STUDY ON MECHANICAL BEHAVIOR OF CABLE-STAYED BRIDGE SUPPORT SYSTEM IN MULTI-FULCRUM UNBALANCED SWIVEL

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ABSTRACT

With the maturity and wide application of the bridge swivel construction technology, the single-fulcrum balance swivel cannot meet the need of crossing over the high-speed railway catenary and other obstacles, so the unbalanced swivel construction is often needed. In order to ensure the stability and safety of the unbalanced swivel process, a multi-fulcrum swivel method is proposed. In this paper, the railway cable-stayed bridge over Harbin West Avenue is taken as the research object, and the multi-fulcrum swivel construction method over the metal contact network is adopted. The abaqus finite element model is established to study the influence of different swivel angular velocity, friction coefficient of slideway and position of support foot on the force of support system in the course of swivel. The results show that, compared with the traditional single-fulcrum swivel, the support foot of the multi-fulcrum swivel becomes the main force component, and the force on the spherical hinge decreases. The swivel angular velocity is positively correlated with Mises stress of the support foot and the spherical hinge. When the friction coefficient of the slideway changes in order of 0.02, 0.04, 0.06, 0.08 and 0.1, the friction stress of the outer edge of the support foot increases linearly. Considering the force of the spherical hinge and the support foot, the best position of support foot is 7.3 m from the center of the spherical hinge. The research in this paper can be used for reference multi-fulcrum unbalanced swivel construction in the future.

KEYWORDS

Unbalanced swivel construction, High-speed railway catenary, Multi-fulcrum swivel method, Finite element model, Support system

INTRODUCTION

Current status of research

The swivel construction refers to a kind of construction method that the bridge structure is first poured and formed outside the completed bridge position, and can reduce the influence of construction on the traffic line to a large extent through turning into position. The commonly used methods of swivel are vertical swivel, horizontal swivel, horizontal swivel and vertical swivel combined method[1]~[4]. the length of the two sides of the main swivel bridge of Wuhan Changqing Road was doubled, and the difference between the bottom of the beam and the railway catenary was 2.5 m, as shown in Figure 1. At this point, the traditional balanced swivel is no longer satisfied with the complex construction conditions, and it is necessary to seek more advanced swivel methods.
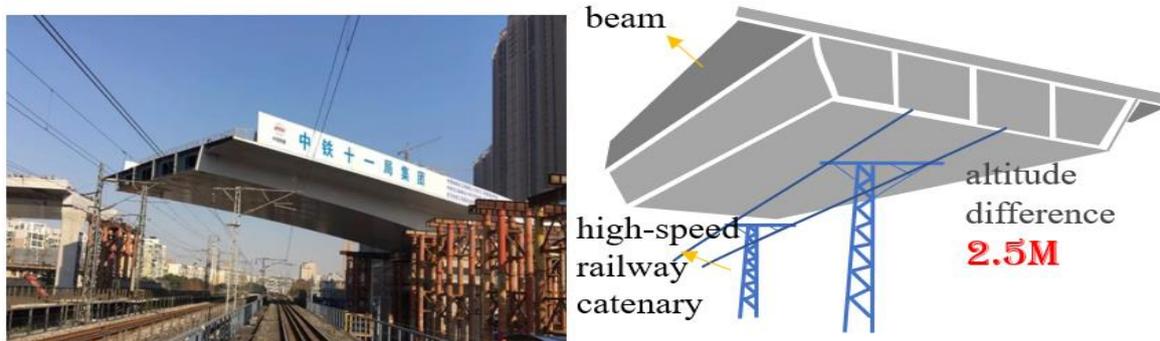
Fig. 1 – Wuhan Changqing Road main line swivel bridge

The traditional swivel is single-fulcrum support, that is, the bridge is supported by the spherical hinge to complete the swivel. Although traditional horizontal swivel construction has many advantages, the overall stability of the swivel structure is the worst at this time because the structure is in a transient equilibrium state during the swivel process[6]~[7]. As for the swivel bridges, the stress of the consolidation of the tower and beam, the maximum cantilever end, the turntable, the shaft and the spherical hinge are complex in the swivel process, which is the focus of domestic and foreign scholars. Sun[8] used finite element software to analyze and study the stress of the beam , the turntable and the shaft during the swivel process of the Suifenhe cable-stayed bridge during the acceleration and uniform processes. Liu[9] analyzed the stress of spherical hinge with different velocities and acceleration by dynamic time history, and obtained the limit value of acceleration. Furthermore, Che [10] conducted in-depth research on key mechanical problems in the process of bridge horizontal swivel by means of theoretical analysis, numerical simulation and experimental measurement.

There are more researches on traditional swivel construction monitoring, force analysis or calculation theory, but less research on swivel bridges with extremely asymmetrical ends or extremely unbalanced swivel across obstacles. At present, the methods adopted by Lv[10]~[11], and others[11]~[15] are the additional front outrigger auxiliary support technology and the auxiliary support walking power system technology. But Wuhan changing road swivel bridge construction method and the method of Lv[11]~[15] have greatly increased the construction volume, construction difficulty and swivel difficulty.

Because the overall stability of the traditional swivel is poor, and it cannot meet the needs of extremely unbalanced swivels, the multi- fulcrum swivel with additional front outrigger support is more complicated. Therefore, in order to provide a reasonable and simple swivel method for the multi- fulcrum swivel in the future, this paper takes the Haxi Street cross-rail cable-stayed bridge (hereinafter referred to as the Haxi cable-stayed bridge) as the research object, and puts forward the method of multi- fulcrum unbalanced swivel of support foot auxiliary spherical hinge. In fact, the support foot of the swivel system, as an auxiliary support component to prevent the roll, can be completely combined with the spherical hinge to form a multi-fulcrum swivel support system. Based on the analysis of the influencing factors of the force of the support foot and the spherical hinge in the process of swivel, the unbalanced swivel construction of the bridge was successfully completed by using the fine finite element analysis, inclined counterweight and unbalanced weighing[16]~[18], which can provide reference for the unbalanced multi-fulcrum swivel construction in the future.

