paper, a physical model test was carried out to measure the average overtopping of a framed seawall at the design frequency of wave height, and the average overtopping was calculated by using the theoretical formula. The results of physical model test and theoretical calculation were compared and analyzed. The results showed that the theoretical formula was 6 to 20% larger than that of the physical model test. Finally, the theoretical formula was proposed to predict the wave overtopping of frame seawall, which met the design requirements and provided a basis for determining the height of the top of the seawall. At the same time, the physical model test showed that the anti-arc cantilever wave absorber on the upstream side of the frame seawall can reduce the overtopping volume by 7%-32%.

1. Introduction

Wave overtopping refers to the amount of water that a wave acts on a seawall to climb over a seawall. The average overtopping is directly related to the stability and safety of seawall and embankment structures. Scholars have done a lot of research on the prediction method of overtopping. Weggle [1] summarized the wave overtopping calculation methods for different types of seawall structures; from 1994 to 2004, Japanese scholars [2-4] collected dozens of test data on the basis of model tests, summarized and analyzed, and put forward the prediction formula of wave overtopping. From 2015 to 2018, Chinese scholars [5-9] carried out numerical and physical model tests to study the calculation methods of average overtopping of vertical dikes, sloping dikes with breast walls and caisson openings. In the past 20 years, a new type of embankment structure, frame type seawall, has been used more and more in the estuaries of China. The structure has the advantages of light deadweight, no water occupation and land saving, but the section of this kind of seawall structure is complex. In the current code of China, the method of calculating the average overtopping of the frame seawall has not been given, and there is little research on this aspect, so it is necessary to study the method of forecasting the average overtopping of the new type seawall. In this paper, a model test of wave overtopping on a frame seawall was carried out to study the theoretical calculation method of the average wave overtopping of the seawall.

2. Overtopping prediction method

2.1 Structural features and typical cross section of framed seawall

With more and more applications, more and more attention has been paid to the calculation of the average overtopping of the frame seawall structure. A large number of physical model tests have been carried out by scholars, including the overtopping test of the open trestle [10], the overtopping test of the energy dissipation chamber pile foundation [11] and the overtopping test of the semi-permeable caisson breakwater [12]. The physical model test of overtopping action of framed seawall was carried out in this paper. The frame type seawall had a 1m or so frame on the top of the slope 1:1.5 on the water side. The frame seawall was arranged in the deep water of the concave bank at the bend of the river. The frame structure was divided into cap section, frame section and bank connection section of retaining wall. The cap section was 7.0 m wide and the foundation is 800 PHC pipe pile. Reinforced concrete cap was installed on the top of the pile, and "Y" shaped column was installed on the cap. The upper part was cast in place beam and wave dissipation structure. The frame section width was 20~30 m, which was an 800 PHC pile high pile structure, and the top was equipped with precast slab beam structure. The foundation of retaining wall was bored cast-in-place pile, and the upper part was L shaped reinforced concrete retaining wall. The walls were filled with earth rock and are connected to the existing shoreline. The framed leading edge of the seawall was arranged with an anti-arc cantilevered plate, and the rear side was equipped with drainage facilities. The anti-arc cantilever slab was a C25 reinforced concrete cast-in-situ structure. The length of the cantilever slab was 2.5 m. It can reverse the rising water flow and reduce the overtopping. And the top of the embankment was overtopping to drain through the drainage channel to the river. The wave fronting on the front side of the frame structure was set up. The thickness of the wave absorber plate was 0. 4m and the height was 0.5 to 1.0 m. The structure had the characteristics of not occupying water area and saving land and materials. The typical section was shown in Figure 1 below.

