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Research paper

Study on sling replacement of concrete-filled steel tube arch bridge

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Abstract: Concrete-filled steel tube arch bridge is filled with concrete inside the steel tube. The radial constraint of the steel tube limits the expansion of the compression concrete, which makes the concrete in the three-way compression state, thus significantly improving the compressive strength of the concrete. At the same time, it can simplify the construction process and shorten the construction period. Since the rapid development of concrete-filled steel tubular tied arch bridge in the 1990s, a large number of such Bridges have suffered from the defects of steel concrete, loose tie rod, and hanger rod rust, etc. Therefore, the reinforcement technology for various diseases has been studied, among which the reinforcement technology for hanger rod replacement is the most complicated and more difficult. As more and more bridges of this type enter the period of reinforcement, it ismore and more urgent to study the reinforcement technology of suspenders. Taking a bridge that has been in service for 23 years as an example, this paper discusses the construction method and construction monitoring of replacing the suspender, so as to guide the construction monitoring of the bridge. Finally, the construction monitoring results of the bridge are given, which can provide reference for the replacement of the suspender of this type of bridge

Keywords: concrete-filled steel tubes arch bridge, arch bridge, sling, simulating computation, monitoring

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1. Introduction

In the 1990s, due to the novel structure and low cost, a large number of CFST arch Bridges were built in China. The most fatal weakness of this system is that its beams are hung directly from the suspendpoles [1]. However, the early concrete-filled steel tube arch bridge was limited to the construction technology level of the cable at that time, and cement mortar grouting technology was generally used to carry out anti-corrosion, resulting in severe corrosion of steel wire, so it had to be replaced after more than ten years of operation [2]. The service life of the sling is generally 15 to 20 years. Disease usually occurs on the cable head, the cable sleeve and the cable body. Cracking is the main disease of the sheath. Through the investigation on the suspension rods and stay cables of some arch Bridges, it is found that the sheath cracks within a few years, the shortest is less than 1 year, the longest is less than 10 years, and the specific forms of cracking are cracking, scratches, scratches and cracks. The main diseases of anchor head are anchor head deformation and corrosion. The deformation of anchor head mainly occurs in the process of hypertension inspection before the hanger rod leaves the factory. Rust is the most common disease of anchor head. Before or in the process of installation, the derrick does not pay enough attention to the corrosion caused by insufficient protection, and the cover plate of the anchor head is not set or the cover plate is not tightly sealed, which leads to the corrosion of the anchor head caused by water accumulation in the anchor box. The steel wire forehead corrosion is the most frequent disease during detection, and it is also the direct cause of cable failure. The corrosion is caused by the contact of the steel wire with the corrosive medium. The rain, moist air and even microorganisms entering the cable body may lead to the corrosion of the steel wire. In the process of removal and replacement, the internal force and linear shape of the derrick, arch ring and main beam are constantly changing. Therefore, it is necessary to monitor the internal force and deformation in the process of replacement of the derrick to ensure that the internal force state after construction reaches the initial design state [3].

2. Project profile

Pengshui wujiang bridge, a large bridge from pengshui to wulong, is located in pengshui county of pengwu highway, line 319 of national highway. This elevation is shown in Fig.1. The main hole of the bridge is a 1×150 m concrete filled steel tubular truss arch bridge, and the arch rib is catenary of equal section. The vector span ratio is 1/5, and the arch axis coefficient m is 1.347. And bottom chord use Φ 600×10 mm steel tube, infusion of C50 concrete, slings using ordinary reinforced concrete structure. The span is 11.60 m, and the derrick spacing is 5.07 m. The design load is truck-20, the trailer -100. The plan and cross section of the bridge are shown in Fig. 2. The bridge was completed and opened to traffic in 1997, and has been in use for more than 23 years. After many years of use, various parts of the bridge have suffered from diseases of different degrees. In August 2019, the inspection department carried out appearance inspection and static and dynamic load tests on the bridge, and carried out maintenance and reinforcement design for the bridge according to the inspection report. Main reinforcement measures include replacing all the derrick, the partial Π board to replace, and Π in beam plate crack and breakage of exposure to repair, to the rail and lighting facilities for repair.

