SEIMIC DESIGN OF A LONG-SPAN CONTINUOUS STEEL TRUSS BRIDGE

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Abstract

The main bridge of the Songpu Bridge across the Huangpu River in Shanghai is a long-span continuous steel truss bridge with span arrangement (96+112+112+96)m. After widening and reconstruction, the self-weight of the bridge superstructure was increased significantly, but the pile foundation was difficult to be strengthened due to the strict conditions. The preliminary seismic checking shows that the bearing capacity of the pile foundation is not enough and some rods will produce plastic deformations under E2 earthquake according to the current seismic specifications, so it is necessary to conduct the seismic design of this bridge after widening and reconstruction. Considering that the bridge lacks the necessary ductility components and the easy repair requirements after earthquake, the seismic isolation design is the best choice. In this paper, the seismic design and comparison of the bridge with friction pendulum bearings and cable-sliding aseismic bearings are carried out, and the key design parameters of these two isolation schemes and the comprehensive seismic isolation effect are studied. It is found that the isolation effect of the friction pendulum bearings on this bridge is better than the cable-sliding aseismic bearings, with smaller structural displacements and larger plastic energy consumption, but the former is always in complex stress with complicated and expensive installation process. Meantime, the cable-sliding aseismic bearings use the free stroke to dissipate earthquake energy and the structural displacements are relatively larger, but it is easy to be installed and replaced with great economic benefits. The results of this paper will provide the necessary technical supports for the seismic design of the widening and reconstruction bridge.

Keywords: Truss bridge, seismic design, friction pendulum bearing, cable-sliding aseismic bearing

1 Project Overview

The main bridge of the Songpu Bridge in Shanghai is a continuous steel truss bridge with the span arrangement of 96m+112m+112m+96m, the standard truss height is 12.8m, the main truss internode is 8m and the middle distance of the main truss is 6.018m with 6-meter high stiffening chords installed on the 1#, 2# and 3# pile foundations. The concrete-filled steel tubular pile foundations with 1.25 meters in diameter are adopted below the pile caps in the water, while the end piers (0# and 4#) are supported on the 1.25-meter-in-diameter drilling cast-in-place pile foundations.

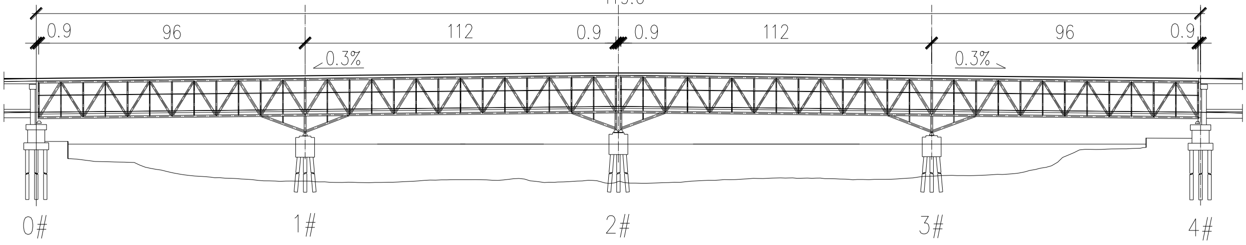


Fig.1 Elevation of the Main Bridge of the Songpu Bridge

In order to make full use of the existing traffic resources, and considering the fact that some bridge components have suffered varying degrees of damage owing to the past service period, necessary retrofit has firstly conducted. The self-weight of the bridge superstructure is obviously increased after widening and reconstruction, yet it is difficult to reinforce the old pile foundations because of the strict construction conditions, which may adversely affect the seismic performance of the bridge. Meantime, the bridge after widening and reconstruction has to meet the current Chinese bridge seismic specifications[1], which asks for a due seismic study of the reconstructed bridge.

2 Analysis model and input waves

2.1 Analysis model

The analysis model of the bridge is built by SAP2000 shown in Fig. 2, and the coupling effect of the approach bridge at the two ends is also considered. The main truss, the bridge deck system and the piers are all simulated by beam elements. The pile cap is similarly simulated as a rigid body with mass concentrated in its centroid, and the centroid of the pile cap is rigidly connected to the pile foundation simulated by 6-dof soil springs. In addition, the secondary dead load is applied uniformly to the bridge deck system. This paper takes the longitudinal direction to the X-axis, the transverse to the Y-axis and vertical Z-axis.

