Passive Control System of a Steel Truss Girder Cable-stayed Bridge

Kehai Wang[1], Qian Li[2], Han Wei[3]

Abstract

Guozigou Bridge is located in Xinjiang Autonomous Region of China. The bridge is a three-span continuous steel truss girder cable-stayed bridge which has a main span length of 360 m and has two reinforced concrete towers which are 209.5m and 215.5m in height respectively. Although floating system was of advantage to the distribution of internal force of the towers, yet relative longitudinal displacements were so large that deformation ability of the bearings at the side piers can't satisfy the demand of potential earthquake. Semi-floating system could reduce the displacement in the longitudinal, but the results weren't perfect still, so viscous dampers were set at the side piers and two towers. The present focused on damping coefficient and damping exponent of the viscous damper and its reasonable position. According to the site condition, the effect of the dynamic pile-soil-structure interaction was considered. Through non-linear time history analysis, the results indicated that the relative displacement of key positions and the forces of the bridge were reduced obviously by setting the dampers in longitudinal direction of the bridge.

Key Words: Passive control, Cable-stayed Bridge, Seismic analysis, Dynamic response, Viscous damper

1. Introduction

Guozigou Bridge is located in Xinjiang Autonomous Region of China. The bridge is a three-span continuous steel truss girder cable-stayed bridge. It has a center-span length of 360 m, two side spans of 170m each and a width of 26m. It has two reinforced concrete towers which are H-shaped and four cross beams each, and they are 209.5m and 215.5m in height respectively. Main beam is designed as steel truss girder with the height of 6m. The cables are arranged over two parallel planes using a fan configuration and full bridge has thirteen pairs of cables totally. The height of left side pier is 69m and the right one is 39.6m. The general configuration is showed in Fig. 1.

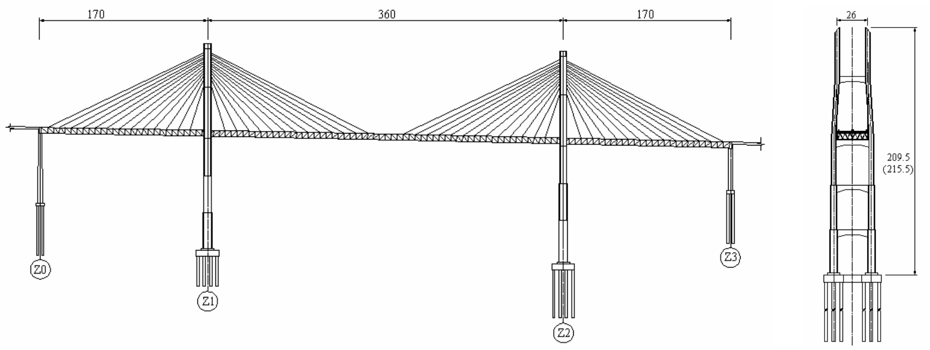

Fig. 1 Elevation of the Guozigou Bridge (units: m)

2. Finite Element Models

A finite element model of the bridge was developed using geometrical and mechanical characteristics of the bridge from the structural design drawings, see Fig. 2.

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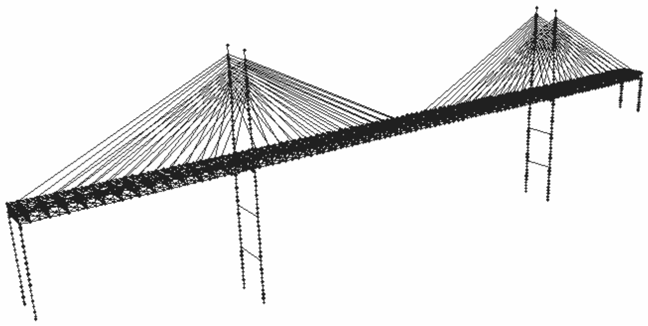


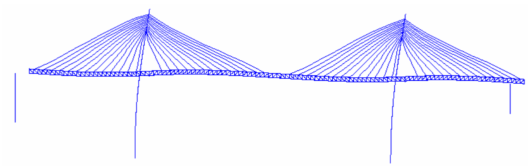
Fig. 2 The 3D finite element model

For this model, truss element was used to present the deck and cables, and beam element is adopted to present the towers, piers and cross beams. The end of the deck is assumed constrained against transverse and vertical motion, but free to displace horizontally along longitudinal direction and rotation about transverse and vertical axes. At the foundation level, six springs were used to consider the pile-soil interaction. In order to consider the effect of the approach bridge, added mass was assigned to the side piers.

