Experimental study of wave force on large steel plate cylinder structure

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Abstract. Steel plate cylinder is more and more widely used as breakwater and revetment structure, but the existing design codes related to breakwater lack the distribution of wave force on the outside of steel plate cylinder under the action of waves. In this paper, the 2-D wave physical model experiment is used to test the pressure distribution of large diameter steel plate cylinder structure under wave action. The results show the wave distributions along different cross sections of the facing side during the crest and trough action. It provides the necessary theoretical basis and technical support for the design of large diameter steel plate cylinder.

1. Introduction

Steel plate cylinder is a typical gravity structure, which can be built directly on the foundation bed or sink into the foundation, without the need for riprap foundation bed. It can reduce the cost, shorten the construction period, and has obvious economic benefits. It has a broad application prospect in the construction of breakwater, bank revetment, wharf, artificial island, bridge, wind power foundation and so on. Steel plate cylinder construction technique is used in the super project of Hong Kong-Zhuhai-Macao Bridge[1] and the new airport project in Sanya. Figure 1 shows the picture of the construction of the steel plate cylinders on site. When designing and using the structure of large diameter steel plate cylinder, it involves how to determine various forces on the curved surface, such as wave force, earth pressure, pressure of internal packing to the side wall, and so on. The determination of these forces directly affects the overall stability of the structure. Among them, the calculation of wave force is of great significance for designing large diameter steel plate cylinder hydraulic structures.

Based on the study of the model test of cylindrical breakwater and vertical breakwater under the action of standing waves, Zhang (1991) puts forward the difference and law of the wave force on the two structures under the action of waves. The test results show that the wave pressure on the cylinder wall is about 15% lower than that on the vertical wall[2]. However, the formula only gives the calculation method of the total wave force and the acting point, but does not give the distribution of the wave force along the curved surface. On the basis of experiments, Qian et al. (2001) introduced multiple linear regression analysis into the study of wave forces, and obtained the calculation formula of wave forces acting on a single large diameter cylinder[3]. However, there are many parameters needed in the formula, so it is difficult to apply it in practice. Liu et al. (2004) carried out random wave flume tests on
plug steel plate cylinder structures, and measured two types of structures: single cylinder and continuous cylinder[4]. The wave pressure of a large diameter steel plate cylinder in the structure-wave-seabed coupling system is studied by using the method of spectral analysis. Based on the linear wave diffraction theory, Li et al. (2003) studied the wave force acting on the steel plate cylinder from three aspects by means of numerical simulation and physical model test[5]. Based on the statistical analysis of experimental data, the empirical formulas of wave force and wave moment on steel plate cylinders at different positions are obtained by nonlinear regression. Through the physical model test, Wang (2003) obtained the position of the maximum wave pressure on the wave-facing side, upper surface and baffle of the steel cylinder[6].

As far as the development of large diameter steel plate cylinder structure is concerned, most of the wave force calculation methods obtained at present are based on the semi-empirical and semi-theoretical formulas on a practical project, and these formulas need to be further improved.

Therefore, the wave force model test of large diameter steel plate cylinder plays a very important role in verifying and optimizing the existing empirical formula.

2. Model test

In this paper, the wave force distribution of steel plate cylinder during construction is measured by cross-section wave physical model test. Through the investigation of the open sea wave conditions of the Hong Kong-Zhuhai-Macao Bridge and Sanya new airport project and the type of steel plate cylinder structure, reasonable test conditions are provided for the cross-section model test.

2.1. Test condition

See Table 1 for the wave input condition of this experiment. The main structure of the test section is a steel plate cylinder with a diameter of 30m and a distance of 3m between the steel plate cylinders, which are connected by auxiliary cells. During the construction period, the top of the steel plate cylinder is sealed with cast-in-place concrete, the top elevation is 2.0m, the bottom elevation is -23.1 m, and the interior of the steel plate cylinder is backfilled medium coarse sand.

| Water Level(m) | Wave Return Period(a) | $H_{1%}$(m) | $H_{13%}$(m) | $\bar{T}$(s) |
|----------------|----------------------|-------------|--------------|-------------|
| 1.84           | 25                   | 10.52       | 7.58         | 11.3        |

