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TECHNOLOGY RESEARCH FOR MAIN ARCH ON STONE ARCH BRIDGE REINFORCEMENT ENGINEERING'S CONSTRUCTION MONITORING

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Abstract: Construction monitoring in bridge construction and reinforcement is an essential part of the reconstruction project. Monitoring the linear deflection and stress of the bridge make it possible to solve problems in time, and to ensure consistent with the design [1]. According to the background of Da Xi He No. 3 bridge reinforcement project and combined with the design scheme of reinforcement and reconstruction, this paper expounds the construction monitoring technology and effect on the linear and stress monitoring.

Keyword: stone arch bridge, main arch, reinforcement, linear, stress, construction monitoring.

I. INTRODUCTION

Arch bridge is widely used in highway for beautiful shape, pass-over capacity and can fully make use of material strength. Stone arch bridge, as a kind of arch bridge, has been built long ago and appears a lot of diseases. With the bearing capacity decreasing, unsafe bridge will cause accidents and endanger the people's lives and property. The period of days spend on constructing a new bridge is longer. It will cost enormous amount of money and certainly cause the traffic interruption for months. Therefore, it seems the bridge reinforcement is one of the best choices. To ensure the construction quality and constructing the bridge safely, the construction of monitor is essential in the reinforcement construction process[2]. Based on the background of DaXiHe No. 3 bridge reinforcement project, this paper offers reference for similar bridge construction monitoring by introducing deformation monitoring and stress monitoring method.

II. PROJECT SUMMARY AND REINFORCEMENT METHODS

A. *Project summary*

DaXiHe No. 3 bridge is a stone arch bridge, located in Fuling, a district belong to the city of Chongqing in China. It is 90 meters long (including two of 30m of vice-arches and 60 meters of main arch) and 20 meters wide (including 6.8 meters of traffic lanes and 0.75 meters of pavement on each side). The arch axis of main arch utilizes the catenary curve. The net span of main arch is 60 meters and rise is 11.25 meters. The rise to span ratio is 0.1875. The net span of spandrel arch is 4 meters and rise is 1 meters. The rise to span ratio is 0.25.The bridge deck system is 1.2%. The layout of the bridge is shown in figure 1.

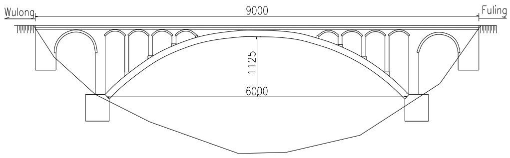

Fig. 1. The layout of DaXiHe No. 3 bridge (unit: mm).

B. *The scheme of the reinforcement design of the main arch bridge*

In this paper, the main arch reinforcement is studied. To minimize the damage of the original structure, simplify the reinforcement structure, safe and convenient construction, the main arch was reinforced by C-S-C (concrete-stone- concrete) method.

(1)The filled spandrel of main arch: Under axial pressure and positive bending moments, which is easy to appear the over- tensile -stress on lower limb under the most unfavorable effect combination. Hence the filled spandrel of main arch reinforcement can adopt l-shaped reinforced concrete arch rib as an auxiliary of the original stone main arch stress, and reduce the trouble and risk of dismantling construction on the filled spandrel of main arch. l -shaped reinforced concrete arch rib is shown in figure 2.

(2)The open spandrel of main arch: Under axial pressure and negative bending moments, and it is easy to appear the over- tensile -stress on upper limb under the most unfavorable effect combination. Hence the filled spandrel of main arch reinforcement can adopt trough type reinforced concrete arch rib as an auxiliary of the original stone main arch stress. Trough type reinforced concrete arch rib is shown in figure 3.

(3)It is essential to set transverse struts between left and right trough type reinforced concrete arch rib with the appropriate spacing in the corresponding position of cross wall and cross section. It greatly improves the integrity of bridge.

(4) The trough type reinforced concrete arch rib in the foot is joined to the reinforced concrete abutment, subsequently a new framework of reinforced concrete arch ribs is formed.