Fig. 1. Lateral view

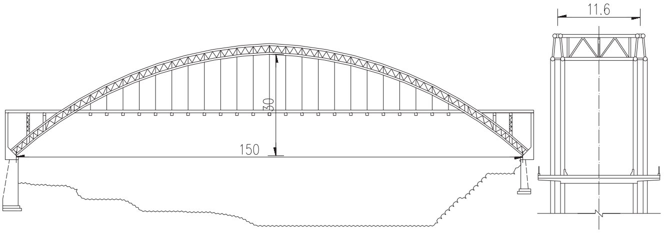

Fig. 2. Elevation and cross-sectional drawing (m

3. Analysis of influencing factors of bridge deck alignment

During the replacement of the derrick, the placement of the new 88 PI plates evenly across the bridge span would affect the deck elevation. Therefore, it is necessary to calculate the effect of the new plate on the alignment of the deck. Finite element analysis software Midas/ Civil was used to establish the full bridge model (See Fig. 3), the weight of all the plates was evenly distributed on both sides of the slings.

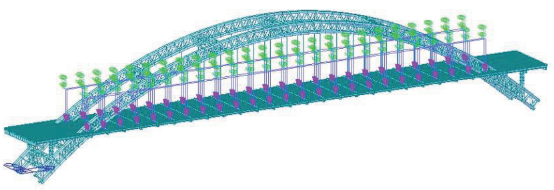

Fig. 3. Bridge finite element model

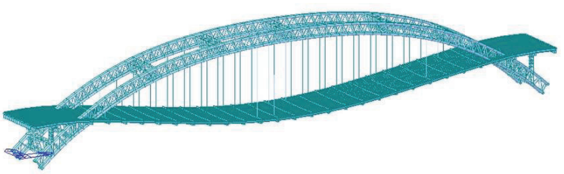

Fig. 4. Linear change

According to the calculation, the maximum variation of bridge deck height variation is 3.13mm in the mid-span area of the bridge structure. The maximum change of deck elevation in the quarter bridge span area is 1.79mm, and the maximum change of deck elevation in the vicinity of No.2 derrick and No.22 derrick is 0.93mm. The most unfavorable state is considered in the calculation model, and the effect of plate on the alignment of deck should be relatively small in practice.

4. Monitor the plan and content

The stress and displacement of the bridge structure change frequently at each stage during the replacement of the suspender, the tension program of the suspender, the environmental temperature and the physical and mechanical parameters of the materials during the construction, etc., all have an impact on the internal force and linear shape of the bridge structure. Therefore, in order to ensure that the internal force and line shape of the bridge after replacement are consistent with those before replacement, it is necessary to control the construction process during the replacement of the bridge suspender [4-5]. The replacement of suspender follows the principle of horizontal and longitudinal symmetry. As follows: Sling 12→Sling 11 (11’) →Sling 10 (10’) →Sling 9 (9’) →Sling 8 (8’) → Sling 7 (7’) →Sling 6 (6’) →Sling 5 (5’) →Sling 4 (4’) →Sling 3 (3’) →Sling 2 (2’) →Sling 1 (1’). The construction will be carried out in twelve stages. Except for the replacement of two derricks in the first stage, four derricks will be replaced symmetrically in each stage.

4.1. Construction control method

The Midas/Civil space finite element model was established to simulate and analyze the construction process of hanger rod replacement, and the internal force and deformation data in each construction stage and under the bridge completion state were obtained as the theoretical data of construction control. It is mainly to monitor the main arch ring, the bridge deck alignment and the key section stress before and after the hanger rod replacement. These test data and theoretical calculation results are compared and analyzed to timely grasp the actual stress state of the structure. By providing construction monitoring information, project construction is guided, Construction monitoring can ensure the safety of the bridge construction process and make the bridge deck alignment and internal force state meet the design requirements after reinforcement and maintenance.

