EXPERIMENTAL STUDY ON WAVE FORCE SPECTRUM ON RECTANGLE BRIDGE PIER

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ABSTRACT: With the development of bridge construction in China, some bridges connected sea bay or strait will be built, such as Hong Kong-Zhuhai-Macao Bridge, Qiongzhou strait Bridge and so on. These bridges will face more atrocious natural conditions than the bridges built in the rivers. Tide, typhoon and wave will influence on the safety of the bridge structure and the water depth will be much deeper than in river. At present, in China the research on wave action on bridge pier has been done rarely due to former bridges being constructed almost in the river and the wave load small, however the wave load is an important factor for strait bridge structure design. If we can’t grasp the disciplinarian of wave effecting on the bridge, it will effect on the design of bridge structure in further. So it has the important significance to study wave acting on pier in deep water. And the object of research is to provide the reference and basis for the design of strait bridge in the future. In this paper, the wave force on the rectangle of cross-section pier has been studied under the different conditions by physical model test. It will introduce the physical model setup and then according to the test data, analyze the relationship of wave spectrums and force spectrums on the pier. Results indicate there is the strong relativity between wave and force, not only the characteristic parameter, such as H1/3 and F1/3, but also the wave spectrum and force spectrum.

Keywords: Bridge pier, wave, wave spectrum, force spectrum

PERFACE

There are two ways to be used to describe the random waves. Firstly, the statistical characteristics parameters of wave are used to describe wave, such as the statistical wave heights and wave periods. Secondly, wave spectrum is used to describe the random waves. For this way, the frequency spectrum is used to express the relationship between wave height and wave frequency, and wave directional distribution is described by the directional distribution function. Corresponding with two ways to describe random waves, there are two ways to describe the force on the structure. There are some research achievements about wave force on special structures under characteristic wave action, and that is embodied by standards and classical formulas in China. There is less research on the wave force spectrum that is used to describe the force process on structure.

When we research and discuss the interaction the interaction between wave and bridge or superstructure, frequency analysis is often a nice way, due to the complexity of factors and the difference of dynamic response frequency. In this paper, based on a series of experiments, relationship between the incident wave spectrum and the force spectrum on the rectangle bridge pier structure is analyzed. Focused on the researches that include the form of force spectrum, the relationship between different characteristic parameters, transfer function between wave and force spectrum.

TEST CASES

Based on 6 series tests (shown in Table 1) and wave incident angle is 0° which is defined by wave incident direction is perpendicular to short line of cross-section of rectangle pier, the relationship between incidence wave and wave force on rectangle pier is analyzed. The dimension of pier is 32cm long, 20cm wide and 80cm high. In order to reduce the boundary effect of wave reflection and wave diffraction caused by pier, the testes were conducted in a wave basin with 12m width. In order to obtain the relation between the wave and force, the follows problems should be answered by tests:

1) The relationship between wave process and the force process on the cylinder;

2) The relationship between wave force and force spectrum;

3) The relationship between wave spectrum and force spectrum.

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**TEST RESULTS**

Force spectrum expresses the frequency distribution of the energy. In the test, the rectangle pier model is completely rigid, so there is strong correlation between the frequency distribution of wave energy and force. If the force spectrum can express the process, then there is an empirical transfer function between wave spectrum and force spectrum. The main parameters in the empirical transfer function are wave parameter, cylinder size and water depth, etc.

