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Seismic performance analysis of concrete-filled steel tubular single pylon cable-stayed bridge with swivel construction

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Abstract: For the cable-stayed bridge with swivel construction, due to the need of swivel construction, there is no consolidation between the bottom of the pier and the foundation during the construction process. Once an earthquake occurs, it is easy to cause the overturning of the bridge or the destruction of the bottom turntable. It can cause major safety incidents. In order to study the seismic safety of the single-pylon cable-stayed bridge in the swivel construction, it uses ANSYS finite element analysis software to establish a finite element analysis model for the construction stage of the single pylon cable-stayed bridge based on a certain project in this paper. Through the calculation and analysis of the single-pylon cable-stayed bridge with swivel construction under earthquake excitation, it is found that the locating pin at the center of the ball-end hinge has excessive shearing force under the 6-degree and 7-degree seismic excitation. It will cause the concrete around the pin to be crushed or even the ball joint to be destroyed. In view of the above problems, it proposes the seismic measures for arranging anchor rods at the edge of the turntable in this study, and calculates and compares the seismic effects of anchoring arrangements with different diameters and different inclination angles. It shows that the solution can significantly reduce the positioning pin shear force and prevent the upper structure from overturning under earthquake from results.

1. Introduction

For the single-tower cable-stayed bridge, because of its relatively light weight and mostly self-anchoring structure, the torque on both sides of the bridge tower is basically balanced, which is suitable for swivel construction, especially for municipal over-the-line bridges and over-the-road bridges along the railway [1-5]. However, there are few seismic studies on the construction phase structure at home and abroad. The seismic research on the construction stage of the cable-stayed bridge is even blank in China. Therefore, it is of great significance to study the seismic resistance of the cable-stayed bridge during the construction phase.

The cable-stayed bridge with swivel construction has a "maximum double cantilever" stage during the construction of the most unfavorable earthquake-resistant stage. In the "maximum double cantilever" stage, the possible damage of the cable-stayed bridge mainly has the following aspects:

(a). When an earthquake occurs, the steel rod used to fix the bottom of the pier and the center of the foundation will bear huge shearing force. On the one hand, the steel bar has the risk of being sheared. On the other hand, the concrete ball joint is also pressed by the steel bar under great shear force. And has the risk of collapse.

(b). Under the action of the earthquake, the bending moment at the bottom of the pier is large, and the entire cantilever system has the risk of overturning.

In summary, the probability of earthquakes occurring during the construction phase of the single-pylon cable-stayed bridge using the swivel construction is low[6-9]. Once the earthquake occurs, the bridge will be seriously damaged and cause a major safety production accident[10]. Therefore, in order to ensure the seismic safety of the bridge during the construction phase, it is very important and far-reaching to carry out seismic analysis and optimization design for the “most unfavorable state” of the cable-stayed bridge in the construction stage.

2. Engineering background

2.1 Project Overview

This study takes the actual project "Yanzhou Beifucheng river Road West Yanshang Crossing Xinyi Railway Overpass Project" as an example. Cable-stayed bridge is a cross-rail bridge. In order to reduce the impact of construction on the railway line that it crosses, the construction of the cable-stayed bridge adopts the method of swivel construction. In the construction stage of the swivel, the cable-stayed bridge structure is a 2x86m diagonally-trailed T-structure. The pier, beam and pylon are consolidated. The 2cm PTFE ball joint sliding layer is arranged between the bottom plane of the pier and the upper and lower turntables of the foundation in order to the rotation of the superstructure. A positioning steel rod of φ300 mm is arranged on the center line of the bottom turntable and the base contact portion, and the lower half of the steel rod is buried in the positioning hole in the center, and the upper half protrudes into the positioning hole in the center of the upper turntable.

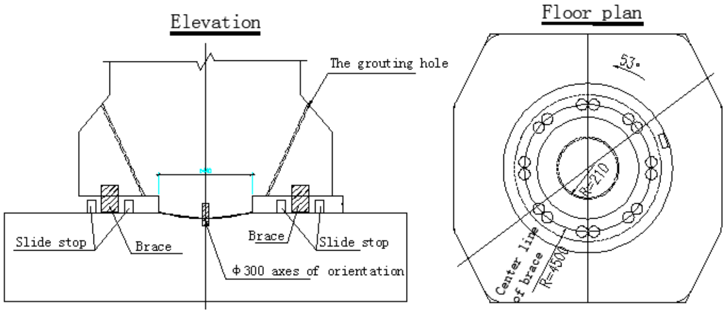

Figure 1. Turntable structure diagram

2.2 Determination of seismic level and selection of seismic waves

According to engineering background information, the engineering geological environment of the cable-stayed bridge is earthy. From the analysis of the dynamic characteristics of the cable-stayed bridge with the largest double-cantilever state, it can be seen that the period of the vertical acceleration is 0.5 times of the peak of the horizontal acceleration, and the horizontal acceleration takes 0.05g (7 degrees).