As the arch ring and deck elevation are greatly affected by the order of suspender replacement and tension, the construction process of the bridge is controlled by the combination of pre-control and feedback control. Before the hanger rod is replaced, the performance of the material is tested to obtain the accurate parameter index value as far as possible, and the finite element software is used for simulation calculation and analysis to obtain the internal force and linear shape. In the construction process, the measured data and theoretical data are compared and analyzed to find out the causes of errors, the least square method is used to identify and correct the parameters, and the subsequent construction process is adjusted for feedback control, so as to finally meet the design requirements for safety and internal force and line shape in the process of hanger rod replacement.

4.2. Internal force monitoring

By monitoring the internal force of the temporary derrick, the construction safety of the temporary derrick can be guaranteed. By monitoring the internal force and deformation of arch ring, derrick and bridge deck, the main structure can be controlled to be safe and linear [6]. The temperature and elastic modulus of materials are monitored in the construction process to facilitate the correction of parameter errors in the construction process of the bridge, so as to reduce the actual stress and theoretical calculation errors [7].

Through the stress calculation of the key section of the hanger rod replacement arch rib, the arch foot section and L /4 section of arch span have great internal force variation during the hanger rod replacement project. Therefore, internal force monitoring should be carried out for the two arch feet of the arch rib and the l/4 section of the left and right half arch span and the middle span. The test section is shown in Fig. 5. The five main test section stresses under each construction stage are shown in Fig. 6~ Fig. 7.

By monitoring the internal force of the temporary sling, the stress state of the sling can be grasped at any time to ensure the safety of the replacement process. The bridge adopts the method of bonding strain sensor, which can be used to read the internal forces at each control point at any time by bonding the strain sensor on the stress arrangement point of arch ring and temporary suspender.

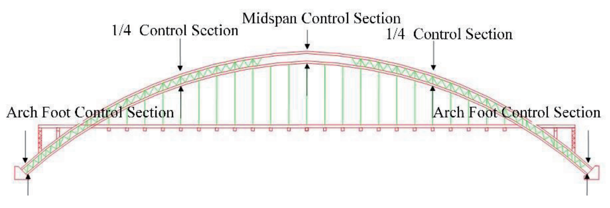

Fig. 5. Stress control section layout

Fig. 6. Temporary derrick internal force monitoring

Fig. 7. Stress arrangement of arch ring

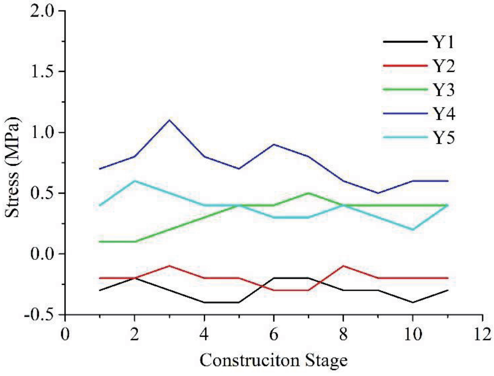

Fig. 8. Y-direction stress diagram of key section at each construction stage (MPa)

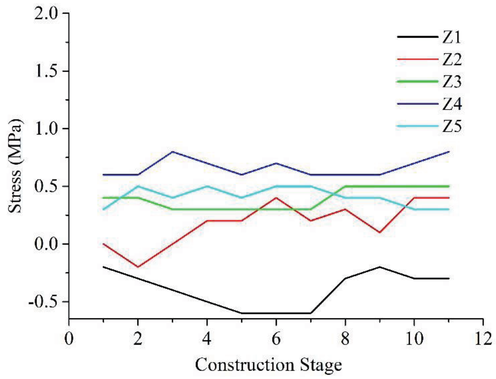

Fig. 9. Z direction stress diagram of key section in each construction stage (MPa)

It can be seen from the stress diagrams in the X and Y directions of the main test sections in each construction stage that the stress changes little in each construction stage, and the maximum is only 1.1mpa. The stress in the whole construction process is reasonable.

4.3. Deformation Monitoring

(1) Bridge elevation

Understand and master the changes of bridge deck alignment during construction to ensure that the elevation and alignment of the strengthened bridge deck meet the design requirements. The monitoring method adopted: the leveling closed loop route and the triangular elevation of the total station rangefinder were observed. The comparison of elevation differences on the right side, center line and right side before and after replacement was shown in Fig. 10.