Engineering situation

Harbin West Avenue Cable-stayed Bridge is located in Harbin West Marshalling Station, across more than 20 railway lines, whose span arrangement is (118+198+118) m, and the intersection angle with the railway line is 80.4°. The total length of the bridge is 434 m. The layout and swivel of the bridge are shown in Figures 2 and 3. The swivel span of the Tower 9 is (97+101) m, and the span of the Tower 10 is (90+107) m. The swivel weight of the two towers both are about 28000 t.

Due to the limitation of the railway line, the bridge side span is larger than that of the conventional cable-stayed bridge (generally 0.45-0.5:1). Since the side span of tower 10 of the bridge crosses the metal catenary of high-speed railway during swivel, the distance between the bottom of the beam and the metal catenary is only 151 mm. Considering the safety of the swivel process, the swivel method of multi-fulcrum unbalanced swivel is adopted to avoid the collision between the bottom of bottom and the catenary during the swivel process. The multi-fulcrum swivel needs to be counterweighted in the middle span to make the mid-span side support foot landing and the side span lifting, so as to increase the spacing between the bottom of the beam and the catenary, which constitutes a multi-fulcrum swivel system with the joint force of the support foot and the spherical hinge, and ensures the smooth and safe swivel process.
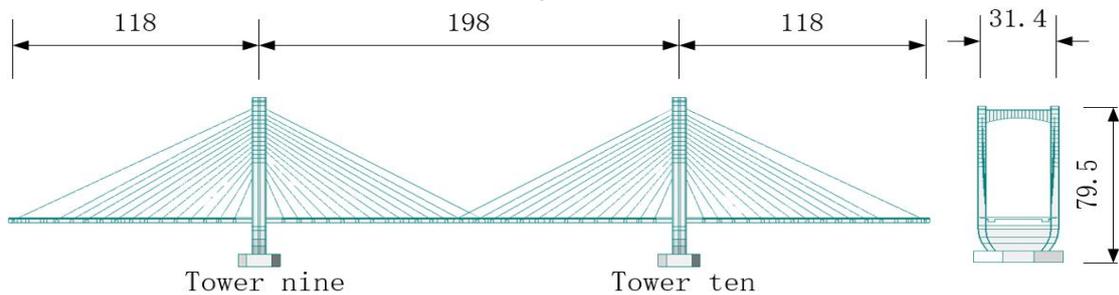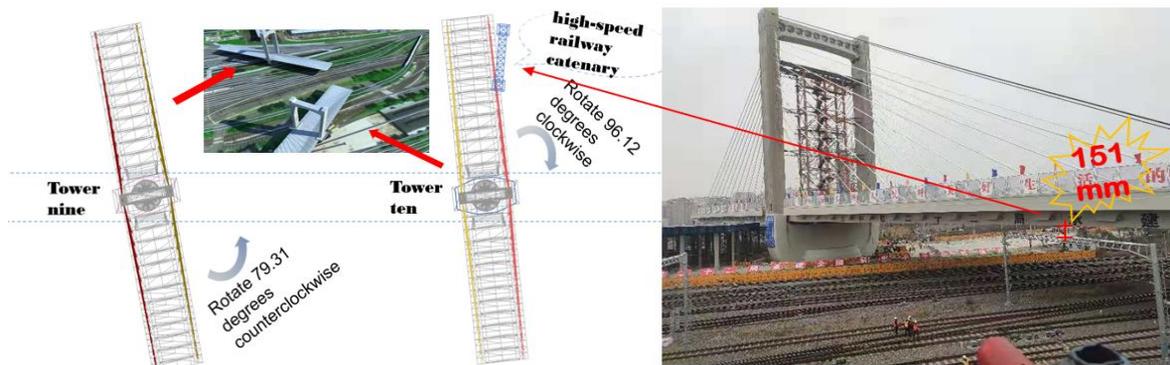

Fig.2 - Bridge type layout(Unit：m)

Fig.3 - Swivel orientation diagram

The difference between multi-fulcrum swivel and traditional swivel system is mainly the support system. The support structure of traditional swivel system is mainly the spherical hinge, while the support system of multi-fulcrum swivel system is composed of the spherical hinge and the support foot. The diameter of the spherical hinge is 4500mm and the total height is 890mm. It is one of the stress components of the support system. The upper turntable is equipped with six support feet symmetrically distributed on both sides of the longitudinal axis of the beam. The structure diagram of the swivel system is shown in Figure 4, and the detailed structure of the support system is shown in Figure 5.
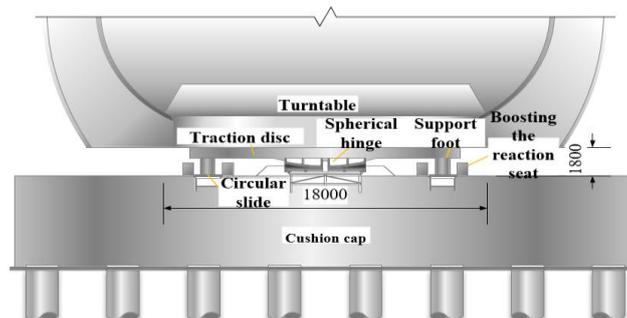

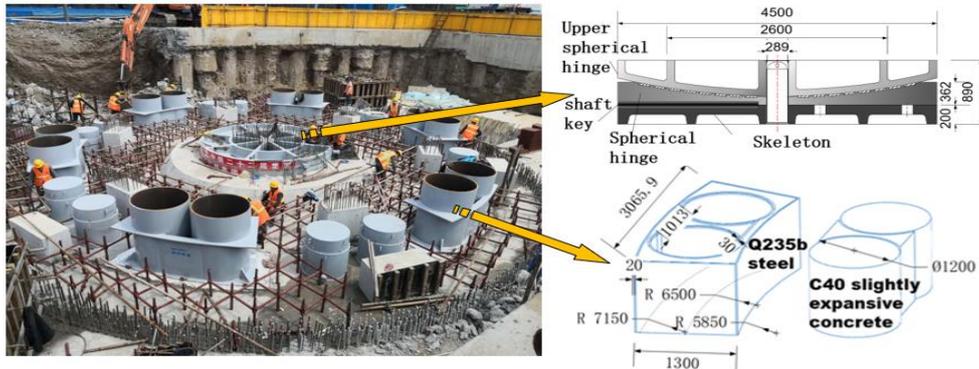*Fig.4 - The structure diagram of the swivel system(Unit：mm)*