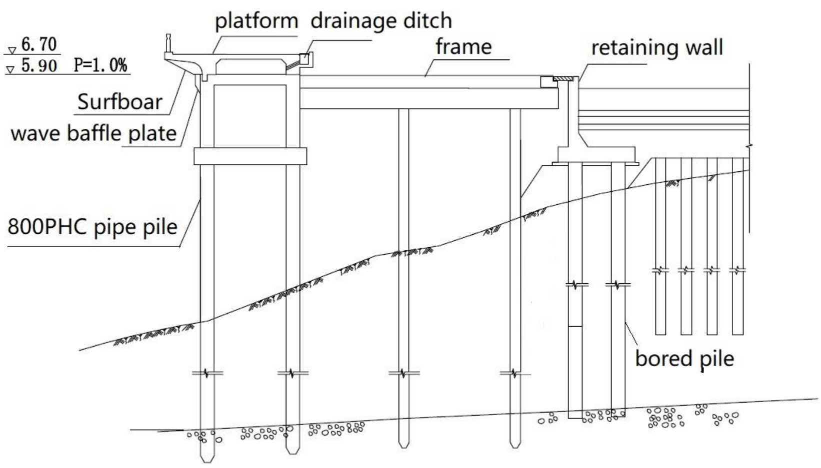

Figure 1. Typical cross section of framed seawall.

2.2 Physical model test

The physical model test adopted simplified frame structure section and was made according to the ratio of 1:10. The experiment was carried out in the wind and wave flume of the Key Laboratory of estuarine and coastal areas in Zhejiang province. The flume was 60 m long, 1.2 m wide and high 1.6 m. The section of model structure was shown in Figure 2. The slope ratio was 1:1.5, and the frame structure was installed on the slope. The surfacing side was a permeable structure, and there were an anti-arc wave board and a wave baffle on the upper.

There were piles on the lower part of the utility model, and there was an impermeable baffle on the back. Behind the breakwater, there were containers to collect overtopping water.
The design frequency wave was used to simulate the actual wave by the hydraulic wave maker system at the front of the flume. The front wave elements of the seawall were measured by the wave height meter, as shown in Table 1.

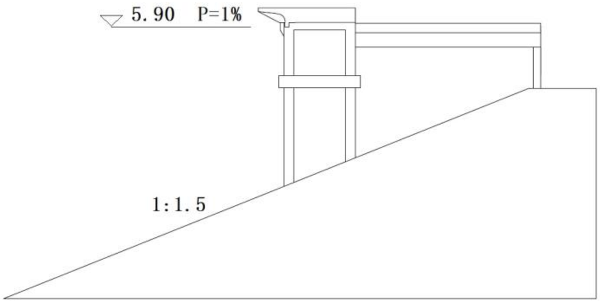

Figure 2. Section of frame type seawall model.

Table 1. Wave elements of framed seawall.

Reappearance period /a	Maximum wave height $H_{1\%}$/m	Effective wave height $H_{13\%}$/m	Average wave height H/m	Average period T/s	Designing wind speed V/(m.s^{-1})	Design water level /m
10	0.99	0.67	0.42	2.9	18.5	5.31
50	1.35	0.92	0.58	3.4	24.7	5.56
100	1.50	1.02	0.65	3.6	27.3	5.90

The effective wave height was used to determine the wave elements by the method of wind wave pushing. The river level was a tidal river, and the design water level was determined by the superposition of flood level and tidal level. The designed high water level combined with 10 years, 50 years and 100 years. The design elevation of the top of the embankment was 6.20 m, 6.50 m and 6.70 m respectively. The overtopping volume of the above combination was tested.