During the tests, the water depth is 40cm, and the wave parameter is: \( H_{1/3}=11.17 \text{cm}, T_{1/3}=1.58 \text{s} \). The test results are as follows:

<table>
<thead>
<tr>
<th>Case</th>
<th>( H_{1/3}(\text{cm}) )</th>
<th>( T_{1/3}(\text{s}) )</th>
<th>Wavelength depth (cm)</th>
<th>Spectrum and Spectral peak factor ( \gamma )</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.1</td>
<td>11.17</td>
<td>1.58</td>
<td>40</td>
<td>JONSWAP, ( \gamma=3.3 )</td>
</tr>
<tr>
<td>No.2</td>
<td>8.50</td>
<td>1.24</td>
<td>40</td>
<td>JONSWAP, ( \gamma=3.3 )</td>
</tr>
<tr>
<td>No.3</td>
<td>9.23</td>
<td>1.68</td>
<td>40</td>
<td>JONSWAP, ( \gamma=3.3 )</td>
</tr>
<tr>
<td>No.4</td>
<td>11.31</td>
<td>1.54</td>
<td>40</td>
<td>JONSWAP, ( \gamma=7.0 )</td>
</tr>
<tr>
<td>No.5</td>
<td>8.07</td>
<td>1.17</td>
<td>40</td>
<td>JONSWAP, ( \gamma=7.0 )</td>
</tr>
<tr>
<td>No.6</td>
<td>10.76</td>
<td>1.68</td>
<td>40</td>
<td>JONSWAP, ( \gamma=7.0 )</td>
</tr>
</tbody>
</table>

**Table 1 Wave parameter and experimental test cases.**

For every wave parameter, there are three times tests, and the average value of the results is as follows:

**Table 2 Element of wave**

**Table 3 Element of wave force (X direction)**

**Table 4 Element of wave spectrum**

**Table 5 Element of wave force spectrum (X direction)**

Here \( M_0 \), \( M_1 \) and \( M_2 \) are the zero-moment, first moment and second-moment respectively. Characteristic force definition is shown in figure 5.
ANALYSIS OF RESULTS

Test results show that the force spectrum is strong consistent with wave spectrum (JONSWAP spectrum). These are shown by the relationship between the character wave height and force and consistency of spectrum peak frequency as shown as fig.6~fig.7 and table 6.

Table 6 Spectrum peak frequency of wave and force

<table>
<thead>
<tr>
<th>Wave spectrum peak frequency (Hz)</th>
<th>Force spectrum peak frequency (Hz)</th>
<th>Relative error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.68</td>
<td>0.68</td>
<td>0.00</td>
</tr>
<tr>
<td>0.87</td>
<td>0.92</td>
<td>5.75</td>
</tr>
<tr>
<td>0.63</td>
<td>0.64</td>
<td>1.59</td>
</tr>
<tr>
<td>0.68</td>
<td>0.68</td>
<td>0.00</td>
</tr>
<tr>
<td>0.97</td>
<td>0.94</td>
<td>-3.09</td>
</tr>
</tbody>
</table>

Because the testing is not overall representative, when force spectrum is used to simulate the process of force, the force process in model should be compared with measured force process and statistical force. The difference of two phases should be analyzed, and the difference is not only the propagation time but also the time when the positive maximum force and the minimum minus force appear. All the above analysis may be based on this test, but it needs further research.

In order to get the force spectrum on the rectangle pier structure, the wave height in JONSWAP spectrum is replaced by statistical wave force, and the wave period is replaced by statistical force period, based on testing results. At the same time, the spectrum peak factors are adjusted, so the force spectrum can be calculated. The comparison of calculated force spectrum and measured spectrum under the different conditions is shown in Fig.8.

Fig. 5 The definition of characteristic force

Fig. 6 Relationship between significant wave height and $M_0$

Fig. 7 Relationship between significant force and $M_0 F$

Fig. 8 Comparison of calculated and measured force spectra.
the wave incident angle changed, the force spectrum would be different and it needs further research.

**CONCLUSIONS**

1. The series of experiments were performed to study the characteristic of wave force spectrum for rectangle pier.

2. The frequency distribution shape of force spectrum is similar with wave spectrum.

3. Based on JONSWAP wave spectrum, the well fitting force spectrum is obtained by adjustment of spectrum peak factor.

4. It needs further research for the wave force spectrum of rectangle shape pier under the different wave incident angle.

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