2.2. Test Design

The model is designed according to the gravity similarity criterion and the Wave Model Test Specification. The Froude scaling law is applied to the physical model where gravity is the predominant
factor in the fluid motion. In consideration of test content, design level, wave parameter, test section and test equipment condition, model scale is determined as $\lambda = 33$. Considering the requirement of test depth and wave period, the test model is set on the horizontal section of the flume. The distance of the model from the wave maker is 6 times the maximum wavelength, and the distance from the rear wave dissipation slope is greater than 2 times the maximum wavelength. The diagram of the model test are shown in Figure 2 and Figure 4, Figure 3 is a picture of the model used in the experiment.

3. Test results
Small pressure sensors are used to measure the wave pressure of the steel plate cylinder structure during the construction period. Three sections are arranged on the wave-facing side of the steel plate cylinder. Section 1 is located at the junction of the steel plate cylinder and the auxiliary cell, section 2 is located at the wave normal facing side of the steel plate cylinder, and section 3 is located at the 1/4 arc surface. It can be seen from tables 2, figure 5 and figure 6, the value of horizontal force in section 1 is similar to that in section 3. When the wave crest acts, the positive wave pressure of section 2 is 3% less than the other two sections. During the trough action, the negative wave pressure of section 2 is about 8% less than the other two sections. The wave pressure distribution of three sections is same. During the wave crest action, the positive wave pressure decreases gradually with the decrease of the measuring point position of the steel plate cylinder. Under the through action, with the decrease of the position of the
measuring point, the negative wave pressure increases at first and then decreases. The maximum positive wave pressure of each section is 70.9 kPa and the maximum negative wave pressure is -103.0 kPa, all of them appear in section 1. The negative wave pressure in each section is about 17% greater than the positive wave pressure.

Table 2. Measurement results of wave forces in different sections of steel plate cylinder

| Elevation of measuring point (m) | Section1 |       | Section2 |       | Section3 |       |
|----------------------------------|----------|-------|----------|-------|----------|-------|
|                                  | Maximum positive wave pressure values (kPa) | Maximum negative wave pressure values (kPa) | Maximum positive wave pressure values (kPa) | Maximum negative wave pressure values (kPa) | Maximum positive wave pressure values (kPa) | Maximum negative wave pressure values (kPa) |
| 1.67                             | 70.9     | -29.9 | 68.5     | -25.5 | 69.3     | -33.6 |
| -0.65                            | 61.5     | -39.1 | 62.2     | -36.0 | 64.3     | -43.7 |
| -5.074                           | 66.8     | -75.3 | 64.2     | -75.7 | 63.7     | -76.9 |
| -9.498                           | 63.6     | -89.7 | 54.6     | -78.7 | 67.3     | -99.3 |
| -13.922                          | 65.4     | -89.5 | 63.1     | -85.5 | 64.0     | -89.8 |
| -18.346                          | 63.1     | -103.0| 65.3     | -90.4 | 62.3     | -87.1 |
| -22.77                           | 54.0     | -74.0 | 54.6     | -73.8 | 56.0     | -79.9 |

Figure 5 Measurement results of wave forces in different sections of steel plate cylinder during the wave crest action

Figure 6 Measurement results of wave forces in different sections of steel plate cylinder during the wave trough action
4. Conclusions

In this paper, the wave force of steel plate cylinder structure is studied by means of physical model test. The main conclusions are as follows:

The distribution of each section of the steel plate cylinder along the vertical line is basically the same, and the pressure increases gradually from the bottom to the top during the wave crest action, and the maximum pressure generally occurs in the upper part of the cylinder; during the trough action, it first increases and then decreases from the bottom up, and the maximum pressure generally occurs in the middle and lower part of the cylinder.

The distribution of the pressure on the wave-facing side of the steel plate cylinder along the curved surface shows that the pressure at arc surfaces (Section 1 and Section 3) is 3% and 8% larger than at normal facing side (Section 2) during the crest and trough action.

The negative wave pressure of the steel plate cylinder is about 17% larger than that of the positive wave pressure.

Acknowledgments

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