Dynamic performance of a new type of damping and wind-resistant bearing in the Nizhou waterway bridge of Nansha Bridge

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Abstract. In order to optimize the transverse structural system of the 1688m long-span steel box girder suspension bridge (Nizhou waterway bridge of Nansha Bridge), a new type of lateral damping energy-consuming wind-resistant bearing is proposed, and the quasi-static test is carried out. Also, the nonlinear time-history analysis method is used to compare and analyze the influence of the lateral fixed restraint and the new lateral damping energy-consuming wind-resistant bearing on the bridge tower internal force, main beam internal force, main beam displacement and rotation angle of the long-span suspension bridge. The research results show that, the new lateral damping energy-consuming wind-resistant bearing has good hysteretic energy consumption; compared with the conventional wind-resistant bearing, the seismic performance is better than the pylon which setting the horizontal fixed constraint, transverse bending moment of the pylon is smaller when adopting the new lateral damping energy-consuming wind-resistant bearing. The shearing force and bending moment of the main beam are obviously smaller than the transverse fixed restraint system, and decrease with the increase of the stroke of the bearing; the use of the new lateral damping wind-resistant bearing has little effect on the lateral displacement and rotation angle of the main beam.

1. Introduction
With the long-span bridges becoming more and more gentle and the structural form becoming more and more complicated, the safe operation of bridges under automobile load, temperature, wind and earthquake, is particularly important. A reasonable vertical and horizontal constraint system is the key to ensure the mechanical performance of bridges [1]. For wind resistance and other normal use of large-span suspension bridge lateral restraint system, it must have sufficient restraint stiffness. The bridge tower and the contact between the girder is often contact rigidity, and the transverse fixed constraint usually causes the pier inertia force is too large [2]. When the strong earthquake action, the system is hard to meet seismic requirements.

At present, many scholars have studied the rational longitudinal restraint system of long-span bridges [3-5], but few studies have been conducted on the transverse structural system. Taking Sutong Bridge as the background, Ye et al. [2] analyzed the effects of three lateral systems on seismic response of super-long span cable-stayed bridges, and showed that neither the lateral sliding system nor the full limit system is an ideal seismic system. Guan et al. [6] studied the application of elastoplastic cable and viscous damper system to the transverse shock absorption of cable-stayed bridges, and the study showed that the system could significantly reduce the bending moment at the bottom of the main tower and the acceleration response of the main beam. Taking Jiajiang self-anchored suspension bridge in Nanjing as the engineering background, Li et al. [7] adopted elastoplastic...
damping bearing to conduct shock reduction, and the results showed that the transverse seismic response was only 15%-50% of that of pier and tower beams of the lateral fixed system. Shen et al. [8] proposed a lateral shock absorption system of side piers, which is combined with a new type of transverse steel damper and sliding support for bridges (the transverse structure between tower beams is still fixed), to carry out lateral shock reduction and isolation design.

It can be seen from the above research that although some research has been done on the optimization design of transverse shock absorption of long-span cable-stayed bridges and suspension bridges, the existing transverse shock absorption and isolation devices of long-span Bridges are relatively complex or inconvenient to install. Based on this, this article combines the transverse vibration-wind resistance design demand of main-span 1688m steel box girder suspension bridge Nizhou waterway bridge of Nansha bridge, put forward a new type of lateral vibration energy dissipation wind bearing, and gives the working principle of the device and the model of mechanics, analysis of transverse fixed constraint system and the new wind and bearing transverse vibration energy dissipation in the application of large span suspension bridge.

