Dynamic response analysis of machine bridge of spillway gate

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Abstract. Under the action of earthquake, the seismic property of the machine bridge directly affects the normal use of spillway gate. At the same time, the type of infilled wall affects the seismic capacity of the machine bridge. To decrease the damage possibility of the machine bridge under earthquake, three finite element models are established by finite element software, and the dynamic time history analysis of the machine bridge is carried out. The stress and displacement of different models are obtained through the dynamic time history analysis. The best type of infilled wall is judged by comparing the seismic responses of three models. Based on the analysis results, the mechanical characteristics of the machine bridge under earthquake action are analyzed and the weak position of the structure is found. Therefore, some measures can be taken to further improve the seismic performance of the machine bridge. The calculation results have important significance for practical engineering.

1. Introduction

Under the action of earthquake, the seismic property of the machine bridge directly affects the normal use of spillway gate. In order to meet the requirements of the opening and closing of the gate, the height of the machine bridge is usually large. The structure is very vulnerable to the earthquake because of the large self-weight of the hoist room. It is important for the safety of spillway gates to fully study the structural dynamic response and damage modes of the machine bridge under earthquake actions. The seismic property of the machine bridge is improved through the result analysis.

In addition, the type of infilled wall of the hoist room has a great impact on the seismic property of machine bridge. The densities of the infilled walls with different materials are different, and the mechanical properties are also different. Of course, it will also affect the seismic performance of the structure. Therefore, it is necessary to carry out dynamic time history analysis for different types of machine bridges. The weak position of the structure is found out through time-history analysis, and then the weak position is improved, so as to improve the seismic capacity of the structure[1].

2. Dynamic time history analysis

2.1. Calculation overview

The infilled wall materials are clay brick, hollow block and non-filling. Among them, the density of clay brick and hollow block is 1700 kg/m³ and 525 kg/m³ respectively. The pier is made of C30 concrete, the bulk density is 25 kN/m³, the elastic modulus is 3.0×10¹⁰ Pa, and the Poisson's ratio is 0.2. The concrete strength grade of machine bridge is C35, the bulk density of gamma is 25 kN/m³, and the elastic modulus is 3.15×10¹⁰ Pa, and the Poisson's ratio is 0.2.
The load mainly includes the self-weight of the gate, wind load, roof live load, engine room load, etc. The dynamic effect of reservoir water on the gate chamber is simulated by the additional mass method, and the magnitude 8 earthquake wave with duration of 20 s is input in the vertical direction of the river.

2.2. Finite element model

When establishing the finite element model, the concrete is assumed to be linear elastic material and the reservoir water is incompressible fluid. In order to improve the accuracy of calculation, SOLID186 solid element is used for piers and bridges. SOLID186 is called high-order 3D 20-node solid element. The element is defined by 20 nodes; each node has three degrees of freedom, i.e. translational displacements $U_x$, $U_y$ and $U_z$ along the x, y and z directions of node coordinates[2]. Three finite element models are established according to different infilled types: (1) clay brick infilled wall; (2) hollow block infilled wall; (3) without infilled wall. As shown in Figure 1 to Figure 3.

2.3. Dynamic time history analysis results

2.3.1. Clay brick infilled wall

The first principal stress $\sigma_1$ time-history diagram and the corresponding contour map are obtained by taking the top of the machine bridge as a control point[3]. It can be seen from Figure 4 that the dynamic response of the structure reaches the maximum value at 13.90 second. The first principal stress fluctuates around 2.4 MPa, with a maximum of 4.7 MPa and a minimum of -6.9 MPa. The stress contour map at 13.90 second is shown in Figure 5.

We can get the vertical river direction $U_x$ time history diagram as shown below by taking the top of the machine bridge as the control point. It can be seen from Figure 6 that the displacement in the x direction of the top of the machine bridge reaches the maximum at 9.70 second, and the corresponding displacement contour map is as shown in Figure 7. The maximum displacement is 59.12 mm.

Because of the high density of clay brick wall, the quality of clay brick is almost three times that of hollow brick compared with the same volume of clay brick. Because of the excessive mass, the top-heavy of the machine bridge is more prominent, and the left-right swing is more violent when subjected to x-direction earthquake. Similarly, due to the excessive mass, the force is more prominent, and the structure is more biased toward the strong beam weak column, so that the force on the joint is greatly increased and it is easy to break.
2.3.2. Hollow block infilled wall

The first principal stress $\sigma_1$ time-history diagram and the corresponding contour map are obtained by taking the top of the machine bridge as a control point. It can be seen from Figure 8 that the dynamic response of the structure reaches the maximum value at 10.00 second. The first principal stress fluctuates around 2.1 MPa, with a maximum of 5.04 MPa and a minimum of -1.26 MPa. The stress contour map at 10.00 second is shown in Figure 9.

