Analysis on Construction Monitoring Scheme of Double Swivel Cross Railway Bridge

Xinyi Li*

City college, Kunming University of Science and Technology, Kunming 650000, China

*Corresponding author Email: li9085@vandals.uidaho.edu

Abstract. As the construction needs to cross more and more existing railways and other obstacles, the swivel technology is widely used in various bridge projects. Based on the engineering background of a double swivel railway bridge, this paper analyses the construction monitoring scheme of this kind of bridge in the following three aspects. Firstly, the swivel environment should be fully considered when formulating the swivel plan. Secondly, the construction schemes of hanging basket, spherical hinge, weighing, bob-weight and traction cable are discussed. Thirdly, cantilever end superelevation monitoring and rotation process angle monitoring has been discussed in the application technology of double swivelling body project. Meanwhile, the three-dimensional laser scanning technology is compared and analyzed with commercial technology. The conclusion shows that 3D technology has advantages over total station monitoring in swivelling body monitoring. Furthermore, it realizes the application of various data monitoring of rotating body, to achieve the purpose of accuracy algorithm optimization.

Keywords: Double Swivel Cross railway bridge; Construction technology; Monitoring program.

1. Introduction

With the rapid increase of traffic volume, it has become increasingly difficult to close or relocate roads due to construction. The swivel construction is carried out in the non-axis direction around the crossing object in advance. After the construction is completed, rotate the building. This method makes it simple and feasible to cross the original obstacles quickly and safely. Therefore, whether from the perspective of economic or public transport, the application of bridge swivel construction technology is becoming more and more widespread, especially the overpass crossing the busy road and railway.

The bridge swivel technology originated in France in the early 1940s. The original swivel method was a single vertical swivel construction method. With the progress of technology, the horizontal swivel construction method followed. So far, a third method combining horizontal and vertical rotation has been derived, of which the horizontal swivel construction method is the most widely used. In the horizontal rotation method, the spherical hinge rotation at the pier bottom is the most widely used.

Swivel construction can be applied to many different bridges, such as T-shaped beams and cable-stayed bridges. For T-frame continuous beam, the key control points in the construction process include: (1) Angle control. Pre-rotation angle test shall be conducted before rotation, and the angular speed shall not exceed the specified unit to avoid over rotation. (2) Swivel super elevation control. During construction, the downward stress and strain caused by gravity shall be fully considered, and the butt joint shall be realized after the rotation. (3) Swivel couple balance control. The front and rear span lengths of the swivel are inconsistent. Through the calculation of the moment of the extended structure on both sides of the swivel, the swivel scheme is designed to balance the structure. A good Jack rotation system is adopted to keep stable and continuous during the rotation.

Nowadays, the swivel technology is gradually being used maturely. More and more bridge projects choose to use the swivel method to cross the existing roads, railways or other obstacles. Most of the swivel projects in China are still single swivel projects, such as the swivel construction of T-structure of Taihang Mountain Expressway and the swivel project of highway and railway overpass crossing Shenyang Dalian line on the interchange of national highway 201. However, in the past two years, China has been braving in trying out the double swivel technology for bridges, and there have been many successful engineering cases. The successful practice of double swivel construction technology has also appeared in projects such as the Cipingcun Super Major Bridge in Yunnan, the Shandong section of Jinan Zhengzhou high speed railway, the Taizao section of Beijing Taiwan Expressway and Chongli railway.

However, compared with the single swivel, the double swivel construction requires higher preparatory calculation and rotation accuracy. BIM Technology and structural finite element method have been used to analyse the double swivel structure. In terms of BIM Technology, they have completed the modelling of piers, pile foundations and the whole bridge. The impact test of the moving combination of model components is completed, as well. In the structural finite element analysis, the maximum stress of the spherical joint and the design maximum compressive stress of the sliding plate are calculated by substituting the key parameters such as elastic modulus and Poisson's ratio.

Based on the analysis of the key elements of the construction technology and the monitoring scheme, the 3D laser scanning monitoring technology is introduced to optimize the construction monitoring content.

