



Vulnerability Analysis of Cable-stayed Bridge in Large Temperature Difference area

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Abstract. In order to study the influence of large temperature difference on the seismic performance of cable-stayed bridge, a cable-stayed bridge with a temperature difference of 105m+240m+105m was used as the background, and the concrete axial compression tests were carried out at 40°C, 20°C and -30°C respectively, and the material characteristics of concrete and steel were obtained at three temperature conditions. Using Opensees finite element software, a fine nonlinear finite element model of the bridge under global temperature is established, and the seismic vulnerability of the bridge under different temperatures is studied based on IDA method. The results show that the seismic vulnerability of the bridge tower under different temperature conditions shows that the bridge tower is greatly affected by temperature, and its failure probability increases with the decrease of temperature. When designing such Bridges in areas with large temperature difference, the effect of low temperature on the seismic performance of the Bridges should be considered.

Keywords: cable-stayed bridge; temperature; concrete; seismic vulnerability analysis

1 Introduction

China has a vast territory, complex terrain and climate conditions, and the temperature difference between different regions is very significant, and there are many temperature zones. On the one hand, the number of various transportation infrastructure projects in Northwest China is increasing day by day, widely distributed in Gansu, Ningxia, Qinghai, Tibet and other regions. These regions are located in the center of the mainland, free from the influence of warm ocean currents, and have drastic climate changes in four seasons, with large temperature difference between day and night and significant seasonal temperature difference, so that the temperature difference between summer and winter in this region can reach 70°C or even lower. The extreme temperature environment will not only have a significant impact on the mechanical constitutive relations of concrete, steel, etc., but also produce changes in the temperature stress and internal force of the structure, which requires that the engineering structure serving in this area

must have higher performance, especially in the extreme temperature service environment. On the other hand, because of the complicated terrain and large relief, the cable-stayed bridge with long span and high pier is widely used in northwest China. Therefore, it is particularly important to study the influence of large temperature difference on seismic response and seismic vulnerability of cable-stayed Bridges.

According to the investigation results of domestic and foreign scholars on building structures after earthquakes, the earthquake damage occurring at low temperature in winter is generally more serious than that at normal temperature, and the earthquake damage of buildings is likely to be related to temperature [1]. Yu Lu Song [2] 's research shows that considering the influence of temperature change on the concrete mechanical parameters of bridge piers, the damage probability of bridge support and system increases by 10.7% and 14.3%, respectively, compared with that without considering this influence. At the same time, many scholars have shown that the influence of temperature on the mechanical properties of concrete and reinforcement of tower pier structure cannot be ignored: The test results of Li Xiang, Xie Jian, Wang Chuanxing [3-4] show that temperature has different degrees of influence on the elastic modulus, peak stress and peak strain of concrete. As the temperature decreases, the brittleness of concrete increases, the elastic modulus and peak stress both increase, while the peak strain presents a linear downward trend. Xie Jian , Pei Jiaming [5], the test results show that with the decrease of temperature, the plasticity of steel bars decreases, the yield strength and tensile strength increase, the fluctuation of elastic modulus has little correlation with temperature, and the ultimate strain of steel bars decreases continuously. As mentioned above, the current research mainly focuses on the mechanical characteristics of bridge damping and isolation supports at different temperatures and the influence of temperature on the natural vibration characteristics of Bridges, but there are few studies on the influence of changes in the mechanical characteristics of tower piers and steel bars on the seismic performance under the action of temperature.

In view of this, this paper takes a semi-floating system cable-stayed bridge as the engineering background, obtains the relevant mechanical parameters of concrete at different temperatures through experiments, and establishes the fine nonlinear finite element model of the whole bridge by using Opensees finite element software. Based on IDA method, the seismic vulnerability analysis of reinforced concrete bearing and pier with large temperature difference is carried out to reveal the influence of large temperature difference on the seismic performance of cable-stayed Bridges, which can provide reference for the seismic design of semi-floating system cable-stayed Bridges in areas with large temperature difference.

2 Construction of Engineering Background and Finite Element Model

2.1 Engineering Background

The cable-stayed bridge in this paper is a 450m(105m+240m+105m) semi-floating cable-stayed bridge with double towers and double cable planes. The upper tower column

is hollow and inverted Y-shaped structure, using C40 concrete. The lower tower column is thin-walled hollow pier, made of C50 concrete. The characteristic period of the basic seismic response spectrum of the area where the bridge site is located is 0.4s, the peak acceleration is 0.2g, the seismic fortification category is class A, and the site category is Class II. The bridge layout is shown in Figure 1.