2. Project overview

Nizhou waterway bridge of Nansha Bridge is a two-tower, double-span steel box girder suspension bridge with a span of 1688m. The span layout is (658+1688+522) m. The overall layout as shown in Fig.1. The span ratio of the suspension bridge is 1/9.5, the distance between the main cable transverse bridge and the center is 42.1m, and the distance between the slings along the bridge and the standard is 12.8m. The stiffening beam adopts integral steel box girder with the height of 4m and the full width of 49.7m. The tower is a portal reinforced concrete structure with a height of 260m and three beams of upper, middle and lower beams. The column adopts rectangular section with circular chamfering. The range from the top of the tower to the lower beam is 8.5m(transverse)×12.5m(longitudinal), and from the bottom to the bottom of the tower is 8.5m(transverse)×16m(longitudinal). The foundation adopts bored cast-in-place pile. The standard of two-way eight-lane expressway is adopted, and the design speed is 100km/h.

![Figure 1. General layout of Nizhou waterway suspension bridge](image)

3. New type of transverse shock absorption-energy dissipation-wind resistance bearing

3.1. The working principle

The design and structure diagram of the new type of transverse shock absorption and energy dissipation and wind resistance bearing is shown in Figure 2. It is arranged at the connection between the bridge tower and the main girder, including sliding plate, compression roof, curved sliding plate, compression steel block and base, among which a disc spring group and a dynamic damper are arranged between the compression steel block and the base. The new type of energy absorption and wind resistance bearing realizes the function of automatic reset through the disc spring and energy dissipation through the damper. Under loads such as transverse bridge earthquake and strong wind, the main beam squeezes the compressed steel block through sliding plate, compressive roof and arc-shaped sliding plate in turn, and the compressed steel block squeezes the disc spring group and the dynamic damping for reciprocating motion, and the reciprocating motion stroke is ±d. Longitudinally,
the main girder of the bridge can slide freely along the sliding plate installed outside the compression roof of the shock absorption and energy dissipation device, so as to ensure the free movement of the main girder and the bridge tower without constraints, and meet the requirements of the large displacement of the main girder in the longitudinal direction of the bridge. In addition, the inner side of the compression roof is installed with a convex arc sliding plate, which is closely matched with the convex arc surface of the outer side of the compression steel block. The two can rotate freely between them, which can meet the needs of the horizontal free rotation of the bridge girder at the junction of the bridge tower. Fig. 3 shows the constitutive curve of the new type of transverse vibration absorption and wind resistance bearing.

3.2. Parameters of design

In order to effectively reduce the mechanical performance of the main girder under earthquake action and reduce the impact between the main girder and the bridge tower, a total of six new transverse shock absorbing energy dissipation and wind resistance bearings are set up in Nizhou Waterway Bridge of Nansha Bridge, which are divided into Class A and Class B. Among them, two class A bearings are provided at the main tower on the Dongguan side and the transition pier on the Guangzhou side, and two class B bearings are provided horizontally at the main tower on the Guangzhou side, and two class B bearings are provided horizontally at the main tower on the Guangzhou side. The specific parameters are shown in Table 1.

| Class | The bearing capacity(KN) | The displacement(mm) | The rotation angle(rad) | The friction coefficient |
|-------|--------------------------|----------------------|------------------------|------------------------|
|       | Along the bridge | The vertical | In the horizontal plane | In the vertical plane |                         |
| A     | 5792 | ±1320 | ±100 | 0.05 | 0.06 | ≤0.03 |
| B     | 17140 | ±1100 | upward300, down500 | 0.05 | 0.06 | ≤0.03 |

According to the above support parameter requirements, the design parameters of two types of transverse wind resistance bearings A and B are formulated, as shown in Table 2.

| Class | k1(kN/m) | k2(kN/m) |
|-------|----------|----------|
| A     | 2×10^5  | 2×10^7  |
| B     | 4×10^5  | 2×10^7  |

The new type of transverse wind bearing contains four viscous dampers, the damping coefficient \( C = 300kN(m/s)^{0.1} \), the velocity index \( \alpha = 0.1 \). In order to verify the energy dissipation capacity of the new type of bearing, a model test was carried out on the device. The test was carried out in the static and dynamic testing system of 3000t shock absorption and isolation device in the testing center of Highway Bridges National Engineering Research Centre. The test layout is shown in Fig. 4. Adopt the
displacement loading, the loading displacement is ±5mm, and the displacement is measured by the displacement sensor. Fig. 5 shows the hysteresis curve of the new type of vibration-absorbing and wind-dissipating bearing. As can be seen from the figure, the hysteretic loop curve is full in shape and has strong energy dissipation capacity.