2. Double Swivel Construction Technology of T-frame beam

2.1. Project Overview

Ciping Village Bridge swivel project in Yunnan Province is located near the toll station in Xiangyun County, Dali Bai Autonomous Prefecture, Yunnan Province, and crosses the broad railway and Chu Da expressway. The project overview of the two swivel members is that the swivel weight of pier 20 is 3341.5t, crossing the vast railway. The swivel weight of pier 21 is 3329.1t, crossing Chu Da expressway. The two rotations need to rotate 60.85 degrees and 79.38 degrees counter clockwise, respectively.

2.2. Construction Difficulties

(1) Considering the environment of the swivel structure, the T-shaped beam of this section spans a large part of the railway. The elevation of the overhead contact system in the railway electrification project needs to be considered. Before turning, the elevation from the railway to the beam bottom shall be measured, and relevant measures shall be taken after consultation with the railway transportation department to properly adjust the height of the overhead contact system, to meet the turning conditions.

(2) In order to minimize the scope of operation impact, basket cast-in-place concrete is used for the project. At the same time, under the closure of the two swivel structures, there are roads and railways to be crossed, with the traffic volume of the line is relatively large. During the construction process, special attention shall be paid to the impact of high-altitude operation on the traffic below to ensure the safety of vehicles and the surrounding environment.

2.3. Summary of Key Construction Technologies

2.3.1. High altitude hanging basket installation

The high-altitude hanging basket construction is flexible and convenient because it does not need the use of large machinery and many steel pipes supports. At the same time, compared with the steel support erected from the ground, the uncertainty is higher for hanging basket. Therefore, the requirements for the stability of the basket platform and the professionalism of the construction personnel are higher. It is necessary to test the local environmental parameters such as temperature, humidity, and wind speed before construction. To meet the conditions greater than the overturning force, the resistance generated by basket platform must be calculated in advance. Select the appropriate basket platform and firm steel wire rope after calculation according to the data such as the beam width of the T-shaped beam and the overhanging length of the swivel structure is of vital importance. The calculation formula is shown in the following Equation (1) - Equation (7), and the calculation diagram is shown in Figure 1 .

The stable moment (MWl) of bob-weigh and support is shown in Equation (1):

$$Mwl=(Ww+Swz)8*\ Lw \tag{1}$$

where WW is bob-weigh weight; SWZ is weight of rear support (bob-weigh support); LW is distance between front and rear supports.

The stability moment (MWll) of the beam between supports is shown in Equation (2):

$$MwII=SwT*LwT \tag{2}$$

where SWT is weight of cross beam between front and rear supports; LWT is the distance from the center of gravity of the cross beam between the front and rear supports to the front fulcrum.

The total stabilizing moment (MW) is shown in Equation (3):

$$Mw=MwI+MwII \tag{3}$$

The actual working load of the lifting mechanism is shown in Equation (4):

$$Wq=We+Wp+Wg+Wz \tag{4}$$

where We is rated load; WP is weight of platform (including hoist, electrical box, and safety lock); WG is weight of steel wire rope (100 m working rope and safety rope); WZ is weight of safety rope hanging hammer.

The overturning moment (Mql) of the actual working load is shown in Equation (5):

$$Mql=Wq*Lq \tag{5}$$

where Wq is actual working load of lifting mechanism; Lq is outer length of suspension support beam.

The overturning moment (MqII) of the front protruding beam is shown in Equation (6):

$$MqII=SqT*LqT \tag{6}$$

where SqT is weight of protruding part of front beam; LqT is the distance from the center of gravity of the front protruding beam to the fulcrum.