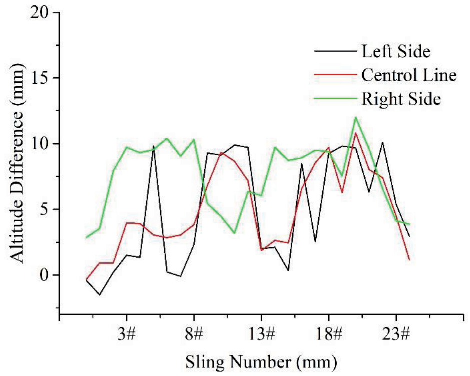

Fig. 10. Change elevation difference between left side, center line and right side of bridge before and after

(2) Arch axis

The monitoring method is as follows: polar coordinate method of total station rangefinder or two-point intersection method for observation. Displacement changes of measuring points in X, Y and Z directions of arch ring before and after replacement are shown in Fig. 11.

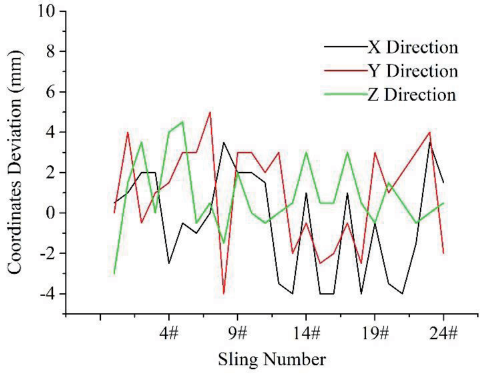

Fig. 11. Before and after replacing the coordinate chart of each direction of the arch ring measuring point

Fig. 10 and Fig. 11 shows that the elevation of the bridge deck at the replacement of the derrick and the adjacent derrick is controlled within ± 10mm, and the local elevation measuring point exceeds 10mm, but the exceeding range is very small. The maximum variation of the transverse coordinates of the arch ring is 5.5mm, the maximum variation of the longitudinal coordinates is 5.0mm, and the maximum variation of the elevation is 4.5mm, which meets the allowable variation range of the main arch ring of the bridge.

4.4. New derrick cable force monitoring

The cable force of the suspender should be measured during the whole cable changing process. After the replacement of the new suspender, the cable force of the newly installed suspenders should be measured. After all derricks have been replaced as required, all new derricks will be cable tested [8]. Anchor cable tester was shown in Fig.12. During the construction, anchor cable meter is mainly used to monitor the cable force. The variation of the force on the left and right side of the whole bridge under the construction stage of each replacement boom is shown in Fig. 13~ Fig. 14.

(a) Anchor cable reader (b) Rope meter

Fig. 12. Anchor cable tester

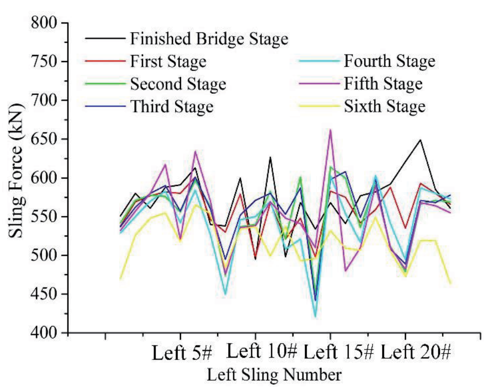

Fig. 13. Sling force at each stage of left sling

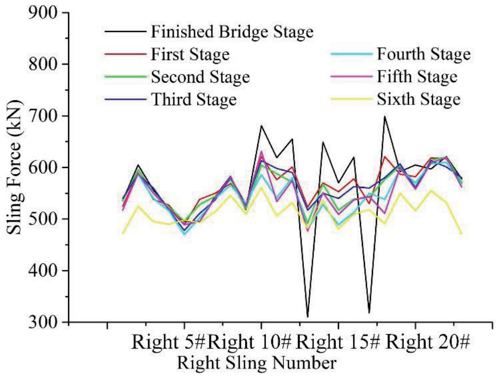

Fig. 14. Sling force of the right sling at each stage

In each working stage, the cable force on the left and right side of the cable changes uniformly, and the cable force value is adjusted to be closer to the design cable force value in the last adjustment (bridge completion).