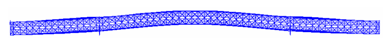
3. Dynamic Characteristics

The dynamic characteristics of the bridge are determined to identify its dominant modes of vibration and to obtain the structural parameters that are needed to select the parameters of the appendage.

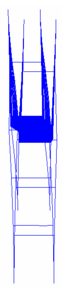
Through the dynamic characteristic analysis, it was observed that some modes were coupled and six modes related to vibration of towers and piers in first 10 modes. Natural period and mode shape above presented that geometrical non-linearity affected first period mainly and made it longer, that is, lateral stiffness of tower is reduced by axial compression.



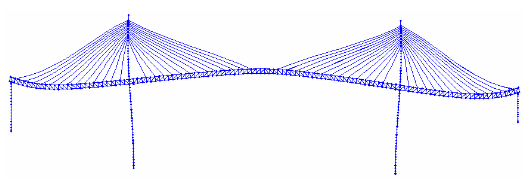
1st mode T=14.66 sec, longitudinal tower mode



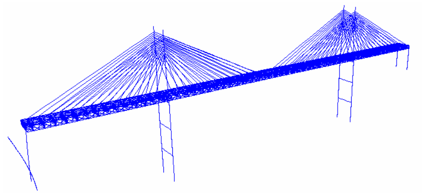
2nd mode T= 4.39 sec, first-order lateral deck mode



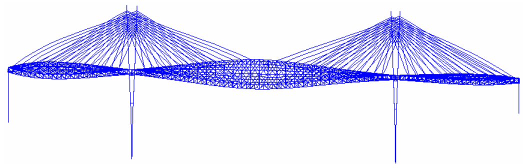
3rd mode T=3.27 sec, transverse tower mode and in the diverse direction



4th mode T=3.06 sec, vertical deck mode



8th mode T=1.82 sec, longitudinal mode of left side pier



10th mode T=1.74 sec, torsion mode

Fig. 3 Mode shape of floating system considered geometrical non-linearity

4. Seismic Analysis of Floating System

Floating system is no constrains between deck and towers and piers, that is, deck can sway freely in the longitudinal direction. The characteristic of such system is that displacement will be larger than semi-floating system and rigid connection system, while internal force due to earthquake load will be smaller than others (Lichu Fan 1997; Xudong Shao 2004).

4.1 Ground acceleration time histories

Dynamic time-history analysis was used to calculate the response of the bridge including forces and deformations. Three acceleration time-history curves obtained by seismic risk analysis were adopted, in which the maximum peak horizontal ground acceleration (PHA) of the ground motion was 282 gal for 5% probability of exceedance in 50 years, see Fig. 4. Three time-history curves having a probability of exceedance of 2% in 50 years were selected and the maximum peak horizontal ground acceleration is 346 gal, see Fig. 5.