We can get the vertical river direction $U_x$ time history diagram as shown below by taking the top of the machine bridge as the control point. It can be seen from Figure 10 that the displacement in the $x$ direction of the top of the machine bridge reaches the maximum at 7.40 second, and the corresponding displacement contour map is as shown in Figure 11. The maximum displacement is 15.7 mm.

The weak position of the working condition 2 when subjected to the $x$-direction earthquake is the column root, the column top and the node part of the rack bridge. Especially the bridge column that is subjected to the lateral earth pressure side is obvious stress concentration. Reason is as follows: 1. When the seismic wave is opposite to the direction of earth pressure, the force will partially offset under the action of lateral earth pressure, so that the absolute value of the force decreases, but the force on the far side does not offset. As a result, the forces on both sides are uneven; when the seismic waves are in the same direction as the earth pressure, the forces on the near side will be partially superimposed, which also causes uneven forces on both sides. 2. When the machine bridge is subjected to earthquakes, the piers on the side away from the soil are narrower and the lateral stiffness is smaller. In order to consume energy, structure will produce a large swing amplitude and the lateral displacement is larger. 3. Because the lateral stiffness of the pier near the soil side is large, the displacement of the same side machine bridge column is small. In order to achieve the force balance, the machine bridge column has to bear a large force, so it leads this side of machine bridge column to the maximum stress.
2.3.3. Without infilled wall

The first principal stress $\sigma_1$ time-history diagram and the corresponding contour map are obtained by taking the top of the machine bridge as a control point. It can be seen from Figure 12 that the dynamic response of the structure reaches the maximum value at 12.60 second. The first principal stress fluctuates around 4 MPa, with a maximum of 9.57 MPa and a minimum of -1.37 MPa. The stress contour map at 12.60 second is shown in Figure 13.

We can get the vertical river direction $U_x$ time history diagram as shown below by taking the top of the machine bridge as the control point. It can be seen from Figure 14 that the displacement in the $x$ direction of the top of the machine bridge reaches the maximum at 12.90 second, and the corresponding displacement contour map is as shown in Figure 15. The maximum displacement is 21.6 mm.

Although there is no additional quality, but the pulling effect of the infill wall is reduced, so that the structure directly bears the effect of seismic load. It results in large stress and displacement of the structure.

3. Results analysis

By performing dynamic time history analysis on different infill wall type machine bridges[4], the maximum values of the stress field and the displacement field, such as clay brick wall, hollow block wall and unfilled wall, can be obtained, and the time to reach the maximum value can be obtained. The results of the stress field analysis are shown in Table 1. The results of the displacement field analysis
are shown in Table 2.

| Table 1. Analysis results table in stress field |
|-----------------------------------------------|
| Maximum time (s) | Maximum (MPa) | Minimum (MPa) | Average value (MPa) |
| Clay brick wall  | 13.90         | 4.7           | -6.9             | 2.4             |
| Hollow block wall| 10.00         | 5.04          | -1.26            | 2.1             |
| Without infilled wall | 12.60 | 9.57          | -1.37            | 4               |

| Table 2. Analysis results table in displacement field |
|------------------------------------------------------|
| Maximum time (s) | Maximum (mm) |
| Clay brick wall  | 9.70          | 59.12         |
| Hollow block wall| 7.40          | 15.7          |
| Without infilled wall | 12.90 | 21.6          |

Taking the top of the machine bridge as the control point, the seismic time history analysis of three types of machine bridges with different infill walls is carried out. Comparing the three time history analysis results, it can be seen that the seismic response of working condition 1 is larger at 13.90 seconds, the maximum value of the first principal stress $S_1$ is 2.4 MPa, the minimum value is -6.9 MPa, and the displacement in x direction reaches 59.12 mm. The offset exceeds the safe distance of 20 mm reserved deformation joint. For working condition 2, the maximum seismic response is achieved at 10.00s, the maximum value of $S_1$ is 5.04 MPa, the minimum value is -1.26 MPa, and the displacement is 15.7 mm, which is more than half of the displacement of working condition 1. For working condition 3, as a comparative experiment, it can be seen from the results of time history analysis that at 12.60s, $S_1$ reaches the maximum 9.57 MPa, while the displacement is 15.7 mm.

4. Conclusion

(1) From the comprehensive analysis of stress and displacement, it clearly shows that the machine bridge has the minimum stress and displacement when the hollow block wall is used. Therefore, the hollow block is the best type of infilled wall.

(2) The top and root of the column of the machine bridge are the weak positions under the X-direction earthquake. Especially, stress concentration will occur in the column of the machine bridge subjected to the lateral pressure.

(3) The calculation results show that, under the earthquake action, the machine bridge can basically meet the normal requirements if the infilled wall is used. The tensile stress on the top and bottom of the machine bridge column is relatively large, and a series of structural measures can be taken to make up for it. The stress and displacement of other positions of the machine bridge are small, so there will be no damage. Therefore, the use of hollow block infilled wall in machine bridge can be popularized in practical engineering.

References

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