Accelerate the calculation speed without affecting the analysis results. In this study, only the EL Centro seismic wave front 40s, the acceleration time history curve of the 2000 load step is selected. In addition to the EL Centro seismic wave, the Nridge seismic wave and the Taft seismic wave are selected in this study, and the first 40 seconds of the seismic wave are selected as the research object.

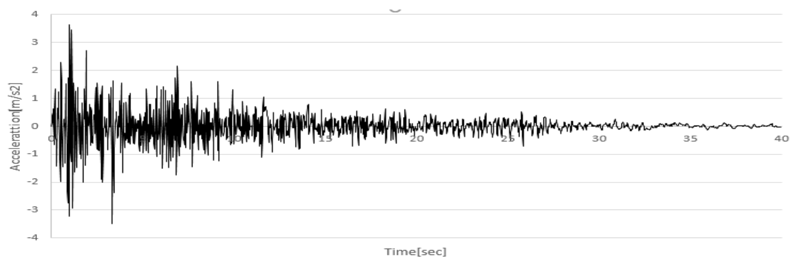

Figure 2. The EL Centro seismic acceleration time history wave （mm/s^2）

3. Seismic analysis

3.1 Determination of the most unfavorable seismic background and establishment of finite element model

The most unfavorable construction seismic stage for the cable-stayed bridge with swivel construction is shown in Figure 3.

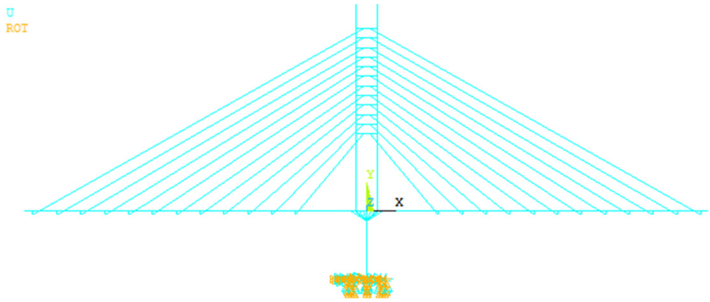

Figure 3. Schematic diagram of the finite element model of the maximum double cantilever stage

3.2 Seismic analysis of the largest double cantilever stage turntable structure

The structure of the turntable is subjected to the combined action of vertical pressure, horizontal shearing force and bending moment transmitted by the bottom of the pier under the action of earthquake. The force is shown in Figure 4.

There are two main types of damage to the structure of the turntable under seismic loading: one is the overall overturning of the upper structure; the other is the shear failure of the center pin. Through the dynamic time history analysis of the bridge structure under different seismic wave conditions, the axial force, bending moment and shear force of the turntable, the foot and the pin under different seismic wave components are obtained, as shown in Table 1.

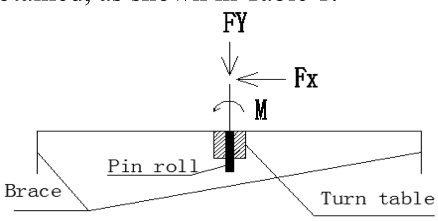

Figure 4. A schematic diagram of the force of a turntable structure

Table1 degree design of the forces of the various structures of the turntable under the earthquake

Load location	Force	EL centro		Taft		Nridge	
		Minimum (N)	Maximum (N)	Minimum (N)	Maximum (N)	Minimum (N)	Maximum (N)
Pin rod	Transverse shear	-2.14E+07	2.03E+07	-1.42E+07	1.02E+07	-8.15E+06	9.61E+06
	Longitudinal shear	-1.51E+07	1.87E+07	-1.72E+07	1.86E+07	-1.81E+07	1.22E+07
	Axial force	-1.33E+05	-3.12E+04	-1.33E+05	-6.38E+04	-1.33E+05	-7.26E+04

