Wind Resistance Analysis for H-shaped Hanger of Long-span Steel Arch Bridge

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Abstract. This paper presents the development history of arch bridge and the structural system of long-span steel arch bridge as well as the damage and load types of wind-induced vibration. It also analyses the characteristics of wind load on an arch bridge especially the half-through or through-type steel arch bridges, the effect of wind-induced vibration on H-shaped hangers. Finally, it introduces the measures to reduce wind-induced effect on long-span steel arch bridges with H-shaped hangers.

1. Effect of Wind Load on Bridge
In recent years, China has made remarkable achievements in bridge construction, with a top rank in terms of both the numbers of bridges and the spans of completed bridges. Meanwhile, importance must be attached to bridge disasters, of which the wind load is one the destructive factors that have to be considered. Wind is formed by the flow of air from a place with high pressure to that with low pressure. When the wind encounters obstacles in the process of its movement, wind pressure is formed, causing wind-induced vibration of the bridge structures. As a major natural disaster, wind disaster brings huge losses to people's lives and property every year.

Bridges, as important transportation facilities across rivers, are often threatened and destroyed by wind. Attention is gradually paid to wind resistance design of bridge structures after occurrence of many bridge collapse accidents.

In bridge engineering, there are four main forms of vibration caused by wind load, namely flutter, galloping, buffeting and vortex-induced vibration.

Flutter refers to the self-vibration of an object in a certain uniform airflow, which is caused by multiple actions of several forces and that does not attenuate in amplitude. Flutter is a kind of torsional divergent vibration or bending and twisting divergent vibration, which often leads to catastrophic structural damage. The old Tacoma Bridge in the United States is an example of bridge collapse caused by flutter damage.
Galloping refers to the large amplitude flexural vibration of slender structures resulting from self-excited action of airflow. Bridge buffeting is an important wind-induced vibration, which is mainly the forced vibration of a structure attributable to application of a non-directional load by natural wind on the structure. Such vibration has a limited amplitude and often occurs in case of low wind speed. It shall be noted that buffeting, as a limited amplitude vibration, will not cause catastrophic damage to the structure, but if its occurrence frequency is too high, it will lead to structural fatigue and thus fatigue damage.

Both Vortex-induced vibration and buffeting have a limited amplitude, will not cause catastrophic damage to structures, and will occur from time to time in the event of lower wind speed.

2. Development of Arch Bridge
China started its arch bridge construction in the late Eastern Han Dynasty, later than western countries, but the construction technology of stone arch bridges in ancient China represented the highest level in this regard at that time. With the development of materials, construction technology and structural system, the span of arch bridges is increasingly long. According to theoretical calculation, the ultimate span of concrete arch bridge can reach 500m, while that of steel arch bridge can be 1200m.

Construction technology of stone arch bridge at the early stage in China was mainly based on experience and did not acquire the mature calculation theory that we have today. Load-bearing requirements vary with region and terrain, so the size of the bridge structures in different regions is also different. For example, in the northern China, there is a large flow of water and ice, requiring the bridge piers to be thicker, and the traffic is mainly composed of vehicles and horses, requiring the bridge deck to be flat, and the dead load effect is larger, requiring the arch ring to be thicker. An example of such bridge is Zhaozhou Bridge in China which was completed 600 years ago.

Compared with the previously used materials such as stone and wood, reinforced concrete arch bridge has great advantages because its own weight is relatively small and its spanning capacity is relatively large. This kind of bridge makes full use of the advantages of concrete and steel, making the economic performance of arch bridge greatly improved. Completed in 1997, the bridge over Yangtze River in Wanzhou, China was the largest reinforced concrete arch bridge in the world at that time.
With the increasing requirements for spanning capacity of bridges, more and more bridges are being constructed in many parts of China. For example, Chaotianmen Bridge in Chongqing, China, built in 2009 and with a main span of 520 meters, is currently the largest steel arch bridge in the world.