Fig.2 Analysis Model

2.2 Input waves

The continuous steel truss bridge is located on IV soil type site, the seismic fortification intensity is 7 degrees and the characteristic period T_g is 0.75s. Meantime, the maximum acceleration S_{max} of the horizontal response spectrum is 0.16g for earthquake level 1 with a return period of 75 years (E1 earthquake) and 0.48g for earthquake level 2 with a return period of 1000 years (E2 earthquake) according to the current bridge seismic specification[1], respectively. The ground motion inputs include the longitudinal direction coupled with the vertical direction (L+V) and the transverse direction coupled with the vertical direction (T+V), in which the vertical acceleration is taken as 0.65 times of the horizontal acceleration. The acceleration response spectrum and a time-history curve of E2 earthquake are shown in Fig. 3.

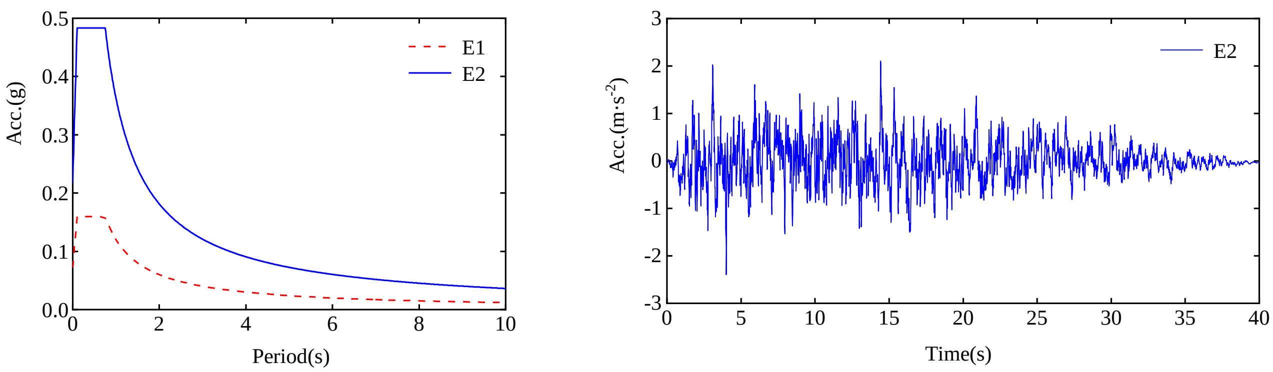


Fig.3 Earthquake Response Spectrum and Time History

3 Seismic design

For the bridge after widening and reconstruction, the seismic performance has to be checked to determine whether it meets the fortification requirements and performance objectives shown in Table 1.

Table 1 Seismic fortification criteria and performance objectives

Fortification level	Performance objectives	Seismic requirements
E1	Elastic	The main truss remains elastic, and the moment of each pile foundation is less than the initial yield moment
E2	The main truss remains elastic, and the pile foundations can continue to be used without repair or with simple repair	The main truss remains elastic, and the moment of each pile foundation is less than the equivalent yield moment

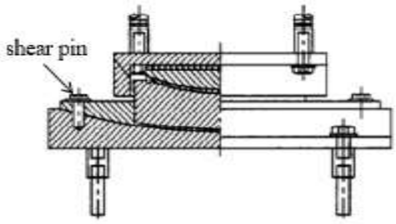
Considering the sliding friction effect of the spherical bearings, the nonlinear dynamic analysis with the Rayleigh damping is carried out by Newmark-β method. Under E1 earthquake, the main truss and the pile foundations meet the seismic requirements and performance objectives. But under E2 earthquake, some rods fail to remain elastic, and the 1#, 2# and 3# pile foundations also fail owing to the insufficient bending capacity and the excessive pulling forces.

Considering that spherical bearings will be sheared off and become sliding bearings under the E2 earthquake, all checking targets will meet the seismic requirements. However, excessive bearing deformations may occur and cause collision between the adjacent spans or falling off span. Therefore, the seismic design of the bridge after widening and reconstruction has to be conducted, and seismic isolation design is a better solution compared with ductile seismic design in terms of the post-earthquake performance.

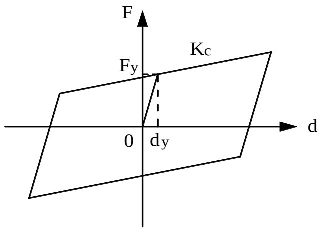
4 Comparison of seismic isolation design schemes

4.1 Seismic isolation design

The friction pendulum bearings shown in Fig. 4a are used in the first scheme. This bearing can effectively control the structural displacements with a certain post-yielding stiffness, and the residual deformation of the bearing is comparatively small[2][3]. The constitutive model of this bearing is shown in Fig. 4b, and the bilinear ideal elastoplastic spring element is used. This scheme takes the friction coefficient μ=0.05, the yield displacement d_y=0.0025m. At the same time, the isolation period T should not be less than twice times the dominant period of the bridge referred to the related paper[4], and considering that the middle distance of the two main truss of the bridge is only 6.018m, so the chosen isolation period T is 3s.