4. Finite element model
The spatial finite element calculation model of Nizhou waterway bridge is established by using the nonlinear finite element analysis program ANSYS. The spatial fish-bone beam model was adopted for the model. The main tower and main girder were simulated by BEAM188 element, and the main cable and derrick were simulated by LINK180 element. The sag effect of cable and the geometrical stiffness of dead load were considered. Pile group foundation is simulated by elastic embedding method. The static limit-dynamic damping device is set longitudes at the two bridge pylon, and the new type of shock absorption, energy dissipation and wind resistance support is set laterally. The seismic vertical tension-compression support is set at the east tower and the west transition pier, and the calculation model is shown in Figure 6. E2 earthquake (return period is 4% surpassing probability of 100 years) [9] was used in calculation. The curve of acceleration time history is shown in Fig. 7.

5. Analysis of mechanical performance
In order to study the influence of a new type of energy dissipation and wind resistance bearing on the overall mechanical performance of a long-span suspension bridge, the internal forces and displacement responses of key parts of the bridge under four conditions of setting transverse fixed constraints and a new type of energy dissipation and wind resistance bearing (reciprocating motion stroke d is 1cm, 5cm and 10cm, respectively) are compared and analyzed. In this paper, the transverse bending moment of the bridge tower and the internal force and displacement of the main girder are selected as the evaluation indexes to analyze the influence of the above different lateral restraint systems on the mechanical performance of the bridge tower and the main girder.
5.1. Internal force of bridge tower

Fig. 8 shows the transverse bending moment distribution of the main tower of Nizhou Water Bridge along the height direction under the earthquake action of four systems.

As can be seen from Fig. 8, the bending moment of the main tower on the Guangzhou side decreases to a certain extent after the installation of the new type of shock absorption, energy dissipation and wind resistance bearing. Since there is no stiffened beam on the side span of the Dongguan side tower, the bending moment of the main tower changes in a small range. For the bending moment of the main tower on the Guangzhou side, the greater the stroke d of the new type of shock absorption, energy dissipation and wind resistance bearing is, the greater the range of bending moment reduction at the bottom of the tower will be. When the stroke d is 1cm, 5cm and 10cm, compared with the transverse bending moments at the bottom of the horizontal fixed restraint tower, the transverse bending moments at the bottom of the Guangzhou side tower are 2160MN.m, 2090MN.m and 2044MN.m respectively, which decrease by 4.6%, 7.7% and 9.8% respectively. For the main tower, the bending moment of the main tower is reduced by 1.1%, 2.0% and 3.4% respectively. In general, the transverse bending moment of the bridge pylon is less than that of the lateral fixed constraint, which is more beneficial to the force of the bridge pylon. The above analysis shows that the greater the stroke of the wind-resistant bearing between the tower beams, the greater the energy dissipation capacity of the bearing. Fig. 9 shows the force-displacement hysteresis curves of the wind resistance bearing when the stroke is 1cm and 10cm. Because the travel between the tower girders is reserved only 1cm, the travel of the new type of vibration absorption and wind resistance bearing of Nizhou waterway bridge of Nansha bridge is set at 1cm.

![Hysteresis curve of wind bearing damper.](image)
5.2. Internal force of main girder
Fig. 10 shows the transverse shear force and bending moment distribution of the stiffening girder of Nizhou waterway bridge under seismic action of four systems.

