Research on Static and Dynamic Load Test of Suspension Bridge with Univalent Hyperboloid Space Cable System

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Abstract. In this paper, a new model of univalent hyperboloid space cable system suspension bridge is proposed, and a comparative test model of 15 m space suspension bridge and parallel suspension bridge is made. Vertical load test, horizontal load test, partial load test and moving load test were carried out. The results show that compared with the parallel and space cable suspension bridge, the vertical stiffness of the suspension bridge increases slightly, the lateral stiffness is greatly improved and the torsional rigidity is tremendously improved. The space suspension bridge has good wind resisting stability.

1. Introduction
With suspension bridge span constantly refresh, the structure of the suspension bridge is becoming more and more flexible, the torsional rigidity and the lateral stiffness decrease, which leads to the increasing problem of wind stability [1-3].

The critical flutter wind speed of super long span suspension bridges is related to the torsional frequency and bend frequency ratio [4-7]. The suspension bridge with space cable system is the most effective method to improve the flutter stability of long-span suspension bridges [8-11].

With the use of single-leaf hyperboloid curvature characteristics, the traditional suspension bridge of the parallel cable system is reformed. The single-plane hyperboloid cable suspension structure is formed by changing a single cable into a dispersed space cable and setting the oval ring beam to fix the space cable cross node (as shown in figure 1).

Figure 1. Single curved hyperboloid space cable suspension bridge.

In order to verify the advantages of this new type of space cable suspension bridge, the static and dynamic characteristics of its structure should be tested and studied. The test includes vertical load test, horizontal load test, partial load test and moving load test.
2. Experiment Model
A comparison test model of 15 m span single curved hyperboloid space cable system suspension bridge and parallel cable system suspension bridge is made (as shown in figure 2 and figure 3). Mechanical properties of single plane hyperboloid cable suspension bridge are investigated by means of comparative tests. The experimental model of single curved hyperboloid space cable suspension bridge is mainly composed of pylon, space cable, steel ring girder, sling, stiffening girder and anchorage system. The suspension bridge model of span ratio is 1/10, the triangular arrangement of cable space, twisted 120 degrees, 24 full bridge main cable, 59 pairs of slings, the elliptic ring stiffened beam, the width of the stiffening beam is 0.3 m, the tower height of 2.25 m.

There are 24 high-strength steel wire ropes in the whole bridge, the diameter of each cable is 3 mm, fptk=1760 Mpa, E=2.0 Gpa. The steel ring beam is bundled with the main cable by a nylon tie band to form a single leaf hyperboloid cable system. The main cable of parallel cable suspension bridge adopts the principle of equal strength conversion, and two diameters are used 10.11 mm, fptk=1860 Mpa, E=1.95 Gpa.

3. Vertical Loading Test
The loading method of vertical loading test adopts standard brick and heavy load, and the brick size is 240 × 115 × 53 mm. The quality of bricks is about 1.67 kg/blocks per meter probably horizontally arranged 9 bricks, it is covered with a layer of brick, the bridge model by uniform load is 150 N/m. The vertical load is divided into four kinds of working conditions. The working conditions are uniformly distributed with a standard brick, and the load is 150 N/m. Case 2 is covered with two layers, and the load is 300 N/m. The work condition is three evenly distributed three standard brick, the load is 450 N/m. The work condition is four evenly distributed four standard brick, the load is 600 N/m (as shown in figure 4).

With the increase of load, the vertical displacement of the stiffening girder in the middle span section of the spatial suspension bridge is 41.5 mm, 65.2 mm, 84.6 mm, 95.5 mm. Under the same load increment, the displacement increment value of each section decreases progressively, and there is
obvious gravity stiffness phenomenon. The same level of vertical load, hyperboloid space cable suspension bridge is reduced by 8.5% compared with the parallel cable suspension bridge shows that the vertical displacement of mega truss composed of steel beam and cable space to improve the structure of the vertical stiffness, indicating hyperboloid space cable suspension bridge compared to the traditional parallel cable suspension bridge vertical stiffness slightly to improve (as shown in figure 5).

Figure 5. Mid span vertical displacement curve.

![Figure 5](image)

Figure 6. Relation curve on internal force of spatial cable load cases.

![Figure 6](image)

Figure 6 is the four 1/4 suspension bridge model root force representative cable varies with the loading diagram. As can be seen from the diagram, the upper and lower direction of the cable 1 and cable 3 closer to the internal force, in the left and right direction of the cable 2 and cable 4 closer to the internal force. With the linear increase of the vertical load, the internal forces of each cable increase linearly. The distribution of cable force of suspension bridge is basically uniform, and it has good cooperative work ability.

4. Horizontal Load Test

The horizontal load static test of single plane hyperboloid space cable suspension bridge model is to simulate the transverse deformation of the stiffening girder and main cable under the horizontal wind load of the suspension bridge, and can provide the experimental basis for the downward displacement response analysis of wind suspension of space cable system suspension bridge (as shown in figure 7).

The steel structure pier is used as the supporting point, and the steel rope is loaded with the flower basket bolt and the spring balance to load the stiffening beam and the space cable. The horizontal load adopts the main cable and the stiffening beam at L/2, 3L/8 and 5L/8 at six points at the same time loading mode, the horizontal load is controlled by the elastic of the flower basket bolt, and the horizontal force is displayed on the electronic spring scale.

![Figure 7](image)

Figure 7. Horizontal load test of space suspension bridge.