The new concrete structure works together with the stone structure which mainly relies on the compatibility of deformation. It increases the area of section and the moment of inertia and decreases the stress of the original stone arch [3]. The main arch reinforcement improves bearing capacity. The reinforced main arch is shown in figure 4.

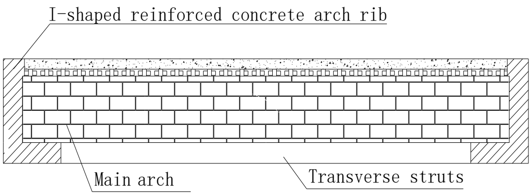

Fig.2. I-shaped reinforced concrete arch rib.

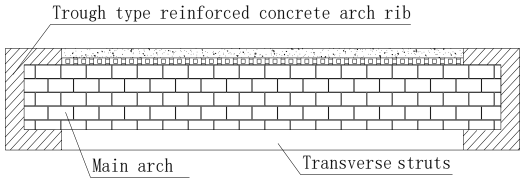

Fig. 3. Trough type reinforced concrete arch rib.

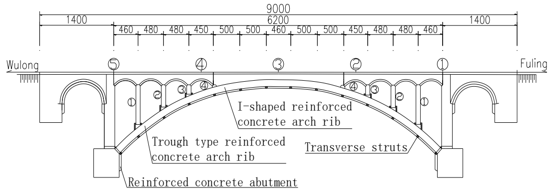

Fig.4. The elevation of reinforced main arch (unit: mm).

III. DEFORMATION MONITOR

The observation data of deflection and plane position is an important content during its construction. Ensuring the process of bridge reinforcement is safe. To reduce the influence of other factors as far as possible, the observation data of deflection and plane position should be measured in the low temperature (in the morning before the sun come out).The temperature should be recorded at the same time[4]. The effects of main construction steps on displacement can be reflected by deformation monitor.

A. The selection of deformation monitoring location and measurement method

The monitor points corresponding to main control sections (vault, arch foot, L/4) on the main arch should be chosen in the upstream and downstream of bridge deck. The monitor points are shown in figure 4. In the upstream of bridge deck, the base point is 1#.The monitor points of arch foot is 2# and 6#. The monitor points of L/4 of main arch are 3# and 5#. The monitor points of vault are 4#. In the downstream of bridge deck, the base point is 7#.The monitor points of arch foot is 8# and 11#. The monitor points of L/4 of main arch are 9# and 12#. The monitor points of vault are 10#. Steel rules ought to be set up at each monitor points by a certain elevation [5]. The deformation of bridge deck is measured by relative level of elevation. The change of elevation between twice measurements is the deformation of main arch between twice measurements.

B. The selection of deformation measurement

As a result of long span of main arch, large amount of concrete volume and difficult construction, the concreting of main arch was divided into five times to complete. The first concreting is from arch foot to the first cross wall. The first concreting is from arch foot to the first cross wall. The second concreting is from the first cross wall to the second cross wall. The third concreting is from the second cross wall to the third cross wall. The fourth concreting is from the third cross wall to the fourth cross wall. The fifth concreting is on the filled spandrel of main arch. Each concreting is symmetrical construction. Each time before and after the concreting is essential stage of construction, starting from the beginning of the main arch reinforcement.

C. The comparison for deformation measurement data and model data

In advance of the main arch reinforcement, the initial data was measured. The next step is measure deformation many times as soon as possible as it is a vital stage of construction. The construction should be shut down and analyze the outcome for the incident when the deformation measurement data has change dramatically.

The model used to simulate the every important construction process should be built before the measurement of main arch reinforcement. This bridge is modeled by the finite element software Midas Civil and by using beam element. The whole bridge model is a total of 744 nodes, 592 units [6]. The model is shown in figure 5.