Fig.5 - Detail structure of support system(Unit：mm)

METHODS

Test determination of parameters

Determination of friction coefficient of the spherical hinge

Unbalanced weighing is needed before multi-fulcrum unbalanced swivel. Different from the traditional balanced rotation, the unbalanced torque of the multi-support unbalanced rotation must be greater than the friction torque, which is caused by the tilt counterweight. Figure 6 shows the unbalanced weighing test process.
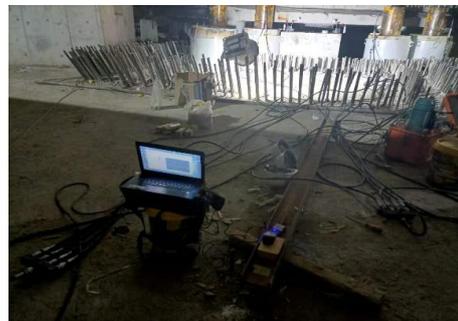
| *(a) Jack arrangement* | *(b) The data collection* |

Fig.6 - Unbalanced weighing test process

According to the measured results of the unbalanced weighing test, the following calculations are obtained: unbalance torque Mg=14200kN·m, friction torque Mz=13000kN·m, friction coefficient μ_0=0.0054, eccentricity e=0.051m.

Determination of swivel angular velocity

The angular velocity sensor is installed on the swivel structure and connected with the acquisition module. The angular velocity collected during the swivel is transmitted to the online monitoring platform through the wireless transmission module and recorded. The angular velocity acquisition process is shown in Figure 7, and the measured angular velocity in the process of multi-fulcrum unbalanced swivel is shown in Figure 8.

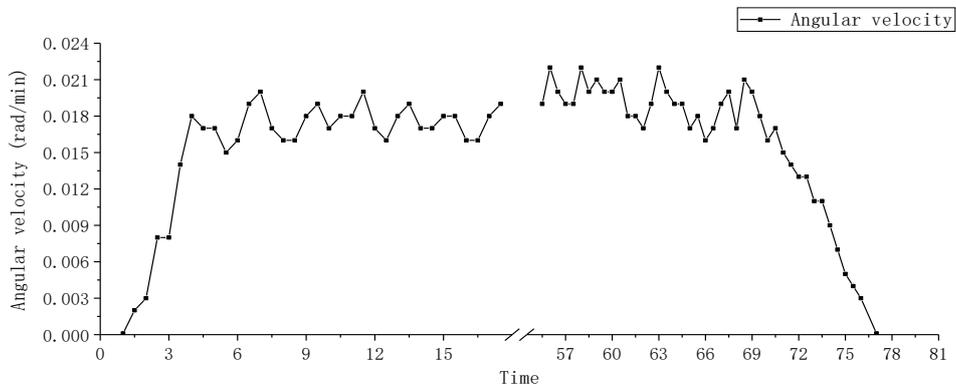*Fig.7 - Angular velocity acquisition process*

Fig.8 - Measured angular velocity during swivel

It can be seen from Figure 8 that the angular velocity is stable in the range of 0.016rad/min ~ 0.024rad/min in the process of uniform swivel.

Establishment of finite element model

The multi-fulcrum swivel system is different from the traditional single-fulcrum swivel. The coordinated force of the entire swivel structure during the swivel is crucial. Therefore, Abaqus is used to establish an accurate and simplified finite element model of the swivel structure. Compare the multi-fulcrum swivel with the single-fulcrum swivel, and conduct in-depth research on the influence of the swivel angular velocity, the friction coefficient of the slideway and the position of the support foot on the force of the support system. The materials and parameters used in the main components of the swivel structure are shown in Table 1.

Tab.1 - Material of the main components of the swivel structure

Structural part	Detailed structure	material	density (kg/m³)	Poisson ratio	Young's modulus (MP$_a$)	Unit
Upper turntable	/	C40 concrete	$2.5×10^3$	0.3	$3.25×10^4$	C3D8R
Turntable	/	C40 concrete	$2.5×10^3$	0.3	$3.25×10^4$	C3D8R
Spherical hinge	Upper spherical hinge	Q345 steel	$7.85×10^3$	0.28	$2.06×10^5$	C3D8R
	Spherical hinge	Q345 steel	$7.85×10^3$	0.28	$2.06×10^5$	C3D8R
Support foot	Support foot steel pipe	Q235b steel	$7.85×10^3$	0.274	$2.06×10^5$	C3D8R
	Concrete in steel pipe	C40 micro-expansion concrete	$2.5×10^3$	0.3	$3.25×10^4$	C3D8R

The element types and material parameters selected for each component of the Abaqus partial model are shown in Table 1. Build the solid parts according to the size of the construction drawings, and then assemble them through the combine in the assembly. For example, the support feet are composed of steel plates, concrete cylinders and steel pipes, and the upper part of the swivel structure is composed of a turntable, six support feet and an upper spherical hinge. The partial model of the swivel structure is shown in Figures 8 and 9.

By calculating the unbalanced load, the uniform force and bending moment on the top surface of the upper cap are obtained. The uniform force is applied to the top surface of the upper cap of the Abaqus partial model, and a feature point is coupled on the top surface of the upper cap. The bending moment and swivel speed are applied to the feature point, so that the mid-span side support foot contacts with the top surface of the lower cap and swivels. The influence of various factors on the force of the support system in the swivel process is studied.