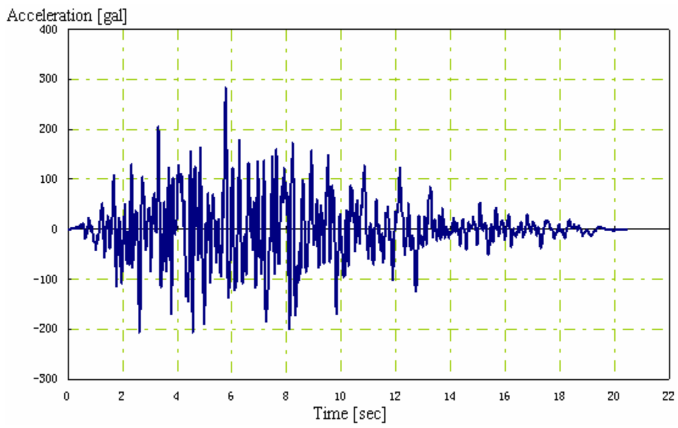


Fig. 4 Ground motion time history (PHA: 282 gal)

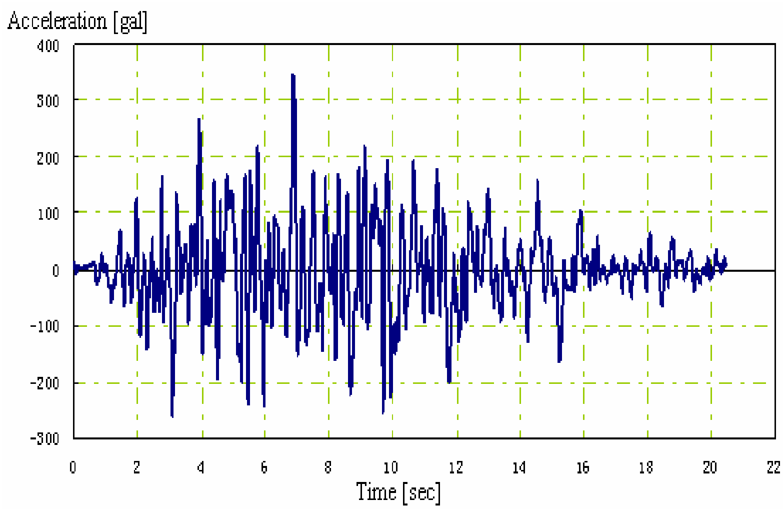
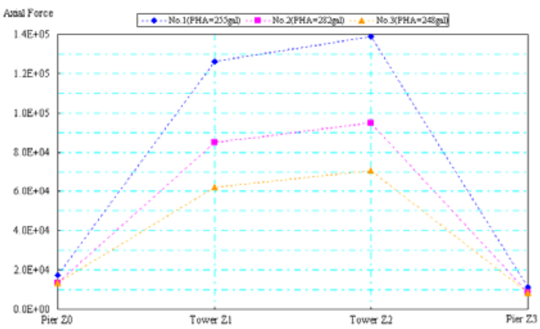


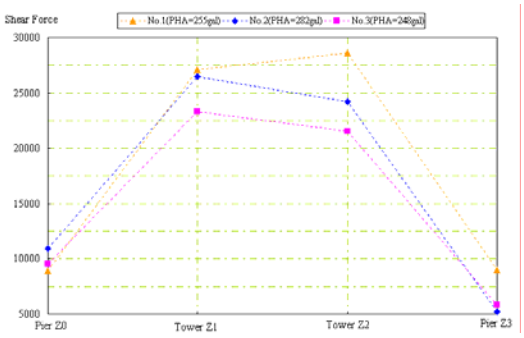
Fig. 5 Ground motion time history (PHA: 346gal）

4.2 Internal force

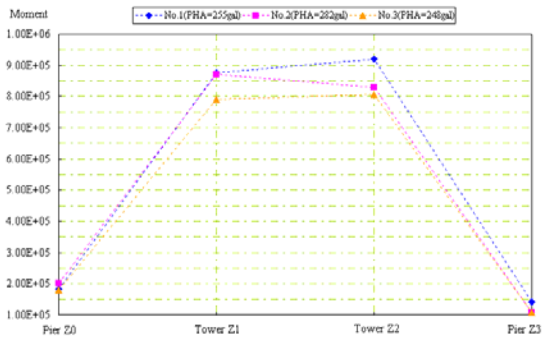
Fig.6 displayed maximum forces got by time-history analysis under earthquakes with 5% and 2% probability of exceedance in 50 years. Response presented that forces in towers are larger than piers and forces distributed in higher pier Z0 are larger than pier Z3 along longitudinal direction. Principle of distribution was same in the transverse direction.