Brace	1	-3.21E+07	0.00E+00	-2.16E+07	0.00E+00	-1.15E+07	0.00E+00
	2	-2.65E+07	0.00E+00	-2.57E+07	0.00E+00	-1.55E+07	0.00E+00
	3	-2.60E+07	0.00E+00	-2.56E+07	0.00E+00	-1.68E+07	0.00E+00
	4	-3.96E+07	0.00E+00	-1.91E+07	0.00E+00	-1.98E+07	0.00E+00
	5	-3.05E+07	0.00E+00	-1.71E+07	0.00E+00	-1.33E+07	0.00E+00
	6	-2.20E+07	0.00E+00	-2.87E+07	0.00E+00	-1.36E+07	0.00E+00
	7	-1.82E+07	0.00E+00	-2.34E+07	0.00E+00	-2.31E+07	0.00E+00
	8	-2.69E+07	0.00E+00	-1.67E+07	0.00E+00	-2.23E+07	0.00E+00
Ball joint	Axial force	-1.83E+08	-8.39E+07	-1.83E+08	-1.09E+08	-1.82E+08	-1.18E+08

Through the comparative analysis of the force of different parts of the turntable under different seismic conditions, the following conclusions can be obtained:

(1). Anti-overturning check calculation of turntable structure.

There are two kinds of evaluation indicators for the turntable structure. There are two kinds of evaluation indexes: the tension on the center pin or the pressure on the brace around the turntable.

Through the above analysis, the maximum double-cantilever stage cable-stayed bridge does not cause overturning due to the center pin tension and the brace crushing under the 7 degree design earthquakes.

(2). Anti-shear check calculation of the center pin.

Through the above calculation and analysis, the maximum shear stress generated by the pin shaft under the 7 degree design earthquake is 331.3MPa. Due to the large diameter of the pin itself (300mm), and the ball joint and foundation used to fix the pin are reinforced concrete structures, the pin will crush the surrounding concrete.

Through the above research, it is found that although the superstructure has no risk of overturning, it is necessary to carry out seismic optimization design of the turntable structure to reduce the shear force on the pin shaft and prevent the ball joint and the foundation from being damaged under the action of earthquake.

4. Seismic optimization design and analysis of calculation

4.1 Principle of seismic optimization scheme

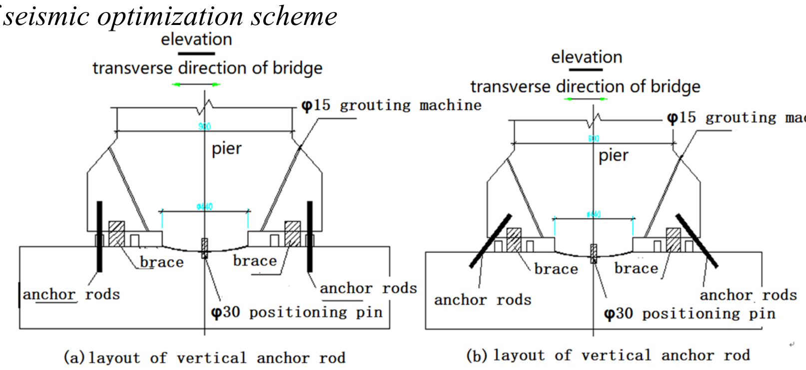

Figure 5. The schematic diagram of the seismic optimization scheme with anchor bars

Based on the basic requirements of cost saving and construction simplification, an anti-seismic optimization scheme is proposed to reduce the shear force of pin shaft by setting anchor bar as shown in figure 5. The basic principle of this scheme is that the steel anchor rod is pre-embedded at the corresponding position outside the support leg of the foundation base when the foundation base is poured, and then the upper end of the anchor rod is poured into the rotary plate during the rotary plate construction. When the rotary body needs to be rotated during the construction stage of the rotary body, only the steel rod needs to be cut off to carry out the construction of rotary body of the upper structure.

Considering the anchor rod of different Angle may produce different seismic effect, so the setting angle of anchor rod which is between anchor rod and horizontal direction respectively sets to 30 °, 45 °, 60 °, 75 ° and 90 °.

4.2 Setting of parameters of the seismic optimization scheme

In order to study the seismic effect of anchor rod layout at different inclination angles, the comparative research background is as follows:

Since the rotary plate under the EL centro three-way seismic wave receives the maximum shear force under the seven-degree seismic design, only EL centro three-way seismic wave load condition is selected to check the condition in the comparative study. In order to study the shock absorption effect of the central pin shaft under different anchorage conditions, 6 sets of comparison conditions are designed for the diameter of the anchorage rod. They are: φ80, φ100, φ20, φ 150, φ175 and φ200.