![Figure 10. Transverse internal force of main girder](image)

As can be seen from Fig. 10, the shear force and bending moment of the main girder on the Guangzhou side and Dongguan side are reduced to a certain extent after the installation of the new vibration absorbing energy dissipation and wind resistance bearing, especially at the connection of the tower beam, the reduction of internal force is obvious, and the greater the bearing stroke \( d \) is, the greater the reduction of internal force of the main girder is. Taking the Guangzhou side as an example, when the transverse fixed restraint support is set, the transverse shear force of the main girder at the tower girder connection is 13.3MN, and the transverse bending moment is 1108mn.m. After setting the new vibration absorbing energy dissipation and wind resistance bearing, when the bearing stroke \( d \) is 1cm, 5cm and 10cm, the transverse shear force of the main beam at the Guangzhou side tower beam connection is 10.3MN, 9.5MN and 6.6MN respectively, which decreases by 22.6%, 28.6% and 50.4%. The transverse bending moments of the main girder are 934MN.m, 897MN.m and 821MN.m respectively, which decrease by 15.7%, 19.0% and 25.9%. The shear force and bending moment of the main girder at the connection of the side tower girder in Dongguan show similar laws. Compared with the lateral fixed constraint system, the main girder under the new type of lateral damping and wind bearing has more gentle force along the longitudinal direction, and the force mutation is reduced a lot. From the above analysis, it can be seen that the new type of shock absorption, energy dissipation and wind resistance bearing plays an effective role in cushioning the transverse earthquake, and significantly improves the mechanical performance of the main girder under earthquake action.

5.3. Displacement and rotation angle of main girder
Fig. 11 shows the transverse displacement, horizontal rotation angle and vertical rotation angle of the main girder at the transition pier on the Guangzhou side, the main tower on the Guangzhou side and the main tower on the Dongguan side under the earthquake action of four restraint systems. As can be seen from Fig. 11, the maximum transverse displacement of the main girder is in the middle of the main span, and there is little difference in the transverse displacement under the four kinds of transverse constraint systems. The maximum horizontal rotation angle and vertical rotation angle occurred in the main girder of Dongguan tower. Under the horizontal fixed constraint system, the horizontal rotation angle was 0.00643rad, and the vertical rotation angle was 0.00225rad. After the installation of the new type of damping and wind bearing, the horizontal rotation angle was reduced to 0.0615rad after the formation \( d \) was greater than 5cm, and the vertical rotation angle remained basically unchanged. It can be seen that the new type of shock absorption energy dissipation and wind resistance bearing has little influence on the transverse displacement, horizontal rotation and vertical rotation of the main girder at the Guangzhou side transition pier, the Guangzhou side main tower and the Dongguan side main tower.
6. Conclusion

To effectively reduce the impact of the bridge tower and the girder under the action of the earthquake and wind, a new type of energy dissipation and wind resistance bearing adopts system of disc spring and damper was proposed. The mechanical behavior of the bridge tower and girder under different lateral system with the transverse fixed constraints and new type bearing. The main conclusions are as follows:

(1) Compared with the lateral fixed constraint, the mechanical performance of the main tower of the suspension bridge can be improved by the new type bearing. The greater the bearing stroke is, the greater the reduction of the internal force of the main tower will be. The transverse bending moment at the bottom of the main tower on the Guangzhou side of Nizhou Waterway Bridge decreases by 4.6%, and the transverse bending moment of the main tower at the lower beam decreases by 1.1%.

(2) Compared with the lateral fixed constraint, the mechanical performance of the main girder is significantly improved by adopting the new type bearing. The greater the bearing stroke is, the greater the shear force and bending moment of the main girder are reduced. The transverse shear force and transverse bending moment of the main girder of Nizhou waterway bridge decrease by 22.6% and 15.7%. The force along the longitudinal direction of the main girder becomes more gentle, which is beneficial to the stress of the main girder, and has little influence on the displacement and rotation angle of the main girder.

(3) The new type bearing can ensure that the main girder and the bearing are always closely fitted. It has a self-reset function and improves the driving comfort.

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