(a) Maximum axial force (Units: kN)



(b) Maximum shear force (Units: kN)



(c) Maximum moment (Units: kN*m)

Figure 6: Internal forces at bottom of the piers and towers under longitudinal and vertical earthquake with 5% probability of exceedance in 50 years

4.3 Relative displacement

Relative displacements in the longitudinal direction under longitudinal and vertical excitation are listed in Table 1. From the results listed, relative displacement was so large that ordinary sliding bearing can't satisfy the demand of deformation and may be destroyed in earthquake. In order to reduce the displacement, elastic cables were added between beam and towers, but this scheme can not achieve the target expected.

Table 1 The maximum relative displacement in the longitudinal direction (units：cm)

Location	5% probability of exceedance in 50 years	2% probability of exceedance in 50 years
Between deck and pier Z0	40.86	106.03
Between deck and tower Z1	33.22	49.11
Between deck and tower Z2	33.08	51.45
Between deck and pier Z3	38.34	74.27

5. Seismic Response of Passive Control System

At present, viscous damper has been applying on many bridges in China, such as Jiangyin Bridge, Egongyan Bridge, Sutong Bridge, Donghai Bridge and so on, and the technical parameters of these dampers were listed in the Table 2. These dampers can reduce effectively the force and displacement of the bridges attacked by earthquake. For passive control system, the parameter of the viscous damper is essential content (Lichu Fan et al 2001). In this paper, positions and two parameters of damping coefficient and damping exponent of the supplemental non-linear viscous dampers were discussed.

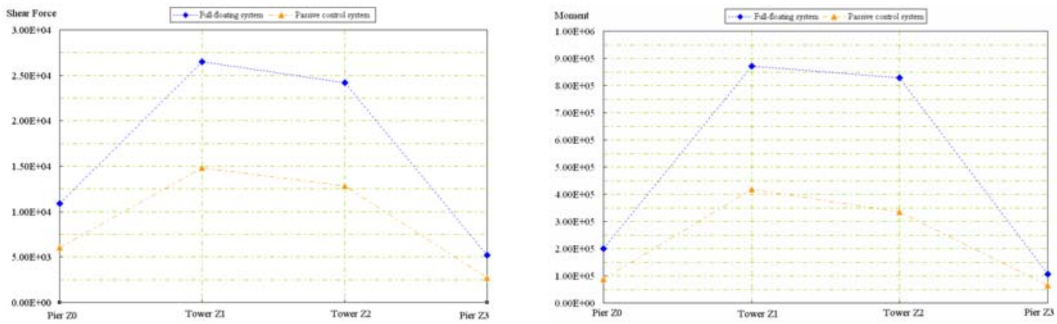
Table 2 Technical parameters of the viscous dampers used in bridges

Project	Structural type	Damping force（kN）	Stroke (mm)
Nanjing 3rd Bridge，Approach Bridge	cable-stayed bridge with a span of 648m; The type of approach bridge is continuous girder bridge and the maximum span is 58m	±150	±120
Sutong Bridge	Cable-stayed bridge with a span of 1088m	±3025/±6580	±850
Jiangyin Bridge	suspension bridge with a span of 1385m	±1000	±1000
Donghai Bridge	cable-stayed bridge with a span of 420m	±2000/±2500	±500/400
Egongyan Bridge	suspension bridge with a span of 600m	±2000	±550
Lupu Bridge	steel arch bridge with a span of 550m	±2000	±200
Shanghai Yangtze River Bridge	cable-stayed bridge with a span of 730m	±2400	±600

According to the engineering experience (Kehai Wang 1999; Kehai Wang et al 2004; Kehai Wang 2007), we put the viscous dampers at two towers firstly. But relative displacement of bearings on the top of the piers will not be reduced obviously. So we put the dampers at side piers and towers just like dampings for Donghai Bridge. Through non-linear analysis, reasonable parameters were determined: damping coefficient $C = 1500$, damping exponent $\xi = 0.2$, and the maximum damping force is about 1500kN.