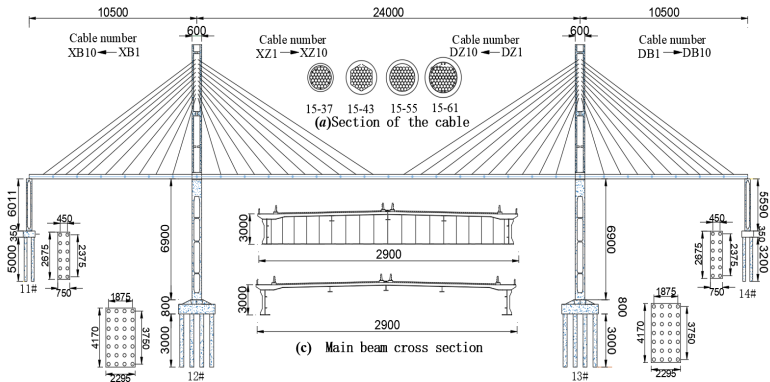


Fig. 1. Full bridge layout.

2.2 The Establishment of Finite Element Model

In this paper, the fine nonlinear finite element model of the whole bridge is established by using OpenSees finite element software (see figure), and the main beam is simulated by elastic beam-column element. The main tower is simulated by the disc beam-column element and the cable is simulated by the truss element. A single friction pendulum bearing unit was used to simulate the bearing. Concrete 02 Material models are used to define confined and unconfined concrete. Using Steel02 material model, the lateral constraint stiffness of friction pile is simulated by "m" method, and the overall temperature load is added. As shown in Figure 2.

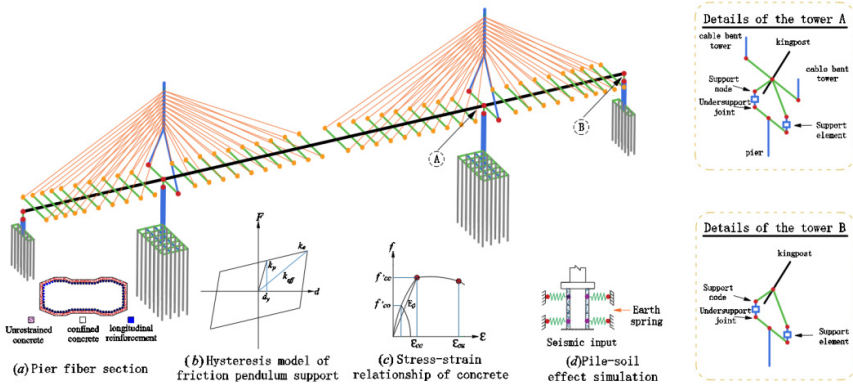


Fig. 2. Finite element model of bridge.

3 Material Constitutive Test and Parameter Fitting

In order to study the change of mechanical parameters of concrete materials under large temperature difference, 36 C40 and C50 concrete prism-concrete specimens, 9 HRB400 steel bars, 9 Q345qd and 9 cable-stayed steel strands were fabricated under three temperature conditions of 40°C, 20°C and -30°C. The average of the results of 3 specimens in each group was taken as the final result of each group, and the mechanical parameters of concrete and steel at different temperatures were obtained. Table 1 and Table 2 give the mechanical parameters of C40, C50 concrete and HRB400 rebar at 40°C, 20°C and -30°C respectively.

Table 1. Average mechanical parameter value of concrete specimens in each group

| T | Specimen set | compressive strength/ <i>MPa</i> | peak strain / $\mu\epsilon$ | elasticity modulus / <i>MPa</i> |
|-------|--------------|----------------------------------|-----------------------------|---------------------------------|
| 40°C | A1 | 42.96 | 2490 | 36344 |
| 20°C | A2 | 47.93 | 2308 | 39742 |
| -30°C | A3 | 61.82 | 1753 | 46938 |
| 40°C | B1 | 52.75 | 2763 | 39545 |
| 20°C | B2 | 56.68 | 2536 | 42571 |
| -30°C | B3 | 68.69 | 1894 | 48915 |

Table 2. HRB400 Reinforcement mechanical parameter value

| T | yield stress / <i>MPa</i> | limiting stress / <i>MPa</i> | elasticity modulus / <i>GPa</i> |
|-------|---------------------------|------------------------------|---------------------------------|
| 40°C | 406.2 | 584.8 | 198 |
| 20°C | 420.17 | 615.5 | 203 |
| -30°C | 447.13 | 646.2 | 211 |

4 Seismic Vulnerability Analysis

4.1 Seismic Wave Selection

Twenty seismic waves conforming to site characteristics were selected, and the standard response spectrum and average response spectrum were shown in Figure 3. Then, the PGA of 20 seismic waves is adjusted to 10 different intensity levels of 0.1g~1.0g, and 200 seismic waves are obtained.