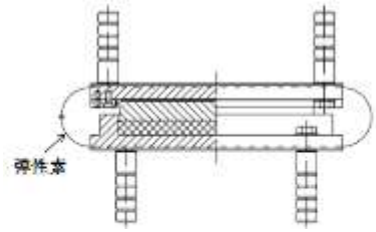
(a) bearing



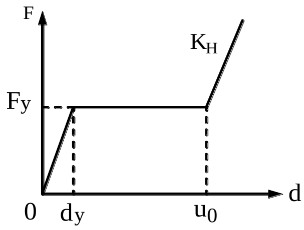
(b) constitutive model

Fig.4 Friction Pendulum Seismic Isolation Bearing

The cable-sliding aseismic bearings are used in the second scheme shown in Fig. 5a. Under strong earthquake, the cable-sliding aseismic bearing tends to be sheared off, becoming sliding bearing and extending the self-vibration period of the bridge to realize the isolation effect, and the energy will be consumed by the friction of the sliding surface. The relative displacement between the pier and the beam is restricted, and the falling beam is prevented by the elastic cable[5][6]. The constitutive model, as shown in Figure 5b, can be regarded as the combination of the sliding bearing and the elastic cable, and the bilinear ideal elastoplastic spring element and multi-linear elastic element are parallel to simulate it. This scheme takes the friction coefficient μ=0.02, the yield displacement d_y=0.003m, and the free stroke u_0 of the elastic cable is equal to the maximum bearing deformation during operation, which is 120mm. Meantime, the parametric optimization analysis is carried out according to the relevant paper[7], and the horizontal stiffness of the cable K_H is finally selected as 1.5×10^5kN/m.



(a) bearing

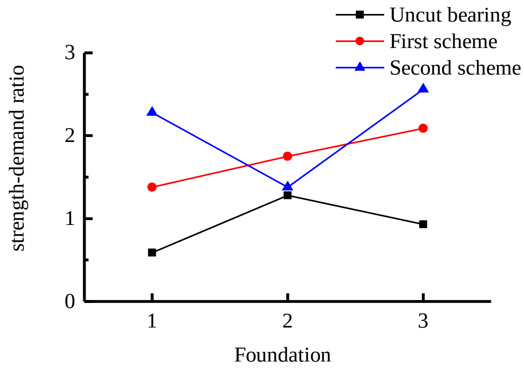


(b) constitutive model

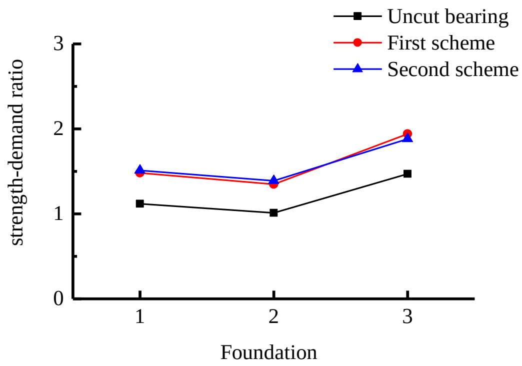
Fig.5 Cable-sliding Friction Aseismic Bearing

4.2 Isolation effect

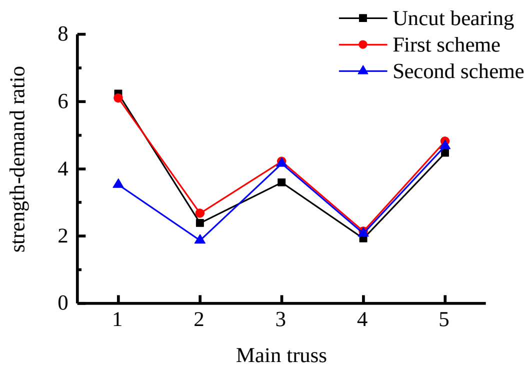
The isolation effects of both schemes under E2 earthquake are compared with the original scheme when bearings are uncut, and it can be seen that both the friction pendulum bearing and the cable-sliding aseimic bearing are able to significantly reduce the seismic response of the pile foundations. However, the friction pendulum bearing can effectively improve the strength-demand ratio of each pile foundation with uniform isolation effects, but the ratio of 2# pile foundation of the second scheme is obviously less than others owing to the great seismic force produced by the elastic cable of the cable-sliding aseimic bearing. For the main truss, both bearings can significantly reduce the seismic response of key rods, especially under T+V input.