4.3 The results and conclusions of calculation and analysis of the optimal scheme of rotary table structure

Through calculating the worst stage of the whole construction under different diameters of anchor rod that is the force condition of maximum double cantilever stage of cable-stayed bridge under the condition of EL centro wave load force of the rotary parts, it gets the stress condition of pin shaft and anchor rod in two directions. The final force of the pin shaft and anchor rod is obtained by superimposing the horizontal shear forces with SRSS. And the concrete stress are shown in figure 6-11.

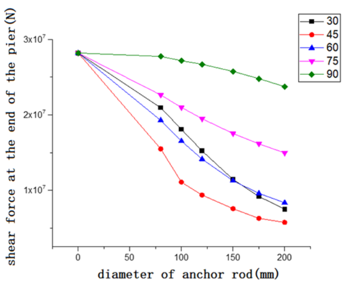

Figure 6. shear force at the end of the pier

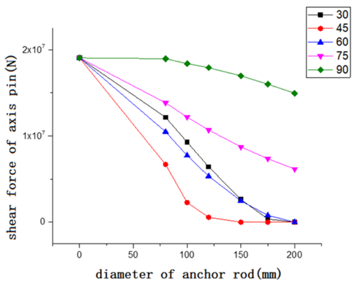

Figure 7. shear force of axis pin

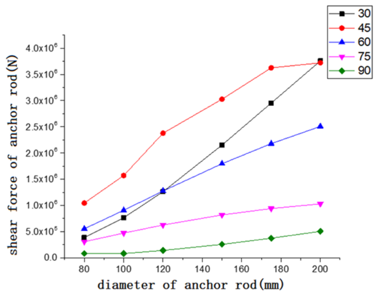

Figure 8. shear force of anchor rod

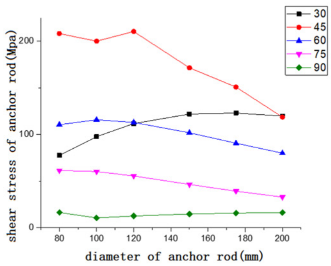

Figure 9. shear stress of anchor rod

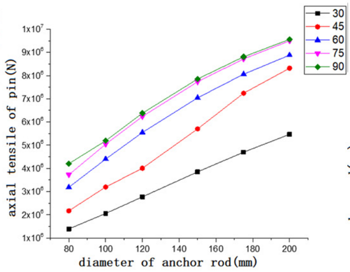

Figure 10. axial tensile of pin

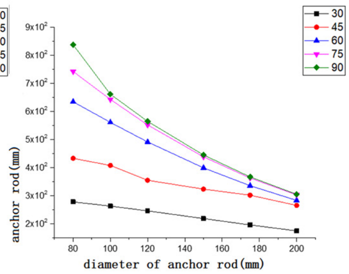

Figure 11. axial tensile stress of anchor rod

According to the calculation results above, the following conclusions can be drawn:

(1). According to the changes of shear diagram of pier bottom in figure 5 and pin shaft in figure 6, the shear force of pier bottom and pin shaft decreases with the increase of the diameter of anchor rod and increases with the increase of inclination angle.

(2). According to the variation curve of the shear diagram of the anchor bar in figure 8. the shear force of the anchor bar increases with the increase of the diameter of the anchor bar, but first grows and then decreases with the increase of the inclination angle. The maximum shear force of the anchor bar is reached when the inclination angle of the anchor bar is 45 degrees.

(3). According to the changes of diagram of shear stress of anchor rod in figure 9 and axis stress of anchor rod in figure 11, in addition to the increase of shear stress of anchor rod at 30 degree angle with the increase of anchor rod diameter, the stress of other anchor bars basically decreases with the increase of anchor rod diameter.

(4). Based on the standard of shear stress of pin bar which is 50Mpa, according to the diagram of shear force of axis pin in figure 7, the axial force, axial stress, shear stress and shear stress of the anchor rod are in the best position when the diameter of the anchor rod is 150mm and the angle of inclination is 30 degrees.

5. Conclusion

(1). Without the application of any anti-seismic measures, the traditional cable-stayed bridge with swivel construction has excessive shearing force on the center pin under seismic excitation.

(2). The method of adding anchor rods can greatly reduce the shear stress of the ball joint center pin under earthquake action, but the magnitude of the pin shear stress reduction varies with the diameter of the anchor rod and the inclination angle of the anchor rod.

(3). Because the excessive axial force and shearing force of the anchoring rod will increase the difficulty of the anchoring rod, comprehensive problems such as material characteristics, construction difficulty and cost of the anchoring rod should be integrated when selecting an appropriate anchoring scheme.

Acknowledgments

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