4.5. Monitoring during rigging

After the replacement of the sling, the internal force of the sling will change greatly due to the influence of construction error and tension stress of adjacent sling or other reasons, The purpose of cable adjustment is to make the bridge structure in the best state of linear and internal forces, so that the suspender cable force to reach the design of the cable force or the design of the cable force error. In fact, when the line of the structure is adjusted to the ideal state, the internal force of the structure is also expected to be in the best state, both must be taken into account. For example, in the design of arch bridge, the internal force of derrick should be controlled within the allowable range while the beam is being leveled. Therefore, the displacement and internal force should be controlled.

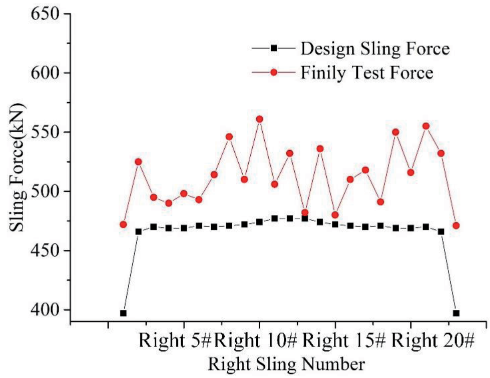

Fig. 15. Comparison diagram of cable force before and after replacement of right cable

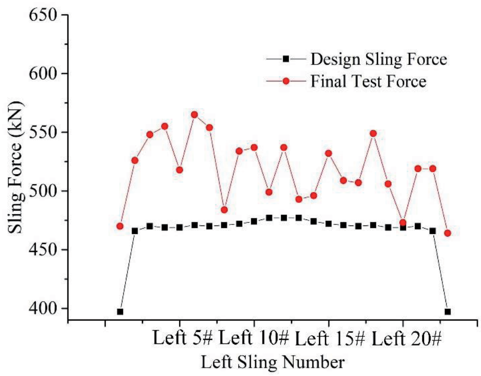

Fig. 16. Comparison diagram of cable force before and after replacement of left cable

According to Fig. 15~ Fig. 16, the deviation between the cable force value of 46 new suspender and the cable force design value is controlled within 20%. After the cable adjustment, the bridge is in linetype and meets the monitoring requirements.

Table 1. The new No.11 and No.13 slings force value during sling replacement

Location	Anchor cable gauge value K	Force on the new derrick after tension P(t)	Actual cable force of temporary suspender after unloading P(t)
Y11	4.650×10-4	49.1	55.6
Y13	4.519×10-4	46.3	49.6

Z11	4.539×10-4	53.2	56.3
Z13	4.460×10-4	52.3	54.4

Table 2. The stress value of key section after No. 11 and No. 13 slings replacement

Number	Stress (MPa)	Number	Stress (MPa)
Y1	-0.2	Z1	-0.3
Y2	-0.2	Z2	-0.2
Y3	0.1	Z3	0.4
Y4	0.8	Z4	0.6
Y5	0.6	Z5	0.5

5. Conclusion

Through the replacement of the suspender of concrete-filled steel tube arch bridge, the following conclusions are drawn:

1. During the derrick replacement, the bridge deck elevation at the derrick replacement and adjacent derrick shall be controlled within ±10 mm. The local elevation measuring point exceeds 10 mm, but the exceeding range is very small, and the change of bridge deck elevation is within the permitted range. No abnormal conditions were observed in the temporary sling system during tensioning and unloading. After the new suspender is tensioned, the maximum compressive stress of each key section of the bridge during the suspender replacement period is 0.8mpa, and the maximum tensile stress is -0.4 MPa, meeting the monitoring requirements.
2. The maximum variation of the transverse coordinates of the arch ring is 5.5mm, the maximum variation of the longitudinal coordinates is 5.0mm, and the maximum variation of the elevation is 4.5mm, which meets the allowable variation range of the main arch ring of the bridge.
3. After the cable adjustment, the bridge is smooth and linear. The deviation of 46 new suspender cable forces from the designed cable forces should be controlled within 20%, and the deviation of cable forces after cable replacement should be within a reasonable range.

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