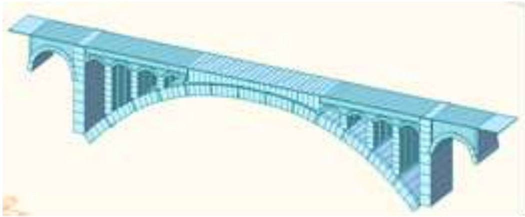

Fig.5. The model of main arch reinforcement of DaXiHe No. 3 bridge.

The construction stage joint interface method is used to simulate the process of main arch reinforcement. Firstly, the main arch section at each construction stage should be confirmed. After that, every stage of construction should be built. Then the new concrete section should be activated in suitable construction stages. So the original stone main arch and the new concrete arch rib are combined into a new main arch. Based on the stiffness of two kinds of components and the principle of deflections consistency, the internal force and stress of new main arch is distributed. Besides the shrinkage and creep caused by different material age should be taken into consideration [7]. The relative elevation can be calculated by dealing with model data, and then compare model data and measurement data. The measurement data is shown in table 1. The model data is shown in table 2.

Table 1.The measurement data of deformation of main arch reinforcement-relative elevation (unit: mm).

Monitor point	Condition	Before the main arch reinforcement	The first concreting	The second concreting	The third concreting	The fourth concreting	The fifth concreting
Base point1	1						
Arch foot of Fuling	2	2.2	2.3	2.3	2.3	2.2	2.2
L/4 of Fuling	3	5.7	5.7	6.1	5.9	5.9	5.8
Vault	4	8.9	8.6	9.2	9.5	8.9	9.4
L/4 of Wulong	5	5.8	5.8	6.4	6.1	6.1	6.4
Arch foot of Wulong	6	1	1.1	1.1	1.2	1	1.3

Base point	7						
Arch foot of Fuling	8	5	5.2	5.3	5	4.9	4.8
L/4 of Fuling	9	8.7	8.8	9.1	8.6	9	8.9
Vault	10	10.9	11	11.4	10.6	10.9	11.1
L/4 of Wulong	11	6.9	7.1	7.5	6.9	7.1	7.1
Arch foot of Wulong	12	4.2	4.2	4.4	4.3	4.2	4

Note: "L" stands for the length of main arch. the same below.

Table2. The model data of deformation of main arch reinforcement-relative elevation (unit: mm).

Condition / Monitor point	Before the main arch reinforcement	The first concreting	The second concreting	The third concreting	The fourth concreting	The fifth concreting
Base point1						
Arch foot of Fuling	1.201	1.21	1.237	1.267	1.28	1.239
L/4 of Fuling	7.32	7.329	7.447	7.787	8.137	8.754
Vault	11.593	11.296	10.38	9.759	9.395	13.981
L/4 of Wulong	6.77	6.804	6.973	7.313	7.594	8.013
Arch foot of Wulong	0.887	0.903	0.948	0.99	1.001	0.923

It is indicate that vault is the most liable to deform in the process of reinforcement after comparing the measurement deformation data and the model data of main arch reinforcement. It is followed by part L/4.Subsequently, the deformation of arch foot is extremely small. Considering the precision of level and steel rule, temperature, wind speed, the manual measurement error and other factors, it is inevitable for the difference between the measurement data and the model data. In general, the change trend of measurement data is consistent with the change trend of model data, besides the change of measurement data is hold within modest bounds.

IV. STRESS MONITORING

A. The selection of stress monitoring location and measurement method

Considering cost of the monitoring, it is impossible for each section of all the components to monitor stress. In general, the monitors are specifically buried on the critical sections so that the critical control sections could take place of all control sections [8]. Consequently, the stress state of the entire bridge could be controlled on the whole and get the most valuable information at cost savings. The sections of stress data acquisition are mainly at arch foot, L/4 and vault in main arch which are in a high stress area or repeated stress area and which are the most easily broken. They are most representative for security status and the most sensitive to precursor information of potential risk [9].