2.3 Prediction method for overtopping

Scholars had rarely studied the overtopping prediction of framed seawall. The representative formula for predicting overtopping is as follows [13]:

$$Q = AT\overline{H}ge^{\left(-\frac{B}{K_\Delta}\frac{H_c}{\sqrt{g\overline{H}}}\right)} \tag{1}$$

Formula (1) for calculating overtopping is under no wind conditions. Q - the overtopping water on the seawall with a single time per unit width (m^3/s.m), H_c - height from the top of the dyke to the static water level, m; $\overline{H}$ -average wave height of embankment, m; T -wave period, s; g -acceleration of gravity, 9.81 m/s^2; K_Δ -roughness coefficient; The coefficient of A and B depends on the empirical coefficient of building shape. Taking into account the influence of wind on overtopping, the formula (1) calculates the overtopping and then takes the wind correction factor K' [10].

$$K' = 1.0 + W_f\left(\frac{H_c}{R} + 0.1\right)\sin\theta \tag{2}$$

The W_f in the formula (2) depends on the wind speed.

$$W_f = \begin{cases} 0 & V = 0 \\ 0.5 & V = 13.4m/s \\ 2.0 & V \geq 26.8m/s \end{cases} \quad (3)$$

Between the above three wind speeds, it is obtained by linear interpolation based on wind speed. The wind speed of 10 years in the area reaches 29 m/s, the value is 2. θ-Slope angle for tidal slope of seawall; R - the wave to climb on the seawall, m. The coefficients A and B were 0.0051 and 25.35 respectively by regression method. The predicted value of overtopping was obtained by substituting formulas (1) and (2).

The results of model test and formula calculation were listed in Table 2. When the wave height and design water level at 10 years were 5.31 m, the overtopping was zero, so it was not listed in Table 2. Table 2 showed the test results and calculation results when the design water level was 5.56 m and 5.90 m.

Table 2. Calculation of wave elements and overtopping.

Seawall elevation /m	Reappearance period /a	water level /m	Water depth in front of seawall /m	Wave element $H_{13\%}$ /m	Wave length /m	wave period /s	Overtopping in model test /$m^3.(m.s)^{-1}$	Formula for overtopping calculation /$m^3.(m.s)^{-1}$
				50 year wave				
6.2	100-year flood + 2-year tide	5.56	4.89	1.32	33.85	3.25	0.00253	0.00313
	2-year flood +100-year tide	5.90	5.23	1.66	43.50	5.15	0.00291	0.00351
6.5	100-year flood + 2-year tide	5.56	4.89	1.32	33.85	3.25	0.000897	0.00120
	2-year flood +100-year tide	5.90	5.23	1.66	43.50	5.15	0.00112	0.00136
6.7	100-year flood + 2-year tide	5.56	4.89	1.32	33.85	3.25	0.000245	0.00030
	2-year flood +100-year tide	5.90	5.23	1.66	43.50	5.15	0.000615	0.00070

3. Results and discussion

The above results were compared with the experimental values and calculated values under windy conditions.

(1) Anti-arc cantilever wave board was installed on the upstream side of the test model, which enlarged the wave dissipation space and decreases the overtopping. When the height of embankment was 6.70 m and the design water level was 5.9 m, the width of the anti-arc cantilever plate was 5 m, the overtopping was 0.000615 m^3 / (m s), less than 0.05 m^3 / (m s), which met the safety requirements.

(2) The anti-arc cantilever plate had obvious wave dissipation effect. Under the designed

water level, the wave overtopping decreases by 7%-32%.

(3) Under the designed water level, the overtopping was 6 to 20% higher than that of the model test.

4. Conclusion

It must be pointed out that the overtopping of the frame seawall was affected by the structure shape, water permeability, incident wave characteristics and reflection characteristics. The structure of framed seawall was complex, and its overtopping was closely related to the safety of the structure of the seawall, pedestrians, cars and buildings. By comparing the results of physical model test with the results of empirical formula, it can be seen that the empirical formula can predict the overtopping of the frame seawall under wind with the modified coefficient, and the estimated value was slightly larger than the experimental value. Using this theoretical method to calculate the overtopping amount can meet the design requirements. In order to reduce the overtopping of the frame seawall, the anti-arc cantilever plate can be installed on the upstream side, which can effectively reduce the overtopping and thus reduce the height of the top of the seawall.

Acknowledgments

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