5.1 Internal force of passive control system

Under longitudinal and vertical excitation, maximum structural responses were showed in Fig.7. The results indicated that internal forces were reduced obviously, especially forces in the side piers were improved for viscous damping set on the top of the piers.



(a) Maximum shear force (units: kN)　　(b) Maximum moment (units: kN*m)

Figure 7: Internal forces at bottom of the piers and towers under longitudinal and vertical earthquake with 5% probability of exceedance in 50 years

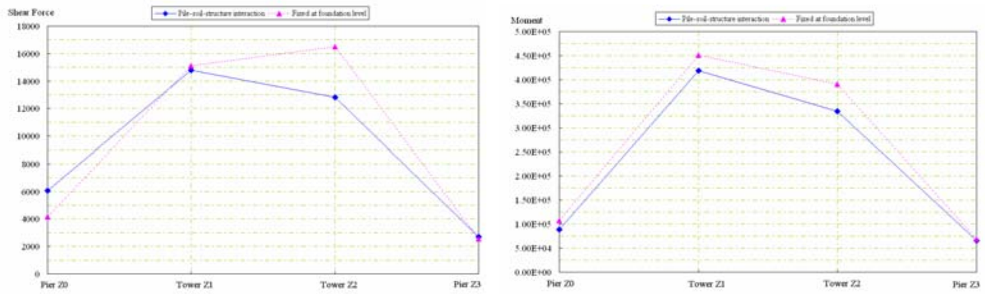
5.2 Relative displacement of passive control system

Table 3 Relative displacement（units：cm)

Location	5% probability of exceedance in 50 years	2% probability of exceedance in 50 years
Between deck and pier Z0	15.0	28.2
Between deck and tower Z1	12.9	22.0
Between deck and tower Z2	11.3	23.4
Between deck and pier Z3	13.3	28.6

5.3 Analysis for effect of pile-soil-structure dynamic interaction on passive control system

Effect of pile-soil-structure dynamic interaction was analyzed with the same parameters of viscous dampers as above, but the towers and piers are assumed fixed at the foundation level. Moment and shear force were showed in Fig. 8 and relative displacement in the longitudinal direction were listed in Table 4. The results indicated that moment and shear force in the longitudinal direction would be increased and the relative displacement would be reduced if the effect of pile-soil-structure dynamic interaction was not considered. Difference between two boundary conditions is markedly, error in force can achieve 10%~30% and that in displacement is about 6%.



(a) Maximum shear force (units: kN)　　　(b) Maximum moment (units: kN*m)

Figure 8: Internal forces at bottom of the piers and towers under longitudinal and vertical earthquake with 5% probability of exceedance in 50 years

Table 4 Relative Displacement (2% probability of exceedance in 50 years)

Location	Fixed at the foundation level (cm)	Considering effect of pile-soil-structure dynamic interaction (cm)	Comparing （%）
Between deck and pier Z0	25.47	28.2	9.68
Between deck and tower Z1	20.58	22.0	6.45
Between deck and tower Z2	21.98	23.4	6.07
Between deck and pier Z3	26.74	28.6	6.50

6. Conclusions

Steel truss girder cable-stayed bridge is a long period structure, natural period is 14.66 sec, and modes are coupled and six modes related to vibration of towers and piers in first 10 modes. Natural period and mode shape presented that geometrical non-linearity affected first period mainly and made it longer.

In order to get more ideal results, non-linear viscous dampers should be set not only at towers, but also on the top of the piers. The relative displacement and the forces were reduced obviously by setting the dampers in longitudinal direction of the bridge, and which would reduce local damage of components due to the potential pounding neighboring members of the bridge also. And it’s necessary to consider the effect of pile-soil-structure dynamic interaction to get exact response of passive energy dissipation system.

Acknowledgement

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7. References

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