The total overturning moment (MQ) is shown in Equation (7):

$$Mq=MqI+MqII \tag{7}$$

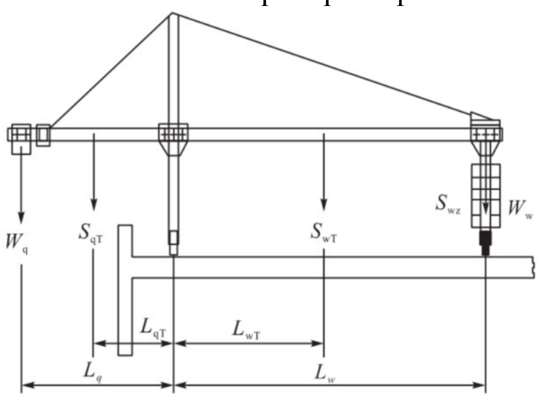

Figure 1. Stress diagram of suspension support

2.3.2. Spherical hinge

The choice of the size of the spherical joint will affect two parameters. The supporting force and the frictional resistance during rotation. A larger size spherical hinge will enhence its supporting force. However, at the same time, as the diameter becomes larger, the contact area of the spherical hinge increases. Therefore, the rotational friction correspondingly rises, which will affect the traction rotation. Vice versa. The influence parameters of spherical joint size are shown in Table 1. Therefore, it is suggested to conduct finite element analysis through BIM technology as far as possible. Simulate the stress state of spherical joints, with different diameters and select the most appropriate scheme after analyzing the two parameters of support force and friction. The project contains two 4000t rotating structures, which do not belong to the heavyweight rotating body in terms of mass. Therefore, the size of the spherical joint does not need to be over large. During the installation of the lower turntable and slide, the working surface shall be kept clean, and the debris on the surface shall be cleaned up. When pouring the concrete into the template, the concrete shall be vibrated regularly to eliminate the air bubbles in the concrete. Ensure that the concrete creep and stress are uniform in the later stage, ensure that the plane elevations of the two components are consistent, and reduce the eccentricity of the rotating body. To reduce the rotating friction, the Teflon sliding plate should be added to the surface of the lower rotary table and filled with silicone grease and other similar measures. The spherical joint structure is shown in Figure 2. In Figure 2, the structures 1 to 5, are upper support plate, lower support plate, crown liner, flat Polytetrafluoroethylene (PTFE) plate and spherical PTFE plate, relatively.

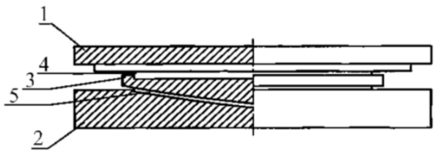

Figure 2. Basic structure of spherical bearing

Table 1. Statistical table of spherical joint stress results

Spherical hinge radius R/m	Sagittal height of spherical hinge f/m	Radius vector ratio f/R	Vertical compressive stress of lower grinding core σ/MPa	Vertical compressive stress of upper grinding cover σ/MPa
7	0.35	0.05	9.60 ~ 34.3	13.70 ~ 29.20
8	0.40	0.05	9.26 ~ 29.7	11.30~27.10
8.5	0.425	0.05	7.87 ~ 24.8	10.90~26.40
9	0.45	0.05	7.75 ~ 23.4	9.72~23.10
10	0.5	0.05	4.65 ~ 19.7	7.85~21.10

2.3.3. Weighing and bob-weigh

Before weighing, remove the temporary support and remove the excess load on the bridge to avoid affecting the weighing data. The method of abrupt change of rigid body displacement is adopted first to push the rotating body. Then measure the displacement of the height of the rotating body. Finally obtain the experimental data. The unbalance moment (MG) and friction moment (MZ) of the spherical joint are calculated by substituting the data into the theoretical formula. Compare the magnitude of two different moments to obtain different force displacement curves, as shown in Figure3- Figure5. Finally, a reasonable bob-weigh scheme is formulated to make the eccentricity meet the design requirements. Calculate the jacking force required for rotation according to the torque and jack arm and select the appropriate Jack model. To ensure the balance of the beam, the jack shall be placed in pairs around the spherical hinge. That is, the opposite side of the test jack must be protected from the protective jack.