The equipment of stress monitoring are vibrating wire sensors which reflect stress of construction by the change of frequencies. The vibration frequency will be altered followed by the change of the distance between the two endpoints under changed load. The stress increment measured will be accurately calculated though the change of vibration frequency. Vibrating wire sensors with characteristics of high precision and small size which have been widely used for monitoring the safety of bridge [10].What calls for special attention is that the measurement of stress data is controlled within 3hrs before sunrise in order to avoid the influence of temperature. The layout of vibrating wire sensors is shown in figure 6.

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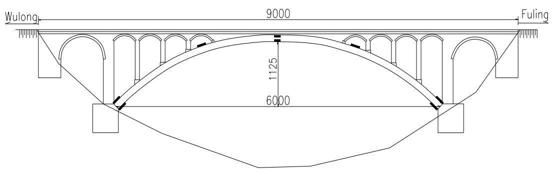

Fig.6. The layout of vibrating wire sensors

B. *Comparison of the stress measurement data with the stress model data*

The stress value on each construction stage can be searched in the output of the main arch reinforcement model. Plus the change of stress on critical control sections on each construction stage can be forecasted. Therefore the model data provide strong support for safety control in construction and construction technology and quality. Receiving the initial data before the measurement of main arch reinforcement, and then measure stress data many times as soon as possible in important construction stages. The construction should be shut down and analyze the results of the incident when the stress data of measurement has changed dramatically [11]. The stress data of measurement is shown in table 3.

Table 3. The stress measurement on each construction stage (unit: MPA)

Condition / Monitor point	Before the main arch reinforcement	The first concreting	The second concreting	The third concreting	The fourth concreting	The fifth concreting
Upper limb of arch foot of Wulong	-0.5004	-0.60048	-0.63384	-0.70056	-0.70056	-0.76728
Lower limb of arch foot of Wulong	-0.90072	-0.96744	-1.03416	-1.06752	-1.03416	-1.1676
L/4 of Wulong	-0.6672	-0.70056	-0.76728	-0.73392	-0.6672	-0.76728
Upper limb of vault	-0.834	-0.6672	-0.76728	-0.80064	-0.80064	-0.73392
Lower limb of vault	-1.16792	-1.16784	-1.1012	-1.16792	-1.16792	-1.13432
L/4 of Fuling	-0.43352	-0.5004	-0.43368	-0.5004	-0.46704	-0.73392
Upper limb of arch foot of Fuling	-0.60048	-0.63384	-0.70056	-0.63384	-0.70056	-0.80064
Lower limb of arch foot of Fuling	-0.93408	-1.23432	-1.23432	-1.3344	-1.3344	-1.26768

Because of the model being built by using beam element in Midas Civil, the stress of beam element in output are just the cross-section mean stress. Whatever the stress value of beam element in construction stage or the stress value of beam element in completion stage should be searched in the table of analysis results. The stress data of model is shown in table4.

Table4.The stress of model on each construction stage (unit: MPA)

Condition / Monitor point	Before the main arch reinforcement	The first concreting	The second concreting	The third concreting	The fourth concreting	The fifth concreting
Arch foot of Wulong	-1.35	-1.37	-1.38	-1.4	-1.42	-1.51
L/4 of Wulong	-0.994	-0.996	-1	-1.02	-1.06	-1.12
Vault	-0.946	-0.948	-0.957	-0.977	-0.99	-1.12
L/4 of Fuling	-0.982	-0.983	-0.991	-0.101	-1.05	-1.11

Arch foot of Fuling	`	-1.39	-1.4	-1.42	-1.44	-1.54

In order to be convenient to view the change of stress on main control sections, five broken line graphs are made. They are shown in figure7-11.