The contact between the lower surface of the ground support foot and the upper surface of the cushion cap, and the contact between the upper and lower spherical hinges is surface-surface contact. The tangential behavior of the contact is a nonlinear algorithm of the penalty function algorithm[19], and the normal behavior uses "hard" contact, and allows separation after contact. The friction coefficient of the upper and lower spherical hinges is 0.0054 measured by weighing test.
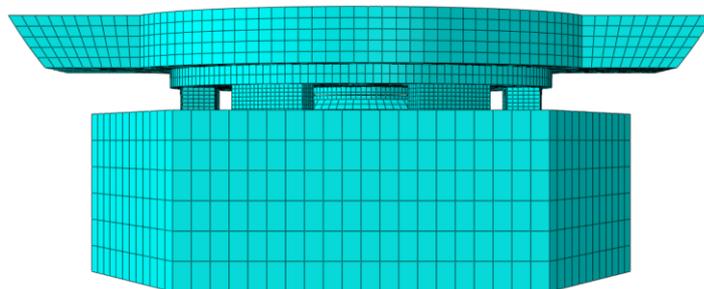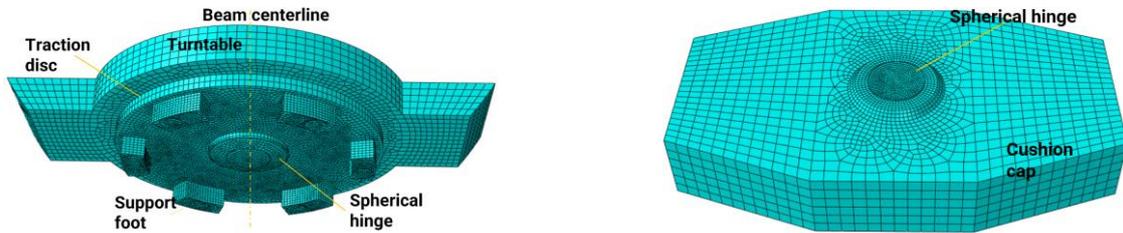

Fig.9 - Overall model of swivel system

Fig.10 - Finite element model of up-and-down turntable

The layout of the support foot nodes is shown in Figure 11, and the layout of the spherical hinge nodes is shown in Figure 12. Strain gauges are arranged on the side of the foot, and when the counterweight is tilted, the strain data when the foot hits the ground will be collected, and the entire rotation process will be monitored through monitoring. The arrangement of the strain gauges is consistent with the side node of support foot layout, as shown in Figure 13.
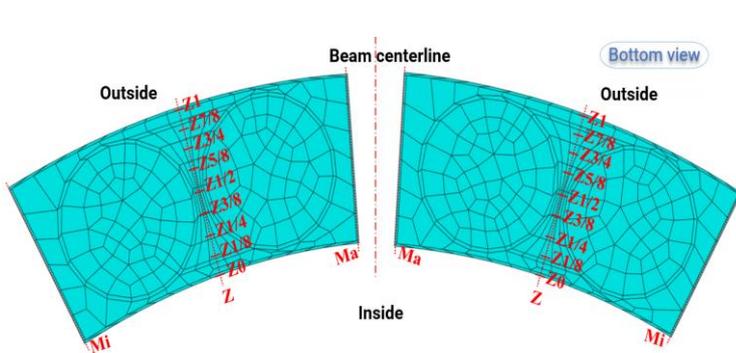

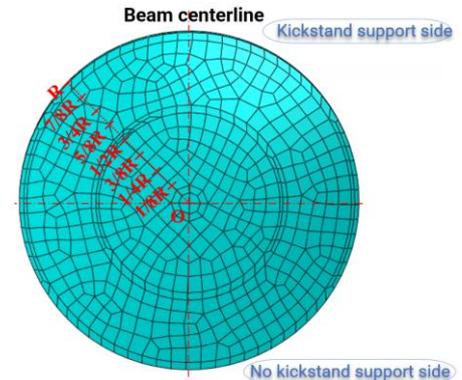*Fig.11 - Support foot node layout*
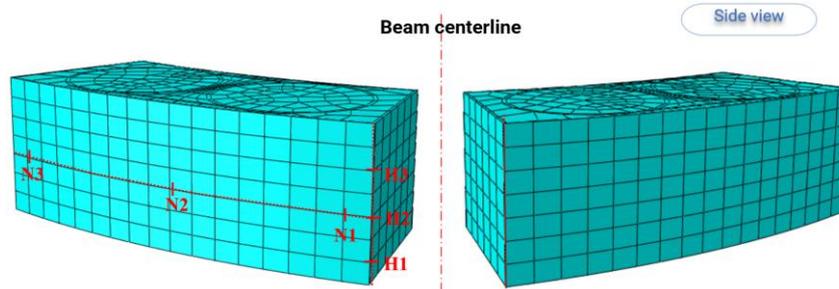

Fig.12 - Spherical joint node layout

Fig.13 - Side node of support foot layout

RESULTS

Comparative Analysis of Multi-Fulcrum Swivel and Traditional Single-Fulcrum Swivel

The traditional swivel method is single fulcrum balanced swivel, and its support system only has spherical hinge single support. The multi-fulcrum swivel is that the support foot and the spherical hinge participate in the force together, forming a multi-fulcrum support system. By comparing the force of the support system of multi-fulcrum swivel and traditional swivel in the process of swivel by finite element method, the force changes of the support foot and spherical hinge of multi-fulcrum swivel and traditional swivel are analyzed. The Mises stress nephograms of the traditional single-fulcrum swivel and multi-fulcrum swivel support systems are shown in Figure 14 and 15, respectively.
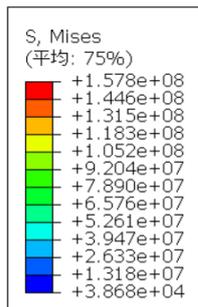
Fig.14 - Mises stress nephogram of single-fulcrum balanced swivel support system(Unit: P_a)
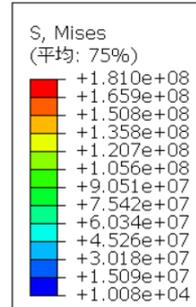

Fig.15 - Mises stress nephogram of multi-fulcrum swivel support system(Unit: P_a)

As shown in Figure 14 and 15, the spherical hinge in the traditional single-fulcrum swivel is the main force component, and the Mises stress at the maximum force is 157.8MP$_a$. Besides the Mises stress at the maximum stress of the support foot is 1.4MP$_a$, which is mainly caused by centrifugal force. Since the inclined counterweight of the bridge increases the unbalanced moment, the inclination of the bridge body makes the counterweight side support foot land, and the support foot of the multi-fulcrum swivel becomes the main force-bearing member. The Mises stress value at the maximum force of the support foot is 181.0MP$_a$, and the Mises stress value at the maximum force of the spherical joint is 106.9MP$_a$. Compared with single-fulcrum swivel, the force of the spherical hinge is reduced by 32.3%, and the maximum Mises stress is far less than its yield strength of 345MP$_a$. Besides the force of the support foot increases by 128 times, and the maximum Mises stress had a strength reserve of 0.77 compared with its yield strength of 235MP$_a$.