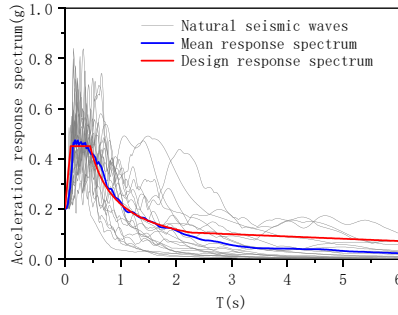


Fig. 3. Response spectra of 20 seismic waves.

4.2 Definition of Structural Damage Limit State

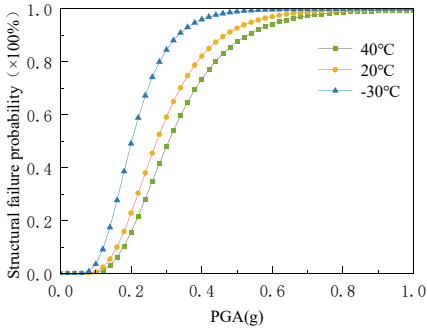
The displacement of pier top and curvature of control section of the bridge with high pier and long span do not appear synchronously, and the relationship between material damage and deformation is not one-to-one correspondence. Therefore, the bending moment-curvature analysis of the control section is carried out, and the curvature is used as the basis for damage evaluation of pier column. Reference [5-6] for moment-curvature analysis of the bridge in this paper, Quantification is divided into four levels, for example $\phi \leq \phi_y$ For minor damage; $\phi_y < \phi \leq \phi_y$ Moderate failure; $\phi_y < \phi \leq \phi_u$ For serious damage; $\phi_u < \phi$ For complete destruction. As show in table 3.

Table 3. moment-curvature curve of lower section of tower column

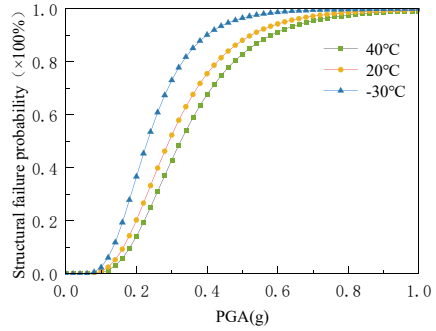
| faulted condition | Along the bridge | | | transverse direction of bridge | | |
|-------------------|------------------|----------|----------|--------------------------------|----------|----------|
| | 40°C | 20°C | -30°C | 40°C | 20°C | -30°C |
| Slight failure | 0.001063 | 0.000954 | 0.000804 | 0.001179 | 0.001095 | 0.000804 |
| Moderate failure | 0.001323 | 0.001207 | 0.001304 | 0.001806 | 0.001710 | 0.001304 |
| Serious failure | 0.004737 | 0.004509 | 0.005029 | 0.006297 | 0.005833 | 0.005203 |
| Complete failure | 0.007561 | 0.006516 | 0.007230 | 0.010292 | 0.008264 | 0.007202 |

4.3 Construction of Seismic Vulnerability Curve of the Whole Bridge

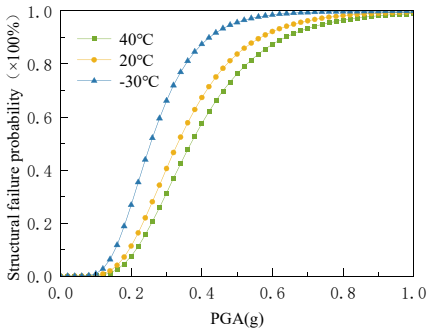
Reference [7] draws the following seismic vulnerability map:



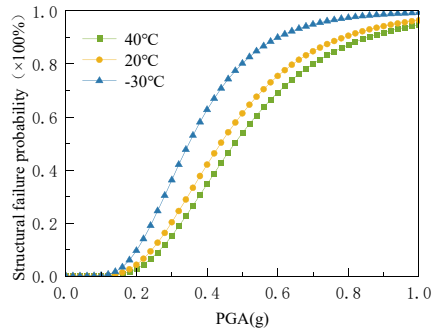
(a) Longitudinal direction of bridge-Slight failure



