Research overview of application of seismic isolation measures for long span suspension Bridges

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Abstract: From the perspective of structural effectiveness and technology of damping control, this paper comprehensively reviews the research on the energy dissipation and damping control of suspension bridges by domestic and foreign scholars, including damper application, central buckle application and other application measures, which provides reference for the further development of similar research in the future. More and more application of energy dissipation and damping measures in long-span suspension bridges will certainly stimulate the development of this field. It will become an inevitable trend to pay attention to the shock absorption of long-span bridges.

1. Introduction
Suspension bridge is a kind of modern bridge with a long history and it mainly consists of main cable, bridge tower, stiffening beam and sling. With cable as the main load-bearing structure, the vertical gravity from the bridge deck is transformed into cable tension. With simple structure and clear force, it can exert the material characteristics to the maximum extent. It has been the optimal choice of bridge type when the span is over 1000m. Therefore, the design requirements are very high, and special seismic study is needed. There are no provisions which are applicable to long-span suspension bridges in the current codes at home and abroad, so it is of great significance to summarize the existing domestic and foreign scholars' research on the suspension bridge.

2. Application of damper
The function of the damper is mainly to provide damping, which can weaken the energy generated by the structure in the process of vibration, so as to control the displacement and internal force of the structure under earthquake action. Among many kinds of damper, viscous fluid damper, metal damper and magnetorheological damper are mainly used in the study of long-span suspension bridge.

2.1 Viscous damper
Viscous damper is a velocity-related damper, which is made according to the principle of fluid motion, especially when the fluid passes through the throttling orifice. By adjusting the viscosity of internal viscous flow body, the damping force can be adjusted to be proportional to different times of the velocity, and it is a kind of damper which is related to the velocity of piston motion.

Li Zeng [1] studied the seismic performance of medium and large-span suspension bridges. The
The damping effect of viscous damper on suspension bridge is mainly reflected in that it greatly reduces the displacement of bridge tower, especially the relative displacement between tower beams. What’s more, the priority order of the damper on the structure is considered as follows: the relative displacement between the tower beams, the maximum value of the bottom bending moment, the maximum value of the bottom shear force, and the damping maximum speed and maximum damping force. Heqiang Tang, Gongyi Xu and Hanshun Liu [2] analyzed the feasibility of using suspension bridges for railway bridges. In view of the characteristics of railway Bridges in China, relevant Suggestions are put forward: the seismic calculation should meet the requirements of the code, and the damper should be set to make the parameters of the expansion device in the normal range under the action of earthquake and rapid load. Tao Jiang, Zhe Zhang and Wenliang Qiu [3] of Wuhan University of technology analyzed the vibration reduction design of self-anchored suspension bridges and found that: It is a good choice to place the viscous damper at the intersection of the tower and the beam in the small self-anchored suspension bridge. This arrangement can effectively exert the damping effect and is also economical. Based on the principle of seismic displacement control, according to the characteristics of seismic response of long-span suspension bridge structures, Aiqun Li, and Hao Wang [4] established three evaluation functions of seismic displacement control effect and proposed an optimal layout method of damper based on penalty function and first-order optimization principle. The results show that the optimal layout scheme of damper is slightly different for large-span suspension bridges. Du Wu and Zhenxin Li [5] analyzed the parameter sensitivity of damping coefficient and damping index of nonlinear viscous damper and found that: the damping constant and the damping index have a much greater influence on the displacement of the damper than the bending moment on the bottom of the tower. Therefore, the most unfavorable situation of the damper displacement should be considered as much as possible.

Liangji Ma and Yongqi Chen [6] studied the seismic isolation measures of Jiangyin Bridge and pointed out that the viscous damper, as a speed-related energy dissipation device, was set at the maximum structural deformation with obvious displacement control effect. Jukao Yan Tianbo Pen and Jianzhong Li [7] analyzed the design of the shaking table test of the Taizhou Changjiang Highway Bridge and the test results of the seismic structure system. The seismic response of the three experimental models of the unconstrained system, the damper system and the elastic cable system is compared. The results showed that the damper system can more evenly limit the relative displacement of the tower and the beam at the middle tower and the side tower under the artificial wave excitation of the site; and the elastic cable system has better ability to limit the relative displacement of the tower and the beam at the middle tower. Suiwen Wu and Jianzhong Li [8] studied on Tongmai Bridge of Qinghai-Tibet Highway and found that: The viscous damper can effectively reduce the longitudinal displacement of the longitudinally slidable single tower anchored suspension cable bridge end, and can reduce the ground motion axial force of the tower bottom. Fei Wang, Minghai Pei, Jian Ma and Zhengrong Li [9] designed and adopted a two-stage seismic design to explore the influence of damper parameters on seismic response based on the seismic fortification standards of large-span bridges at home and abroad.