Study on the force influence of support system swivel process

The influence of the angular velocity of swivel on the force of the support system

The whole swivel process of cable-stayed bridge is divided into four stages: accelerated swivel, uniform swivel, deceleration braking and inching adjustment posture. The acceleration and deceleration process is relatively short, and the uniform swivel process will last for several tens of minutes, which is the longest period[20]. In the process of swivel, due to the existence of centrifugal force, it will inevitably produce a "centrifugal" tendency to the swivel structure, that is, tensile stress will be generated. At the same time, the size of the centrifugal force is closely related to the swivel speed, and the centrifugal force is proportional to the square of the swivel angular velocity. As the swivel speed increases, the centrifugal force also increases significantly[21]. Therefore, the angular velocity of swivel is an important factor in the swivel of the swivel bridge. This paper studies and analyzes the angular velocity of the angular velocity on the force of the support system in the process of multi-fulcrum swivel.

By collecting the angular velocity in the process of multi-fulcrum swivel, the angular velocity in the process of uniform swivel is obtained to be 0.016rad/min~0.024rad/min. Therefore, the angular velocity of 0.016rad/min is used as the benchmark to study the force of the multi-fulcrum swivel support system at the angular velocities of 0.016rad/min, 0.032rad/min, 0.048rad/min, 0.064rad/min, and 0.080rad/min. The Mises stress nephograms of the support system are shown in Figure 16 and Figure 17.
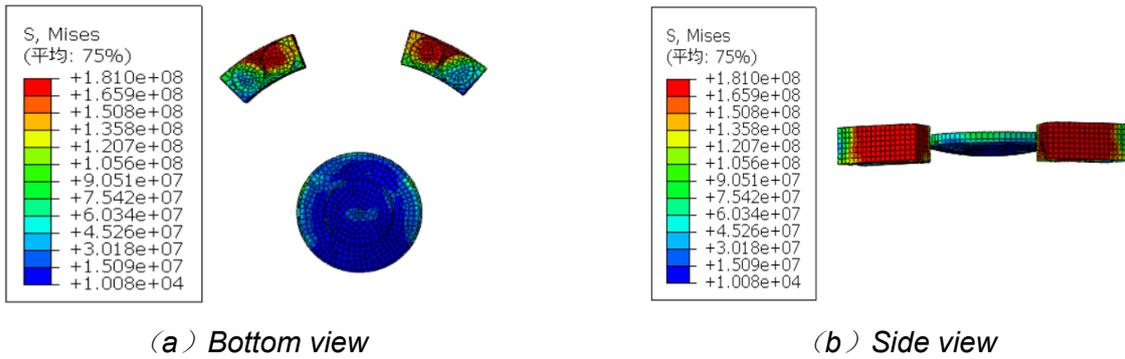
（a）Bottom view   （b）Side view

Fig.16 - Mises stress nephograms of the support foot and the spherical hinge at speed 0.016rad/min （Unit： P_a）

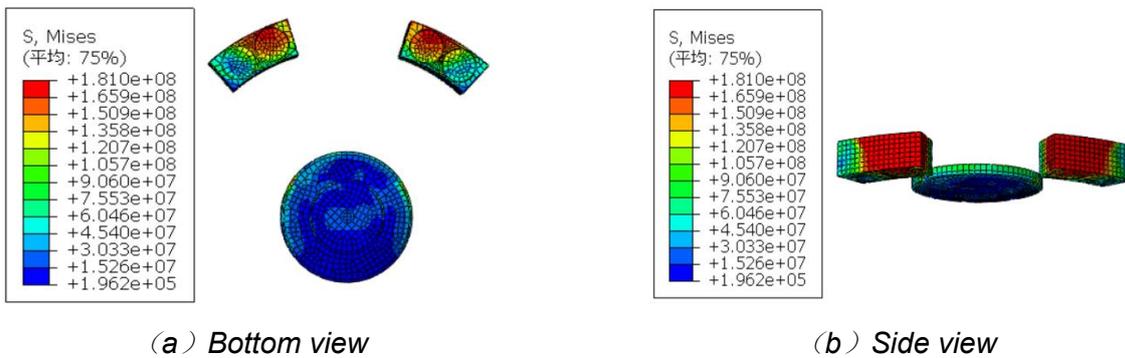（a）Bottom view   （b）Side view

Fig.17 - Mises stress nephograms of the support foot and the spherical hinge at speed 0.032rad/min （Unit： P_a）

As shown in Figures 16 and 17, in the multi-fulcrum system, the stress on the side of the spherical hinge near the ground support foot is larger, and the Mises stress at the edge R is the maximum, and the stress at the center O of the spherical hinge is about 12.3 % of the stress at the edge R.

The Mises stress curves at support foot Z1 and the spherical joint R of five swivel angular velocities are shown in Figure 18.
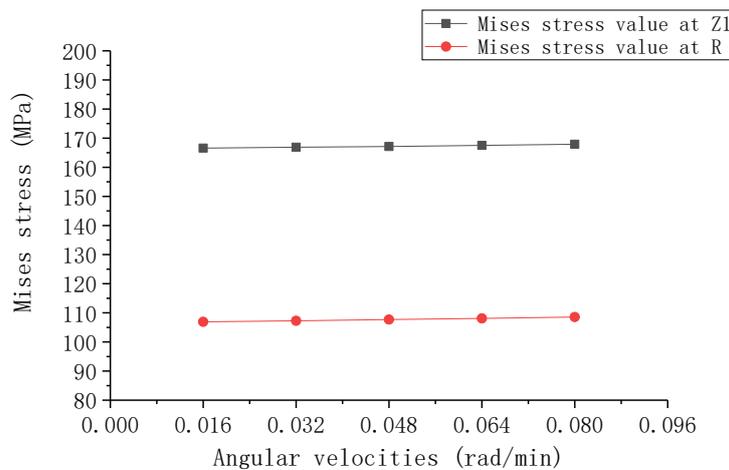

Fig.18 - Mises stress of five angular velocities at the support foot Z1 and the spherical hinge R

As shown in Figure 18, the Mises stress at the bottom of the support foot Z1 and the spherical hinge R is positively correlated with the angular velocity, which is the result of the centrifugal force generated by the swivel angular velocity. With every increase of the angular velocity of 0.016rad/min,

the Mises stress at the support foot Z1 only increases by 0.18%, and the Mises stress at the spherical hinge R only increases by 0.33%.

