

Research on seismic isolation control of long-span mid-supported CFST arch bridge

Hou Chao¹, Zhong Tieyi^{1*}, Xincheng Chen¹, Hongbin Li¹, Jiawei Wang¹

¹ School of Civil Engineering, Beijing Jiaotong University, Beijing, 100044, China

*Tieyi Zhong's e-mail: tyzhong2012@163.com

Abstract: The seismic problem of long-span arch bridges has attracted great attention at home and abroad in recent years and the technology of seismic isolation provides an effective way for seismic protection of long-span arch bridges. In this article, a practical arch bridge is taken as the object of research. The parameters of the friction pendulum support and buckling-restrained brace are analyzed, and the damping effect of friction pendulum support, buckling-restrained brace and friction pendulum support combined with buckling-restrained brace are compared and analyzed. It turns out that the friction pendulum support and the buckling-restrained brace have a good damping effect on the seismic response of the transverse bridge, and the damping effect on the inward force and displacement response of the arch bridge which applies both friction pendulum support and the buckling-restrained brace is better than that of the bridge which applies the friction pendulum support or buckling-restrained brace alone.

1. Introduction

In China, it makes the long-span arch bridge to be the main type of bridge in the southwestern parts due to its special Geographical environment. At the same time, the devastating earthquakes mainly occurs in the southwestern region, accounting for more than 80%.

The CFST arch bridge improves the resistance of materials to deformation by means of combining the fine tensile resistance of steel and high-quality compressive strength of concrete. On the other hand, if the resistance of the arch bridge is repeatedly increased, it will lead to the malignant result of the structural resistance to earthquakes and the increasing seismic response of the structure.

The rapidly evolving technology of structural vibration control is designed to mitigate the seismic response of structures. In terms of bridges' structure, the vibration control mainly adopts the appropriate control method and lets the control system and the structure itself work together to achieve the purpose of resisting external excitation, thereby reducing the vibration response of the structure. However, there is no systematic study on damping control in large-span arch bridges. Therefore, the study of seismic isolation control for long-span arch bridges and its corresponding reference for seismic isolation design has urgent practical significance and value.

In this paper, a practical large-span CFST arch bridge is used to analyze the three schemes of friction pendulum supports, buckling-restrained braces and friction pendulum supports combined with buckling-restrained braces, and then the corresponding conclusions and recommendations are given.

2. Project overview and model building

2.1. Project overview



The bridge is a mid-supported CFST arch bridge with a span ratio of 1/3.84 and the arch axis coefficient of 2.1, and arch axis is a catenary line. The arch bridge adopts a basket arch structure with an inner inclination angle of 4.6091 degrees. The center distance between the arch rib and dome is 7m, and the center distance of the arch is 25m. The height of the dome is 8.8m and that of the arch is 15m. The overall layout of the span-type CFST arch bridge is shown in the figure 2-1.



Figure 2-1. General layout of the long span half-through CFST arch bridge

2.2. Model building

Based on the ANSYS finite element software, the spatial finite element analysis model of the long-span mid-supported CFST arch bridge is established. The ribs of CFST are simulated by the converted section method. In the finite element model, the arch ribs, the webs, the flat joints, the cross braces, the side piers and the main beams are all simulated by three-dimensional beam elements. The suspension rods are simulated by rod elements, and the support is simulated by a spring unit. The second stage dead load is simulated by the mass unit mass21, and the constraints at the arch, the abutment and the bottom of the side pier are fixed.

2.3. Analysis of self-vibration characteristics

In general, the first several low-frequency natural vibration mode of the structure plays a major role in controlling the dynamic characteristics of the structure itself. The following conclusions can be drawn from the analysis:

1) The bridge has a low first natural frequency, which indicates that the integral rigidity of the bridge is soft. The first ten-order self-vibration period of the bridge ranges from 0.89s to 4.67s, avoiding the characteristic period (0.45s) of the site where the bridge is located.

2) The statistic shows that the out-plane stiffness of the bridge is much smaller than the in-plane stiffness. Therefore, attention should be paid to the lateral stiffness and lateral stability of long-span CFST arch bridges in design.

3. Analysis of corresponding parameter

3.1 Selection of seismic wave

The seismic intensity of the bridge span of the long-span mid-supported CFST arch bridge is 8 degrees, and the characteristic period of the ground motion response spectrum is 0.45s. In this paper, the ground motion acceleration with a 50-year probability of surpassing 2% is used as the input seismic wave, and the ground motion peak acceleration is 0.4g. In this paper, based on the generated response spectrum curve, two actual seismic waves (CHICHI wave and El-Centro wave) on the PEER are selected and an artificial wave is fitted.