It is shown that by comparing the relative displacement of the tower beam under the damping parameters, the bending moment and the shearing force of the tower bottom, it is proper that the damper index is 0.3-0.5, and the damping coefficient is 4000-8000.

2.2 Metal damper
CC McDaniel, CM Uang, F Seible[10] studied San Francisco – Oakland Bay Bridge, New San Francisco, USA. In the newly built self-anchored suspension bridge on the east bank, a shock-absorbing energy member called a shear link is installed on the main tower, which is equivalent to three side-by-side shear plate dampers. It is found that in strong winds or strong earthquakes, these metal dampers undergo shear deformation, which dissipates seismic input energy and attenuates structural vibration. Besides, it allows the steel joints of the four steel sleeves of the main tower to form a shear joint to yield the tower legs.
A.S.NAZMY, A.M.ABDEL-GHAFFA Rand S.F.MASRI [11] evaluated the seismic modification plan of the Vincent-Thomas suspension bridge in the United States. The retrofit scheme includes the use of longitudinal damper in the span of suspension cable and the limitation of axial force in the stiffening truss member. In addition, there are other dampers placed between the trusses and towers and between the trusses and the cable racks. Through the research, it is found that the metal damper on the side span is an effective measure to reduce the seismic response of truss.

Jun Yang [12] and Shibin Kang [13] studied on the application of metal damper by using the Yellow River Road Bridge in Chaoyang City as a model. Metal energy dissipators are set at the junction of the tower beam. There are four metal energy dissipators in total. It is found that setting energy dissipator at the junction of the tower beam can not only reduce the displacement of the main beam, but also enable the inertial force of the main beam under seismic action to pass directly from the height of the beam to the main tower, reduce the height of the inertial force, reduce the force on the base of the main tower, and protect the main tower. MJ Abrahams, JK Tse[14]modeled and analyzed the of seismic strengthening and reinforcement of the Lion’s Gate Bridge. The design of restraining impact effect is realized by combining TADAS metal damping equipment on the base of bridge pier.

2.3 Magnetorheological Damper

The MR damper is made of sub-nanometer intelligent material-magnetorheological fluid. By adjusting the magnetic field intensity of the application of magnetorheological fluid, the magnetorheological fluid can inversely convert from liquid to semi-solid, thus producing variable damping, which has the characteristics of intelligent damper.

Kui Ouyang [15] installed MR damper horizontally between the tower beams, compared three different installation positions of the MR damper, and concluded that as the number of MR dampers installed at the tower beam increases, the longitudinal displacement response of the main beam decreases. With the increase of MR damper number, the mechanical properties of the structure gradually transformed from the sliding connection form of the tower beam to the main and subordinate connection form of the tower beam. The damper is arranged at the connection between the main tower and the main girder, and connected with the main tower and the main girder through the support. In the case of the input of vertical seismic wave, the structural vibration control of MR damper can significantly reduce the longitudinal displacement of the main beam, and the damping effect is relatively obvious. The damping effect of the longitudinal displacement of the main girder is related to the optimal active control force. With the increase of the active control force, the damping effect of the longitudinal displacement of the main beam is better.

3. Application of central buckle

An effective measure to improve the stiffness of the suspension bridge is to set a central buckle at its mid-span position, that is, to buckle the main beam and the main cable [14]. The central deduction has evolved into three forms [15]: (1) The main beam is connected to the main cable in a relatively stable connection manner at a mid-span position, which is called a rigid central buckle; (2) Connection by means of limited longitudinal displacement, which is called flexible central buckles; (3) The main beam and the main cable are directly consolidated at the center of the span. Many bridge in Europe and the United States tend to use rigid central buckles. In Japan, the flexible central buckle is widely used [16].