The model data using the actual rotational angular velocity is compared with the measured data, that is, the force comparison of the support foot, which is divided into the vertical H-axis and the horizontal N-axis. The data comparison diagram is shown in Figure 19.

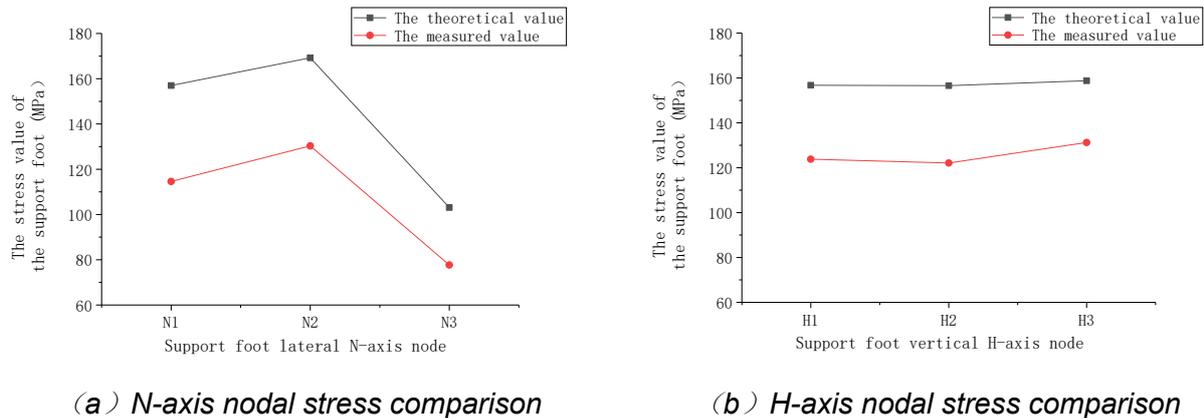（a）N-axis nodal stress comparison   （b）H-axis nodal stress comparison

Fig.19 - Comparison between the measured stress on the side of the support foot and the stress calculated by the model

It can be seen from Figure 19 that the measured values of the lateral and vertical node stresses on the side of the support foot are roughly the same as the theoretical values calculated by the model. The measured value is up to 82.67% of the calculated value of the model, and the smallest is 73.09%. By comparing with the measured values, it can be seen that the model simulation is more accurate.

The influence of friction coefficient on the force of support system

The traditional swivel support system only produces friction between the upper and lower spherical hinges. However, the friction between the support feet and the slideway and the upper and lower spherical hinges is both produced in the multi-fulcrum swivel system. Through the field unbalanced weighing test, the friction coefficient of the spherical hinge in the multi-fulcrum support system is 0.054. Here, only the influence of the friction coefficient between the support foot and the slideway on the force of the support system is studied. In order to reduce the friction between the support foot and the slideway to minish the tonnage of the tension traction equipment, the method of brushing lubricating materials on the slide is selected. The friction coefficient of butter method is 0.06, and the friction coefficient of butter adding poly tetra fluoroethylene(PTFE) powder is 0.03~0.06[22]~[24]. In order to simulate the different friction coefficients of the slideway, at a constant angular velocity of 0.016 rad/min, it is assumed that the friction coefficients between the support foot and the slideway are 0.001, 0.02, 0.04, 0.06, 0.08 and 0.1. In the absence of friction, the friction coefficient is selected to be 0.001.
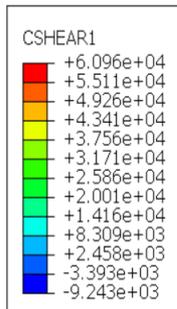
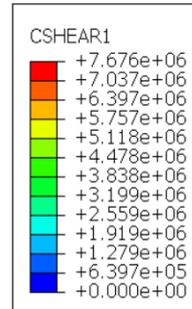*Fig.20 - Friction stress nephogram of the support foot and the spherical hinge when the friction coefficient is 0.001（Unit：P_a）*

Fig.21 - Friction stress nephogram of the support foot and the spherical hinge when the friction coefficient is 0.02（Unit：P_a）

The friction stress nephograms of the support foot and the bottom surface of the spherical hinge are shown in Figures 20 and 21. The friction stress values of each node on the Z-axis of the support foot bottom surface with the friction coefficients of 0.001, 0.02, 0.04, 0.06, 0.08 and 0.1 are extracted, sorted and drawn as shown in Figure 22.
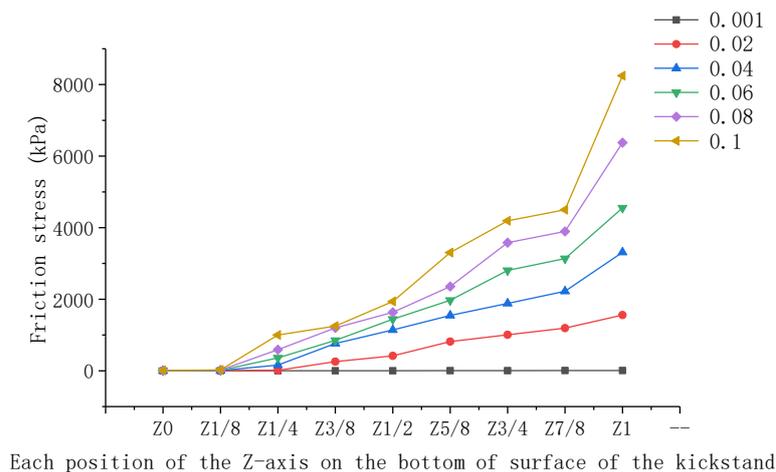

Each position of the Z-axis on the bottom of surface of the kickstand

Fig.22 - Friction stress at various positions on the Z-axis of the bottom surface of the support foot with different friction coefficients

It can be seen from Figures 20~22 that: at a constant angular velocity of 0.016 rad/min, the friction stress at each point on the Z-axis of the foot bottom surface is proportional to the friction coefficient. As the friction coefficient increases by 0.02, the friction stress at the support foot Z1 increases by 112.7%, 186.0%, 309.5% and 430.0%. The increase in stress value is linearly related to the friction coefficient, which conforms to the Coulomb friction law. The friction stress on the outside of the support foot is larger than that on the inside, that is, the greater the distance from the center of the spherical hinge, the greater the friction stress. With a friction coefficient of 0.06, the friction stress at Z1 is 4552.34KP_a, and the friction stress at Z0 is 4.56KP_a. Consequently, the friction stress at Z1 on the outside is 998 times that at Z0 on the inside.