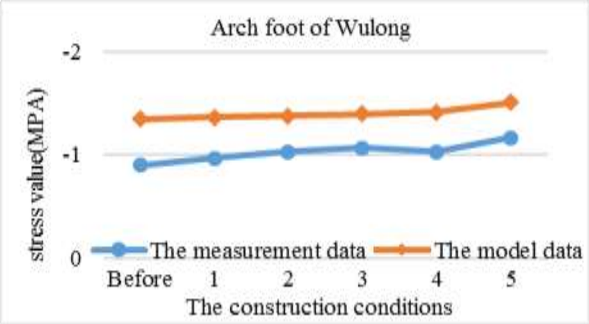

Fig.7.The change of stress on arch foot of Wulong

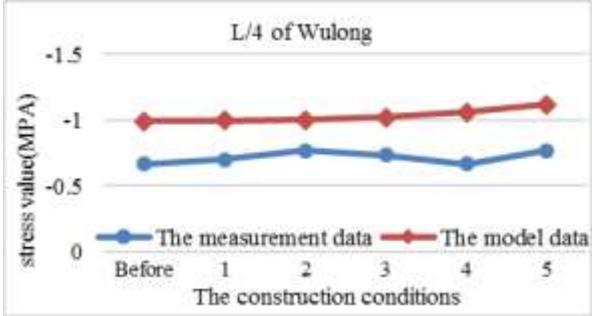

Fig.8.The change of stress on L/4 of Wulong

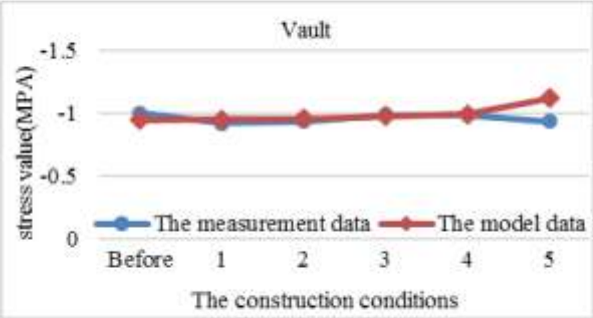

Fig.9.The change of stress on vault

Fig.10.The change of stress on arch foot of Fuling

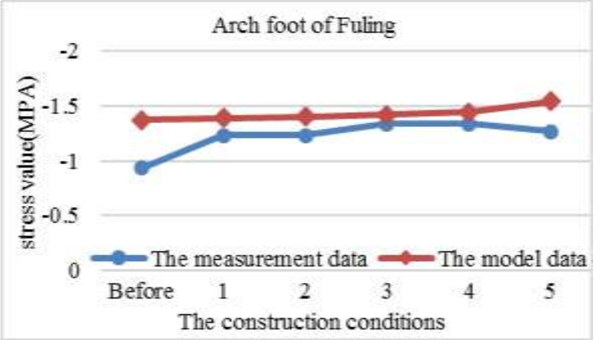

Fig.11. The change of stress on arch foot of Fuling

It is observed that the stress of arch foot、L/4 and vault have a tendency to gradually increase, however the variation is small. The stress on critical control sections for each construction stage are in state of compression and no more tension stress. It shows that the stress of arch foot、L/4 and vault are reasonable. Accordingly, we can ensure that the stress measurement value on each section is less than the stress model value and the limit value. The main arch is within safe levels and stress which can meet the requirement of the specifications.

V. CONCLUSION

By deformation monitoring, stress measurement and the finite element model analysis for the construction stages of main arch reinforcement of DaXiHe No.3 bridge, we can get the following main conclusions:

1. Vault is the most liable to deform in the process of reinforcement. It is followed by part L/4.The deformation of arch foot is particularly small. Because of the deformation being most easily detected in monitoring, the vault is the most important part of measurement on similar deformation monitoring in the future.

2. The stress on critical control sections on each construction stage are in state of compression. What is more, they have a tendency to gradually increase,however the variation is small. This shows that the adverse impact of C-S-C (concrete-stone-concrete) method on the original construction is very small and the integrity and bearing capacity of bridge are improved significantly. The good

reinforcement effect of bridge will prolong the service life of bridge.

The bridge have been safe and stable during the construction process of the main arch. The deformation and stress monitoring of main arch provide valuable guidance and reference for the construction. Monitoring work shows the results are satisfying.

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