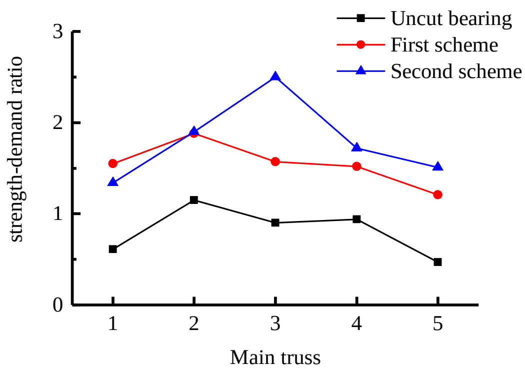
(a) Foundation：L+V



(b) Foundation：T+V



(c) Main truss：L+V

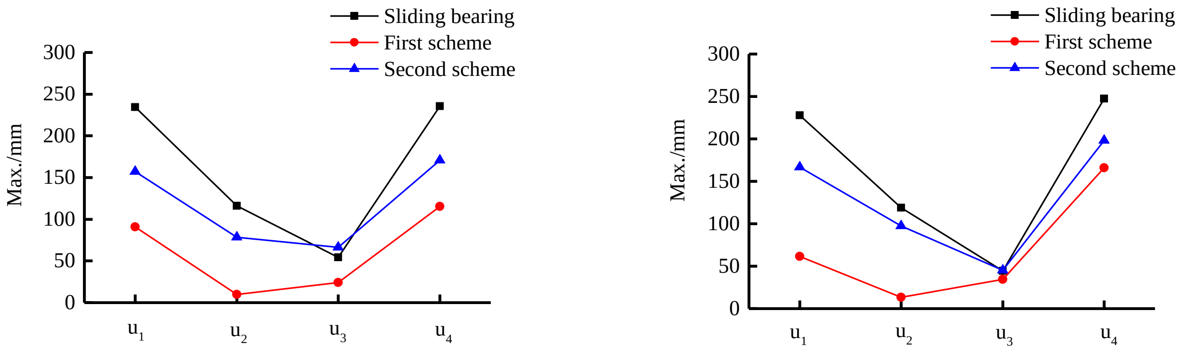


(d) Main truss：T+V

Fig.6 Comparison of Isolation Effects

4.3 Spacing effect

As shown in Fig. 7, Compared with the condition when the bearings are sheared off, both the friction pendulum bearing and the cable-sliding aseimic bearing can effectively control the bearing deformations and structural displacements under E2 earthquake. Because the free stroke of the cable-sliding aseimic bearing is up to 120mm and the friction pendulum bearing has excellent self-centering and energy-dissipation ability, so bearing deformations and structural displacements of the second scheme are greater than the first scheme.



(a) L+V (b) T+V

(u_1: Beairng deformation; u_2: Residual deformation of the bearing; u_3: Relative displacement between the adjacent bridge span; u_4: Relative displacement between the main bridge and the approach bridge)

Fig.7 Comparison of Spacing Effects

5 Conclusion

（1）For bridges after widening and reconstruction, the mass of the superstructure is significantly increased, while foundations can not be strengthened because of the strict construction condition. Considering the easy repair performance after the earthquake, the seismic isolation design is a good choice.

（2）The friction pendulum bearings show great isolation effect with comparatively small structural displacements, but they are in complex stress condition, camplicated to be installed and expensive. While the cable-sliding aseismic bearings use the free stroke to dissipate energy, and structural displacements are relatively large, but they are simple, easy to be installed and replaced with great economy.

References:

[1] Chongqing Communications Technology Research & Design Institute CO., LTD. Guidelines for Seismic Design of Highway Bridges[M]. China Communications Press, 2008. （In Chinese）

[2] Ministry of Transport of the People’s Republic of China. Friction pendulum seismic isolation bearing for highway bridge (JT/T 852-2013). Beijing: People’s Communications Press 2013. （In Chinese）

[3] Dicleli M, Mansour MY. Seismic retrofitting of highway bridges in Illinois using friction pendulum seismic isolation bearings and modeling procedures. Eng Struct 2003;25(9):1139-1156.

[4] LIU Feng, WANG Zhen-hai, WANG Zhe. Parameter Analysis of Seismic Isolation Design of Continuous Bridge Based on Friction Pendulum[J]. Journal of Chongqing Jiaotong University(Natural Science), 2015, 34(6):8-13. （In Chinese）

[5] YUAN Wan-cheng, WEI Zheng-hua, CAO Xin-jian, et al. Cable-sliding Friction Aseismic Bearing and its Application in Bridge Seismic Design[J]. Engineering Mechanics, 2011(s2):204-209. （In Chinese）

[6] YUAN Wan-cheng, WANG Bin-bin. Numerical Model and Seismic Performance of Cable-sliding Friction Aseismic Bearing[J]. Journal of Tongji University, 2011, 39(8):1126-1131. （in Chinese）

[7] CHEN Zhi-gang, ZHAO Ying-ce. Study of Transverse Seismic Performance of Rigid-Frame Bridge Using Cable Sliding Friction Aseismic Bearings[J]. Bridge Construction, 2014, 44(2):38-42. （in Chinese）