The influence of the position of the support foot on the force of the support system

The support foot is the "fulcrum" in the "lever" of the support system, and the distance between the support foot and the center of the spherical hinge is an important factor affecting the force of the support system. For the sake of study the influence of support foot position on the force of support system, it is proposed to choose 0.016rad/min angular velocity and 0.06 friction coefficient. Under the premise of not increasing the superstructure, the distance between the support foot position and the center radius of the spherical hinge is changed to: 7.1m, 7.3m and 7.5m.
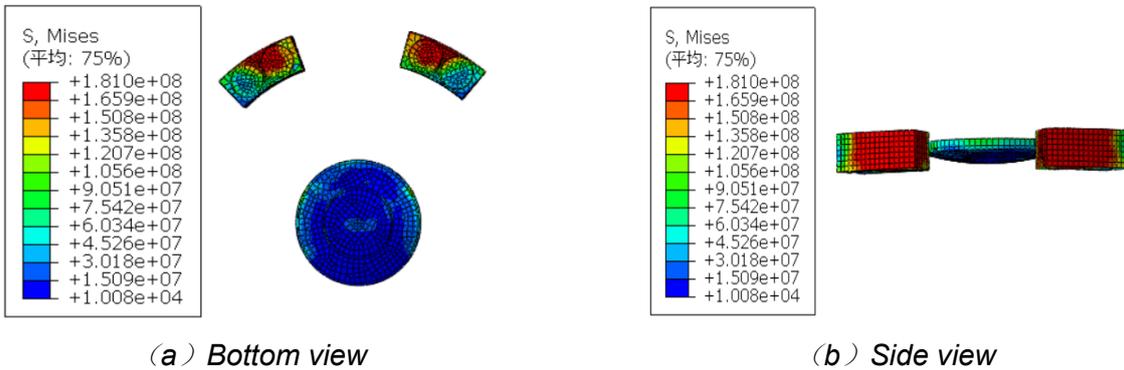
（a）Bottom view   （b）Side view

Fig.23- Mises stress nephograms of the support foot and the spherical hinge and when the radius from the spherical joint is 7.1m（Unit：P_a）

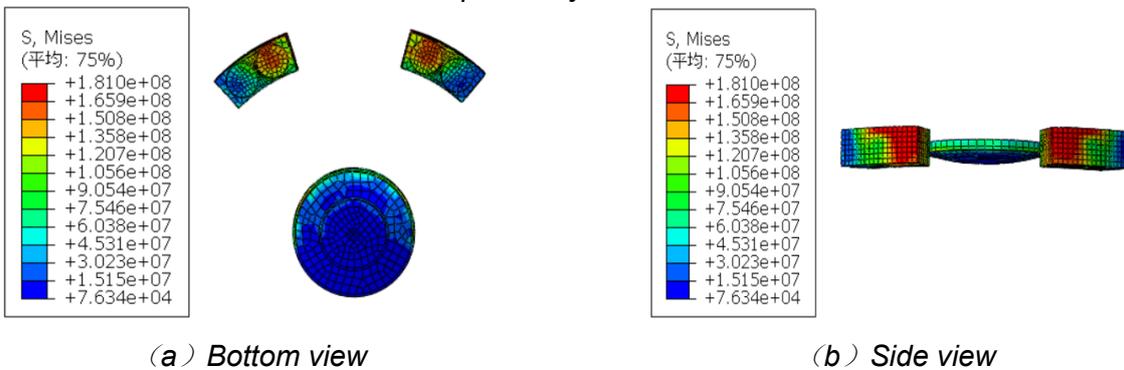（a）Bottom view   （b）Side view

Fig.24 - Mises stress nephograms of the support foot and the spherical hinge when the radius from the spherical joint is 7.5m（Unit：P_a）

The Mises stress nephograms of the support foot and the spherical joint are shown in Figures 23 and 24. When the radius of the spherical hinge is 7.1m, 7.3m and 7.5m, the Mises stress of each node of the Z-axis at the bottom of the foot is plotted as Figure 25, and the Mises stress of each node of the R-axis at the bottom of the spherical hinge is plotted as Figure 26.
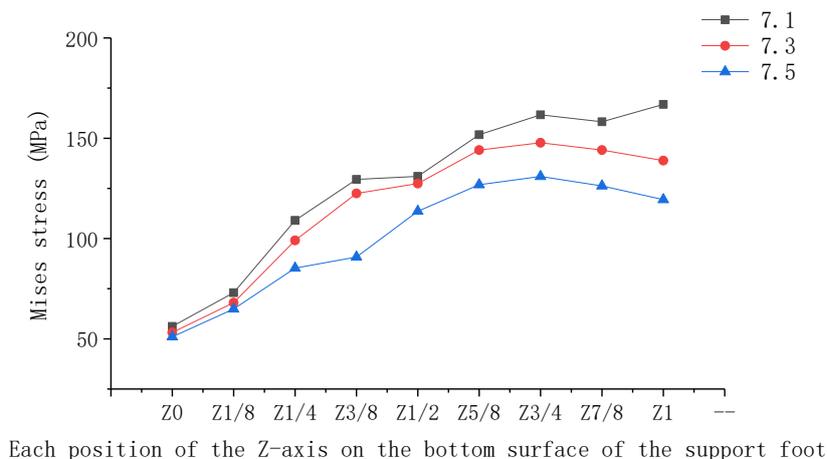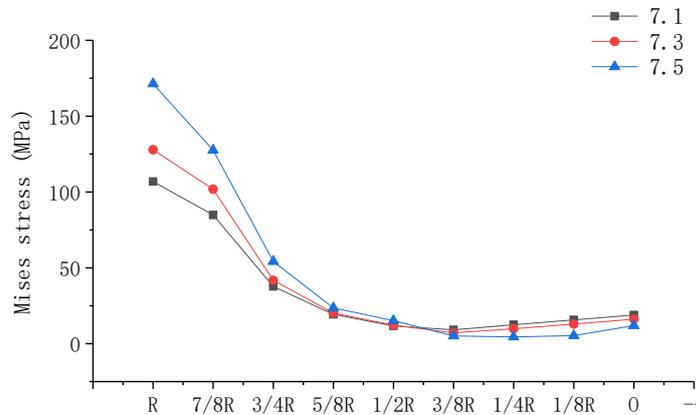