3.2 Parameter of friction pendulum support

Friction pendulum system/bearing is an effective friction sliding isolation system. The principle of

FPB's isolation and energy dissipation is that it uses a concave spherical sliding surface to extend the vibration period of the structure, which aims to avoid the excellent cycle of input seismic waves and reduce the response of bridge structures. It will also consume most of the seismic energy and it has an automatic reset function, which can effectively limit the displacement of the friction pendulum support.

In this paper, the double sliding surface friction pendulum support is arranged at all 12 supports of the intercostal beam, the side pier and the abutment. The radius of curvature of the friction pendulum support selected is 4, 5, 6m, and the friction coefficient is 0.01, 0.03, 0.05. By means of cross-contrast analysis, the response to earthquakes and displacement of cross bridge are shown in figure 3-1~3-2.

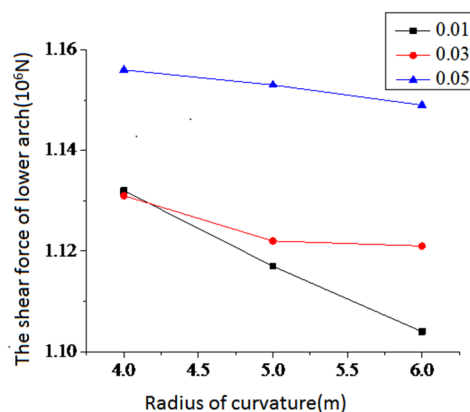


Figure 3-1 The relationship between the transverse shear force of lower arch springing and the parameters of bearing

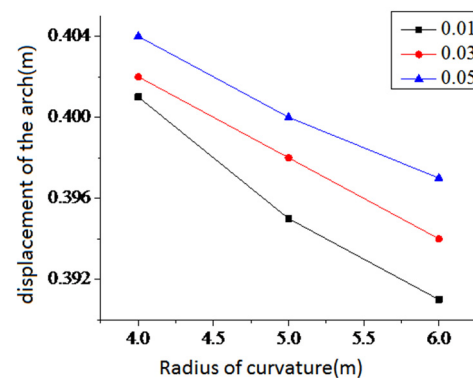


Figure 3-2 The relationship between transverse displacement of arch vault and the parameters of bearing

1) By using the friction pendulum supports, the inward force of the transverse direction decreases significantly with the increase of the curvature radius.

2) The support system of the transverse bridge changes from the fixed system to the active system. The displacements of the support increase significantly but still less than the displacements limit specified by the conventional friction pendulum support. The displacement of the bearing is more sensitive to the friction coefficient than the radius of curvature.

According to the analysis, the seismic response of the bridge needs to consider both the displacement and the damping rate of the bearing. So the curvature radius of the support is 6m and the friction coefficient is 0.03, which is as the optimal parameter of the friction pendulum support.

3.3. Parameter of buckling-restrained brace

The buckling-restrained brace (BRB) is a metal yielding energy-consuming support member consisting mainly of a peripheral constraining sleeve, a core steel, and an unbonded insulation material therebetween. In the range of elastic deformation, the BRB is the same as the traditional support. When the seismic load is strong, the core steel support enters the plastic deformation stage without being destabilized due to the constrained effect. Therefore, the BRB have the ability of energy consuming of the metal damper and can achieve sufficient yield under the action of tension and pressure with a full hysteresis curve stable which are obviously better than ordinary steel support.

Three options are proposed for buckling-restrained brace arrangements in the article:

Option one: Replace the X-type and K-type common supports between the arched springing and L/5 (L is the span) with BRB.

Option two: Replace the single slanted bar common support between L/5 and 2L/5 with BRB.

Option three: Adding additional single slanted BRB between the 2L/5 of the arch ring to the dome.