![Figure 8](image)

Figure 8. Displacement comparison curve.
Group A test: vertical piled a full story brick (150 N/m), two layers of full brick (300 N/m), three layers of full brick (450 N/m), four layers of full brick (600 N/m), six loading points, while the horizontal load is Q=120 N.

Group B test: Six loading points applied horizontal load at the same time, four grades: Q=30 N, 60 N, 90 N and 120 N, and the vertical load is four layers of full brick (600 N/m).

The horizontal load test of A group shows that under the same horizontal force, the lateral displacement of the stiffening girder decreases gradually with the increase of the brick on the bridge deck. This is because with the increase of the vertical pile load, the phenomenon of gravity stiffness leads to the increase of cable stress and the increase of the horizontal stiffness of the suspension bridge structure.

The horizontal load test of B group shows that under the same vertical load, the horizontal displacement of the two bridges shows a linear increasing trend with the increase of the horizontal load. But under the same load grade, the single curved hyperboloid space cable suspension bridge is smaller than the traditional parallel cable suspension bridge. The horizontal displacement at the same level of load under the hyperboloid space cable suspension bridge is reduced by 36.6%, this is because the space cable net pull each other tightly grabbed the elliptical ring beam, cable provides horizontal component of horizontal load resistance. The spatial cable system of cable suspension bridge with single plane hyperboloid space has large horizontal stiffness (as shown in figure 8).

5. Eccentric Load Test

The eccentric load test mainly compares the relative vertical displacement of the ends of the stiffening beam by comparing the torque generated by the eccentricity, to prove that the torsional rigidity of the cable stayed bridge with single plane hyperboloid is better than that of the cable stayed bridge with plane cable shape (as shown in figure 9).

![Figure 9. Load condition of vertical eccentric load.](image1)

![Figure 10. Data representation of vertical bias load.](image2)

The bias load test still adopts standard brick loading. The brick size is 240 x 115 x 53 mm, the bias load is full of two layers of standard brick + single track, a half load plus a standard brick, the vertical uniform load is 300 N/m, the eccentric load is P=60 N/m, and the eccentric distance is e=62.5 mm (as shown in figure10).

![Figure 11. Vertical relative displacement of main beam control points.](image3)
The ratio of the vertical relative displacement of the control point A and the B to the width of the bridge surface is the torsional angle of the stiffening beam under the vertical bias load. The torsion angles of the space suspension bridge and the parallel suspension bridge are 0.69 and 1.59 degrees respectively. Thus, under the action of eccentric loading, the cable network of the space suspension bridge provides a good spatial torsional rigidity for the stiffening beam, which shows that the single plane hyperboloid spatial cable suspension bridge has good wind stability (as shown in figure 11).

6. Load Test of Moving Vehicle
The moving vehicle load test is mainly divided into two parts: vehicle at different speed simulated speed effect on the displacement of the stiffening girder; the vehicle is covered with mass blocks and without mass blocks to simulate the influence of moving vehicles with different mass sizes on the displacement of stiffening beams (see table 1 for working conditions). Each car is about 15 kg, about 0.75 kg of each small block, each car can be laid on the 10 small block. The two cars unloaded a total weight of 300N, two cars covered with iron, total weight of 450 N (as shown in figure 12).

| working condition | loading method                                      |
|-------------------|----------------------------------------------------|
| 1                 | The trolley travels at a speed of 1.0 m /s without load |
| 2                 | The trolley travels at a speed of 0.5 m /s without load |
| 3                 | Full load driving speed of the trolley is 1.0 m/s     |
| 4                 | Full load driving speed of the trolley is 0.5 m/s     |

As can be seen from the figure 13 for the 1/4 section, when the load is moved to this section, the maximum vertical displacement; move to deck 3/4 section, the section displacement in the opposite direction and the direction of the maximum offset value. As shown in figure 14, for the 1/2 section, when the load moves to the cross section, the vertical downward displacement is the maximum; it moves to both sides of the bridge at about 1/4 cross section, the displacement shifts in the opposite direction, and reaches the maximum value in this direction.
The test results show that the greater the vehicle speed, the greater the vertical displacements of the stiffening beam. This is because the flexible suspension bridge is a bridge structure, the bridge bottoms only configure a layer of bricks (less ballast), the vehicle speed fluctuation caused by the deck deformation of suspension bridge, Vehicle Bridge coupling vibration effect is obvious. At the same speed, the larger the mass of the moving load, the greater the displacement response of the bridge deck; When the vehicle goes out of the suspension bridge, the vibration converges rapidly, which shows that the cable network of the space suspension bridge provides great damping.

7. Conclusion
(1) The vertical displacement of the space suspension bridge decreases with the increase of the vertical load, and there is the phenomenon of gravity stiffness. With the increase of load, the stress of main cable wire increases linearly, and the distribution of cable force of space suspension bridge is basically uniform, and it has good cooperative work ability.
(2) Compared with the parallel cable suspension bridge, the vertical stiffness of single plane hyperboloid cable suspension bridge increases slightly, the lateral stiffness increases greatly, and the torsional rigidity of the cable suspension bridge is greatly improved. It shows that the new space suspension bridge will have good spatial rigidity.
(3) Analysis showed that the hyperboloid space suspension bridge has good integrity and space stiffness, can greatly improve the torsional frequency and torsional frequency ratio, which can solve the problem of large span suspension bridge flutter stability fundamentally, 4000~5000m is expected to build suspension bridge.

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