The spherical joint unbalance moment (MG) is calculated as per Equation (8):

$$M_G = \frac{P_2L_2 - P_1L_1}{2} \tag{8}$$

The friction moment (MZ) is calculated according to Equation (9):

$$M_Z = \frac{P_2L_2 + P_1L_1}{2} \tag{9}$$

where P1 is refers to the jacking force when there is obvious displacement change of the pushing rotating body; P2 is refers to the jacking force when unloading the jacking force and the rotating body reacts to the displacement; L1, L2 are right and left cantilever end jacking thrust arms.

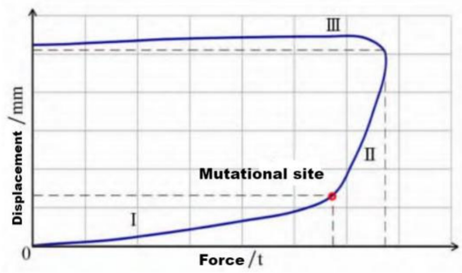

Figure 3. Friction torque greater than unbalance torque

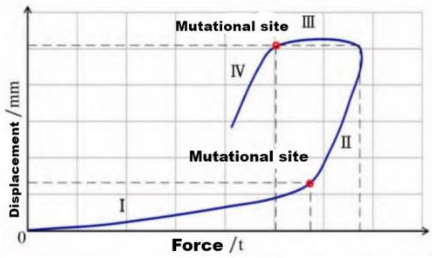

Figure 4. Friction torque less than unbalance torque

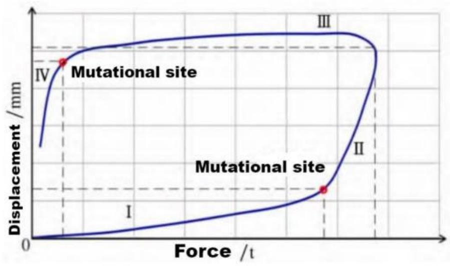

Figure 5. Friction moment is slightly less than unbalance moment

2.3.4. Towing cable.

Double swivel projects can be divided into two types: sequential swivel operation and parallel swivel operation. The project adopts the sequential turning operation. The fixed position of the anchor cable shall be considered after the friction of the two spherical joints is calculated respectively.

3. T-frame beam double swivel monitoring technology

3.1. Cantilever end superelevation monitoring.

Both sides of the double swivel closure section are swivel structures, and the elevation difference is more likely to change. Therefore, it is necessary to continuously monitor the elevation during the rotation process. Electronic level is used to set up several elevation survey stations at the closure. If the height difference is greater than the allowable proposed value, vertical adjustment measures shall be taken for the swivel. After comparing the effect of the forced closure method with bob-weigh on the stress of the bridge, it is suggested to use the rotating spherical hinge method to reduce the change of the bridge stress. As shown in figure6 and figure7. Figure 6 shows that when changing the angle of spherical hinge, the stress of the beam approximately maintains in the same numerical value. Figure 7 shows that when changing the load that applied on the beam, the stress lines misalign. In addition, as the high-altitude hanging basket is cast-in-place concrete construction, it is necessary to carry out elevation monitoring on the newly poured part for many times before the hanging basket moves forward.

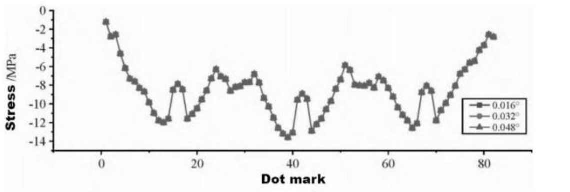

Figure 6. Comparison of section stress of main beam of the whole bridge when deflecting different spherical hinge angles

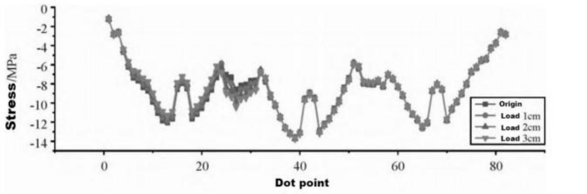

Figure 7. Comparison of section stress of main beam of the whole bridge at different forced displacements

3.2. Angle monitoring during rotation

The project is a 4000t swivel support. The precision error of the spherical hinge is required to be less than 2mm, and the deviation of the beam axis is less than or equal to 10mm. The monitoring technology of the rotation angle is highly required. The total station is used for dynamic monitoring in the project to ensure that the rotation is carried out at a stable, continuous and low-speed angular speed. Avoid over rotation as far as possible.