Wanghu Peng[17] deduced the vibration differential equation of the continuous suspension bridge with the central buckle. It is pointed out that in the anti-symmetric torsional vibration, the main cable will generate an anti-weighing additional cable force before and after the central buckle, thus increasing the frequency of the vibration mode. Hao Wang [18] studied the dynamic performance of the suspension bridge. It is pointed out that the setting of the central buckle increases the structural rigidity, and the corresponding frequency increases, among which the cable vibration’s frequency increases significantly. Keguan Zhou [19] studied the influence of the central button on the dynamic performance of the three-bridge tower anchor suspension bridge. It is concluded that the setting of the
central button has a great influence on some vertical bending modes, and it significantly delays the emergence of the first-order anti-symmetric torsional mode and increases the frequency of lateral bending vibration. Xiaofeng Zhen [20] analyzed the effect of the central buckle on the distribution law of the live load deflection of the long-span suspension bridge by the virtual beam method. It is pointed out that the difference between different forms of deflection envelope is due to the longitudinal displacement constraint of the central buckle to the main cable. Different from the traditional two-tower and three-tower suspension bridges, the use of central buckles has an important influence on the overall stress of the structure. The stress problem is prominent, the structure and connection are complex, and the design is difficult [21-23].

Many experts studied the rigid central button and flexible central button and draw the conclusions:

1. Setting central buckles at middle position of suspension bridge can improve the overall stiffness and seismic performance of suspension bridge. The frequency of each step will increase, among which the rigid central button is stronger than the flexible central button.
2. The central buckle can significantly reduce the displacement of the main beam and the shear and bending moment of the tower bottom, but it will increase the horizontal force of the main cable saddle and the internal force of the side tower.
3. The setting of central buckle has more influence on anti-symmetric side bend, vertical bend and torsion of long-span suspension bridge than positive symmetry side bend, vertical bend and torsion.
4. The setting of the rigid central buckle makes the vibration mode of the suspension bridge mainly driven by the main cable, and the influence is relatively large.

4. Application of other measures

4.1 Zip device

The research on the application of FRP cable to super-large span Bridges began in 1987 when professor U.Meier [24] proposed the use of CFRP cable to build a super-large span bridge across the strait of Gibraltar with the main span of 8400m. Since then, scholars around the world have carried out a lot of research.

Yaqiang Yang of Southeast University studied the lightweight FRP cable of super large span bridges. According to the analysis results of seismic response of large-span suspension bridges with different materials, it can be known that since the weight of the FRP cable is small, the damping is relatively large, and the energy dissipation performance of vibration reduction is good, the FRP cable uses as the cable of the large-span suspension bridge according to the theory of equal stiffness, which can effectively reduce the seismic displacement response of the large-span suspension bridge, and is conducive to improving the seismic safety of the large-span suspension bridge.

4.2 Isolation bearing

The Dalian bay sea-crossing bridge adopts the form of variable friction sliding support, that is, the longitudinal sliding support is set between the bridge tower, the bridge pier and the main beam. The longitudinal internal force of the main tower and pier is reduced after the friction sliding support is adopted.

Zhongguo Guan, Jianzhong Li and Yu Zhu [25] studied the self-anchored suspension bridge. Elastoplastic damping support is used as shock absorber for the Jiajiang Bridge. The elastoplastic damper support integrates the mild steel damper and the support, which can be combined with vertical support and horizontal hysteretic energy dissipation, greatly simplifying the design of the corresponding connecting structure device. The transverse elastoplastic constraint mechanism is adopted for all supports of the transverse bridge, and the transverse velocity locking mode is adopted to make the supports not only achieve the transverse fixed constraint but also meet the transverse temperature and other deformation demands in the normal operation state, but also make all the piers and foundations jointly resist the horizontal seismic force under the seismic condition, it shows that the elastoplastic damping support can be used effectively in seismic design of suspension bridge.
5. Conclusion
Summarizing the damping device mentioned above, we can get the following conclusions.

1) A longitudinal viscous damper is arranged between the pylon and the main beam, which can effectively reduce the longitudinal displacement of the main beam and improve the force at the bottom of the tower, reduce the collision between the structures and improve the seismic safety of the bridge.

2) The magnetorheological damper has the advantages of less energy consumption, large output, fast response speed, simple structure, continuously adjustable damping force and convenient combination with microcomputer control.

3) Setting central buckles at middle position of suspension bridge can improve the overall stiffness and seismic performance of suspension bridge.

4) It is shown that the choice of reasonable elastic cable stiffness can effectively control the displacement of the main girder, and at the same time keep the forces of the middle tower and the side tower within a reasonable range.

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