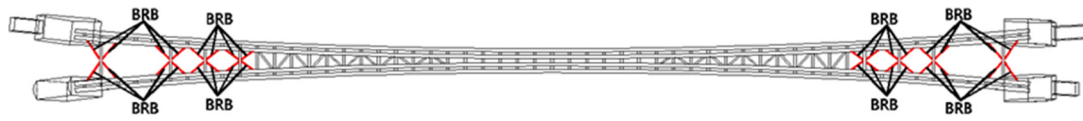


Figure 3-3. The first condition: layout of BRB in Bridge

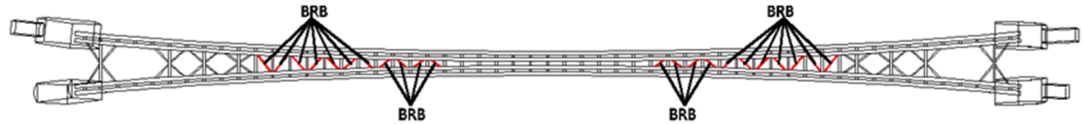


Figure 3-4. The second condition: layout of BRB in Bridge

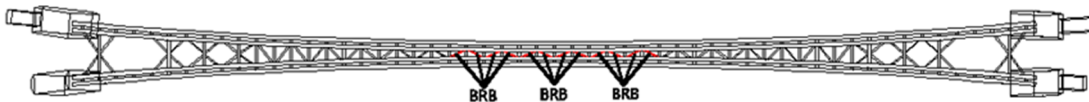


Figure 3-5. The third condition: layout of BRB in Bridge

In this paper, the BRB of different yield parameters (1000, 2000, 3000, 4000 and 5000kN) are selected for comparative analysis and the response to earthquake and the displacement of the transverse bridge are shown as follows.

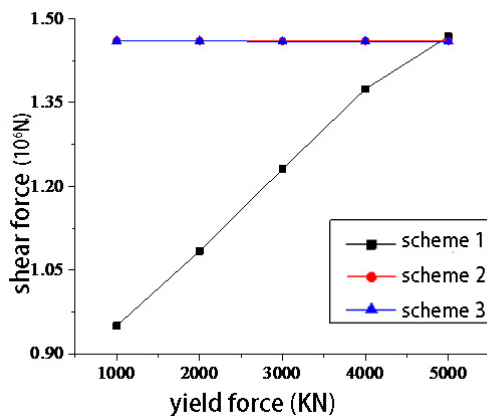


Figure 3-6 The relationship between transverse shear force of upper arch springing and the parameters of BRB

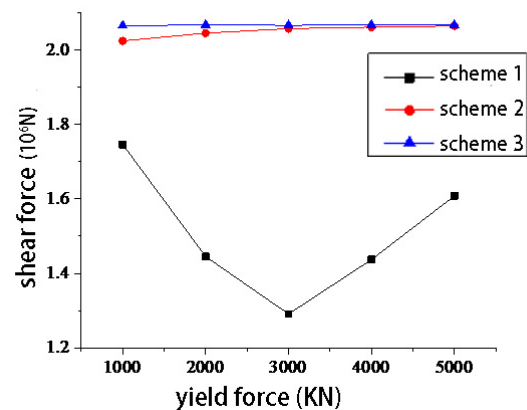


Figure 3-7 The relationship between transverse shear force of lower arch springing and the parameters of BRB

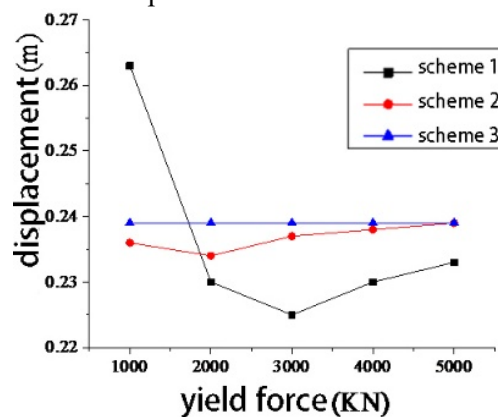


Figure 3-8 The relationship between transverse displacement of L/4 arch rib and the parameters of BRB

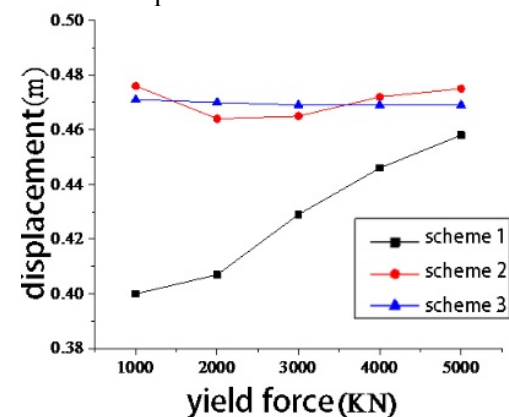


Figure 3-9 The relationship between transverse displacement of arch rib vault and the parameters of BRB

1) Through comparing the results under the different options, the seismic response of the arch bridge is not obvious decrease under option two. It increases the inward force of the transverse bridge on the cross-section near the vault, but doesn't significantly reduce the seismic response of dangerous sections of arches or others under option three. It can significantly reduce the seismic response of the arch bridge under option one. Consider various situations and select the option one.

2) It can be seen that the lower arch rib section is more dangerous than the upper one. The use of the BRB with lower yield force is likely to cause premature yield failure, which is also the reason why nonlinear response of the lower rib bending moment appears. Therefore, for the inward force of the arch bridge, the buckling-restrained brace with a yield force of 3000 KN should be used when adopting the option one.