Fig.25 - Mises stress at each position of the Z-axis on the bottom surface of the support foot at different positions

Fig.26 - Mises stress at each position of the R-axis on the bottom surface of the spherical joint at different positions

It can be seen from Figures 23 -26 that: moving the support foot outward means increasing the radius from the center of the spherical joint, which can effectively reduce the force on the support foot. The position of the support foot moved from 7.1m away from the center of the spherical hinge to 7.3m and 7.5m. The Mises stress at Z1 decreased by 28.1MP$_a$ and 19.4MP$_a$, respectively, accounting for 16.8% and 13.9%. At the same time, as the position of the support foot moves outward, the center of force of the spherical hinge moves outward, the force of the spherical hinge center O decreases, and the force of the edge R near the support foot increases. The position of the support foot is moved from 7.1m away from the spherical hinge center to 7.3m and 7.5m. The Mises stress values at O decreases by 2.69MP$_a$ and 4.2MP$_a$ respectively, and the Mises stress values at R increases by 21.0MP$_a$ and 43.5MP$_a$ respectively, accounting for 19.6% and 34.0%. Therefore, the position of the support foot needs to be considered together according to the force of the support foot and the spherical hinge. According to the above conclusions, the force of the support foot is reduced by 16.8% and the force of the outer edge of the spherical hinge increases by 19.6% when the position of the support foot is moved to 7.3m from the center of the spherical hinge. When the support foot position moves to 7.5m away from the center of the spherical hinge, the force of the support foot decreases by 13.9%, and the decrease amplitude decreases to 82.7%. The force of the outer edge of the spherical hinge increases by 34.0%, and the increase amplitude doubles to 204.8%. In summary, the position of the support foot at a distance of 7.3m from the center of the spherical hinge, which is 325% of the radius of the spherical hinge, is more suitable for Haxi Cable-stayed Bridge.

SUCCESSFUL SWIVEL

Through the research on the mechanical behavior of the support system in the swivel process to select each parameter, such as a swivel angular velocity of 0.016rad/min, a method of reducing friction between the slide feet with butter and PTFE powder, and the position of the support feet 7.3m away from the spherical joint, at 12:02 on November 12, 2020, Haxi cable-stayed bridge crossed the high-speed rail catenary and successfully swiveled. This swivel refreshes the world 's swivel bridge with the largest total weight in cold region, cross-railway operation railway tracks most, the most ' unbalanced ' bridge swivel weight and the most accurate (centimeter level) swivel precision control.

Fig.27 - Successful swivel

CONCLUSION

In order to study the support system of multi-fulcrum swivel, the unbalanced swivel is simulated by abaqus finite element simulation. The traditional swivel and multi-fulcrum swivel are compared and analyzed. In view of the influence of swivel angular velocity, friction coefficient and support foot position on the force of the support system in the swivel process, the following conclusions are drawn :

(1)   Swivel bridges usually need to be swivelled across lines, but many obstacles such as high-speed rail metal contact network prevent the swivel of the beam body and cannot be removed in the process of swivel. In view of the swivel bridge in such cases, this paper puts forward a multi-fulcrum swivel method under the joint force of the support foot and the spherical hinge. Through the comparative analysis with the traditional single-fulcrum swivel, it can be seen that the force of the spherical hinge of the multi-fulcrum swivel is reduced by 32.3%. The force of the support foot increases by 128 times and becomes the main force component. Therefore, for multi-fulcrum swivel bridges, steels with lower strength, such as Q235 steel, can be selected for the spherical hinge, and steels with higher strength, such as Q355 steel, should be selected for the support foot to provide higher strength reserves.

(2)   This paper studies the force of the support system at angular velocities of 0.016rad/min, 0.032rad/min, 0.048rad/min, 0.064rad/min, and 0.080rad/min. For every 0.016 rad/min increase in angular velocity, the Mises stress values at Z1 and R of the spherical hinge only increase by 0.18% and 0.33%, which indicates that the angular velocity has a small effect on the support system.

(3)   The swivel bridge usually discusses the influence of the friction coefficient at the spherical hinge. In this paper, the friction coefficient between the support foot and the slideway is analyzed. As the coefficient of friction increases, the frictional stress on the spacer foot increases，which conforms to the Coulomb friction law. It can be seen from the stress clouds that the friction stress on the outside of the support foot is larger than that on the inside, that is, the greater the distance from the center of the spherical hinge, the greater the friction stress. It follows that a material with a lower coefficient of friction can be used on the outer edge of the slideway.

(4)   Although the position of the support foot can be moved out to effectively reduce the force of the support foot, as the force of the support foot decreases, the force on the outer edge of the spherical hinge increases. From the above analysis, the position of the support foot at a distance of 7.3m from the center of the spherical hinge, which is 325% of the radius of the spherical hinge, is more suitable for Haxi Cable-stayed Bridge.

In this paper, the construction method of multi-fulcrum swivel is proposed for unbalanced swivel unbalanced swivel bridges with excessive obstacles. The abaqus finite element model is established. Meanwhile the multi-fulcrum swivel and the traditional swivel are compared and

analyzed. Based on the traditional swivel, the force characteristics of multi-fulcrum swivel are obtained. The influence of swivel angular velocity, friction coefficient and support foot position on the force of support system is studied. The following work can change the contact form between the support foot and the slideway according to the above research data, such as adding pulleys under the support foot to optimize the multi-fulcrum swivel system, and provide reliable reference for the future projects using multi-fulcrum swivel.

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