4. 3D laser scanning technology to detection

In this paper, a hypothesis is put forward to apply the three-dimensional laser scanning technology to the project. Compared with the traditional total station, the three-dimensional laser scanner can achieve 360° horizontal three-dimensional coverage scanning. It can effectively reduce the number of monitoring points, as shown in Figure8, to reduce the different impacts of site factors on monitoring points. Finally, after comparing the professional point cloud processing software Geomagic platform algorithm and the laser scanning NURBS surface reconstruction algorithm, it is concluded that for the monitoring of elevation deviation, the three-dimensional laser scanner can control the error within plus or minus 0.25mm, as shown in Figure 9, which is far less than the error accuracy of the total station. After analysis, it is feasible to apply this technology to the technical monitoring of bridge engineering, and the construction accuracy can be greatly improved.

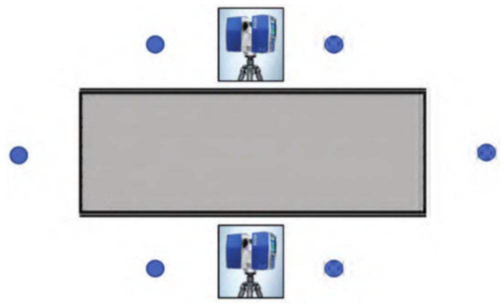

Figure 8. Layout scheme of laser scanner

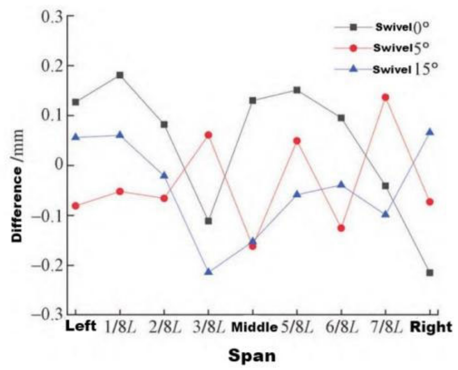

Figure 9. Difference distribution

5. Conclusion

Based on the case study of the swivel project of Ciping Village Bridge in Yunnan Province at Xiangyun toll station, and on the basis of summarizing the swivel technology, this paper discusses the construction monitoring technical scheme of the double swivel Cross railway bridge.

(1) For the swivel structure that needs to cross the existing railway, it is necessary to give priority to whether the elevation meets the minimum requirements of the overhead contact system. When the overhead basket is used for operation, the local environmental conditions shall be investigated to ensure the safety of the basket.

(2) In the construction and installation, it is concluded that the choice of spherical joint size should be determined according to the mass of the rotating body. The two rotating bodies are weighed respectively, and the rigid body displacement mutation method and the couple formula are used to calculate the types of forces and determine the bob-weigh scheme. Key construction items such as traction rope and high-altitude hanging basket are also discussed accordingly.

(3) In the construction monitoring, the monitoring technology of cantilever end superelevation and rotation process angle control is analyzed. It is suggested to adjust the superelevation error by adjusting the spherical joint. Finally, the three-dimensional laser scanning technology is substituted into the engineering monitoring part, which proves that the traditional total station monitoring can be replaced in accuracy and algorithm, and the monitoring data scheme optimization in accuracy can be realized.

Since this case is a double turn sequential operation, which is different from parallel operation, there are certain limitations to apply on all double swivel projects. It is hoped that the parallel operation double rotation can be incorporated into the study in the future research.

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