4. Comparative analysis of seismic isolation scheme

This section adopts the optimal parameters of the previous analysis. It separately sets the friction pendulum support, separately sets the buckling-restrained brace, and combines the friction pendulum support with the buckling-restrained brace. Then combined with other combination schemes, the Seismic isolation effect of transverse direction of bridge are analyzed. The seismic response and displacement of transverse bridge are shown below.

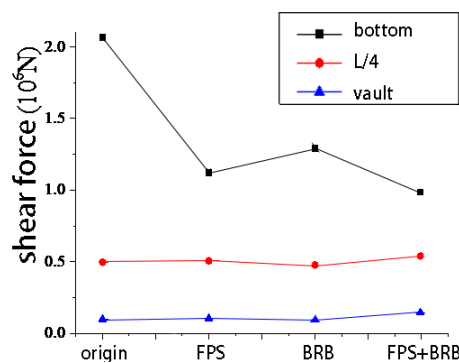


Figure 4-1 The relationship between transverse shear force of the lower arch springing and damping system

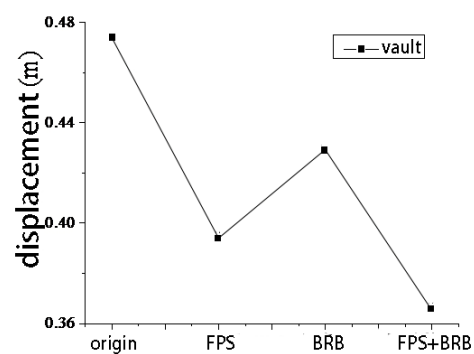


Figure 4-2 The relationship between transverse displacement of arch vault and damping system

1) Comparing the seismic response of the transverse direction, for the internal force of the lower arch springing and the transverse displacement of the arch ring, the damping effect of the friction pendulum support is obviously better than the buckling-restrained brace.

2) The damping effect of the friction pendulum support combined with the buckling-restrained brace on the transverse force and the transverse displacement is better than using the friction pendulum support alone or the buckling-restrained brace alone.

5. Conclusion

1. The friction pendulum support releases the constraint of the fixed bearing in the lateral direction, which has a good effect of seismic isolation. The seismic response of the arch springing is effectively mitigated, and the effective transmission of the response between the upper and lower arch ring can be coordinated. It makes the superstructure more integrated, the response is transferred gradually upward to the position of the crown, and the internal force of the arch springing decreases significantly with the increase of curvature radius, which makes full use of the section to increase the seismic capacity.

2. There is great difference in the different layout Scheme of buckling-restrained brace on the damping effect of the long-span half-through concrete filled steel tubular arch bridge. This paper has compared the damping effect of buckling-restrained brace in three layout schemes, and it is suggested that for the long-span half-through concrete filled steel tubular arch bridge, the buckling-restrained brace should be arranged between the springing and L/5 on arch ring.

3. The friction pendulum support and buckling-restrained brace have a great damping effect on the seismic response in the lateral direction. When the friction pendulum support or buckling-restrained brace doesn't meet the seismic response requirements of arch ring in the lateral direction, it is suggested to use the buckling-restrained brace in combination under the premise of setting the friction pendulum support.

Acknowledgments

This study is sponsored by the Science & Technology Research Development Project of China Railway (Grant No.2015G002-B, Grant No.2010G004-I).

References:

- [1] Yun Zhou, Xinping Li. (1997) New measures for bridge damage, shock absorption and disaster prevention. In: World Earthquake Engineering. 13(1): 8-15.
- [2] Hai Zhang, Li Jiao. (2002) Summary of development of bridge structure vibration control. In: Journal of Shenyang Institute of Vibration Absorption Engineering. 18(1): 15-18.
- [3] Yoshino T, Karino Y. (1976) Experiment study on shear wall with braces. Part 2 Summaries of technical papers of annual meeting. Architectural Institute of Japan, Japan.
- [4] Wakabayashi M, Nakamura T, Katagihara A, et al. (1973) Experimental study on the elast-plastic behavior of braces enclosed by precast concrete panels under horizontal cyclic loading. Kinki Branch of the Architectural Institute of Japan, Japan.
- [5] Shengkui Di, Jia Wang. (2013) Seismic behavior and seismic analysis of long-span CFST tied arch bridges under multi-dimensional earthquakes. In: Lanzhou University of Technology, Lanzhou.
- [6] Liangdao Wei. (2011) Seismic analysis of long-span railway CFST arch bridges. In: Lanzhou Jiaotong University, Lanzhou.
- [7] Xiangli Kong. (2008) Seismic performance analysis of different models of long-span mid-supported CFST arch bridges. In: Hehai university.
- [8] Youdong Kong. (2017) Research and application of concrete filled steel tube structure and its latest development. In: Industrial building. 2017(1):332-334.