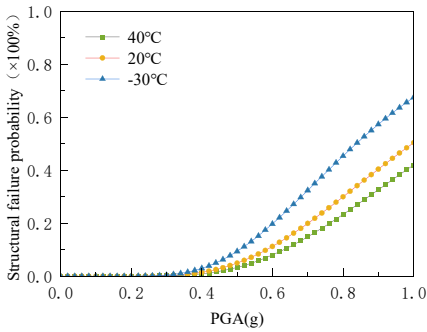
(b) Transverse direction of bridge-Slight failure



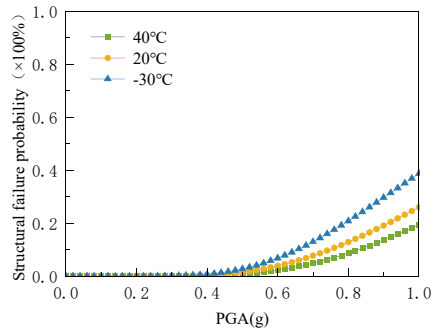
(c) Longitudinal direction of bridge-Moderate failure



(d) Transverse direction of bridge-Moderate failure



(e) Longitudinal direction of bridge-Serious failure



(f) Transverse direction of bridge-Serious failure

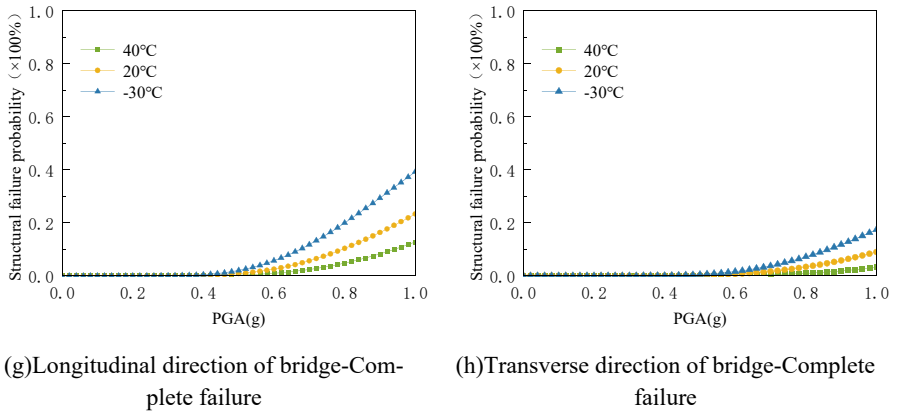


Fig. 4. Comparison of seismic vulnerability of tower at different temperatures

Affected by the ambient temperature, the structure will have different degrees of damage, which will change the seismic performance of the structure. It is not difficult to find from Figure 4 that the exceedance damage probability of each failure state under low temperature conditions is significantly higher than that under normal temperature and high temperature conditions. This is mainly because low temperature will affect parameters such as elastic modulus and compressive strength of the bridge tower, resulting in an increase in the tower stiffness and a decrease in displacement ductility, and ultimately a decrease in the seismic performance of the bridge tower. Compared with normal temperature condition, when the local vibration is in the direction of the bridge, the exceedance damage probability of the bridge tower under high temperature condition is smaller than that under normal temperature condition under slight, moderate, severe and complete failure state.

5 Conclusion

Through the analysis of cable-stayed bridge under various temperature conditions, the following conclusions are drawn:

- (1) With the decrease of temperature, the peak stress and elastic modulus of concrete show an increasing trend, while the peak strain shows a decreasing trend.
- (2) The comparative analysis of seismic vulnerability of bridge tower under different temperature conditions shows that the bridge tower is greatly affected by temperature, and its failure probability increases with the decrease of temperature.
- (3) With the increase of earthquake intensity, the failure probability of bridge tower structure increases significantly, showing the same law. Therefore, it is necessary to consider the influence of temperature on the seismic performance of the bridge.

Acknowledgments

This work was financially supported by the:

(1) 2022 Autonomous Region key Research and Development Plan Yellow River Basin Ecological Environment Protection and high-quality development of science and technology support special "Yellow River Ningxia Highway Cable-stayed Bridge Green low-carbon construction and maintenance key technology Research" (Grant No.2022BEG02056)

(2) Education Science and Technology Innovation Fund of Gansu Province (2022A-033)

(3) Tianyou Postdoctoral Foundation, Lanzhou Jiaotong University (TYBSH_KJ_202306)

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