3. Effect of Wind Load on H-shaped Hanger of Arch Bridge

Arch bridges have a better rigidity and stability than cable-stayed bridges and suspension bridges and are theoretically less affected by wind-induced vibration. However, in half-through and through-type arch bridges, due to the existence of rigid hangers, wind load often causes damage, so wind-induced vibration has to be deeply considered in steel arch bridges with tied-arches or hangers. As shown in Figures 5 and 6, H-shaped hangers of both the Bridge over Yangtze River in Jiujiang, China and the Bridge over Yangtze River in Dongping, China are all affected by wind load.

3.1. Features of Wind Load on Arch Bridge

The main force-bearing component of an arch bridge is arch rib, and the average wind speed on the arch rib changes regularly with the height of a bridge. In general, most of the cross-sections of main girder of cable supported bridges are regular with an equal height. As for an arch bridge, the force on the arch abutment is larger and that on the span smaller. The aerodynamic parameters of the arch bridge cross-section are dependent on the span of a bridge. Arch bridges with different structures differ from each other in respect of arch rib cross-section, because the arch rib cross-section is blunt and its aerodynamic parameters are different from those of ordinary streamlined bridges. Vortex-induced vibration is one of the most easily caused vibration damages under the action of wind.

3.2. Effect of Wind-induced Vibration of H-shaped Hanger

As its name implies, a H-shaped hanger refers to one with a H-shaped cross-section. It is widely used for bridge construction because of its many advantages and convenient manufacture and maintenance. However, this kind of steel hangers with non-smooth cross-sections are slender and have small wind resistance per unit cross-section, so such hanger has a low aerodynamic stability and is easily subjected to vibration-induced damage under wind load, which will seriously affect the stability of the bridge structure.

As for a H-shaped hanger, the most common damage caused by wind load is vortex-induced vibration. A H-shaped hanger with a blunt cross-section is different from a circular one, and wind flow will form vortex on both sides of the cross section of a H-shaped hanger when wind load passes through its surface at a certain speed. A H-shaped hanger is an open thin-walled member, and its torsional stress is shown in the following figure.
The differential equilibrium equation for torsion is obtained based on the above stress analysis, shown as follows.

\[ T_x + \frac{\partial T_y}{\partial x} + T_y + \frac{\partial T_z}{\partial x} + T_p + \frac{\partial T_p}{\partial x} = 0 \]

4. Improvement Measures

Actions to improve wind-induced vibration for a H-shaped hanger mainly include aerodynamic measures, damping measures and structural measures. The first are aerodynamic measure, which means that some tests, such as pneumatic test, are conducted to make changes to the cross-section of a H-shaped hanger so as to improve wind resistance. The second are damping measures, which suggests that dampers are installed to reduce the initial vibration of a H-shaped hanger. The third are structural measures, which requires that structural rigidity is changed to improve the natural vibration frequency of a H-shaped hanger itself. In actual bridges, the wind-resistant cables of each hanger are connected together by horizontal cables, which have been used in many bridges at home and abroad since 1930s, and the typical application is Dongping Bridge in Foshan, China.

Scientific researches show that the number of wind-resistant cables, the number of wind-resistant cableways, the installation position, boundary conditions and the magnitude of initial tension all affect the wind-resistant of hangers, and the extent of their effect descends in the following order: (i) the number of wind-resistant cables, (ii) the number of wind-resistant cableways, (iii) the installation position, (iv) boundary conditions and (v) the magnitude of initial tension.

5. Conclusions

Wind-induced vibration has a great influence on suspension and cable-stayed bridges. Although the rigidity of arch bridges is larger and its structure is more stable than that of cable supported bridges, the wind-induced vibration causes obvious damage to arch bridges with H-shaped hangers. This problem can be solved by use of horizontal wind-resistant cables, but this is not the only solution. With the continuous emergence of new materials and the continuous improvement of structural stress system, better solutions will surely appear to avoid the effect of wind-induced vibration on arch bridges with H-shaped hangers.

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