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Analysis and Research on Displacement Monitoring of Operating Period of Large Span Continuous Rigid Frame Bridge

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Based on a large span continuous rigid frame bridge in Chongqing, this paper studies the bridge linear, the vertical displacement and offset of the pier and the deformation of the expansion joints. Firstly, the deformation data of the bridge was artificially measured. And then, calculates the theoretical values of the bridge deformation with finite element software named Midas. Finally, the author compares and analyzes the theoretical data and practical data on bridge linear, the vertical displacement and offset of the pier and the deformation of the expansion joints. It shows that the bridge is under normal working condition. The indicators of monitoring large span continuous rigid frame bridge are completed and the convenient evaluation methods of the working condition of large span continuous rigid frame bridge are put forward.

Keywords: Deformation monitoring; continuous rigid frame bridge; comparison and analysis.

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1. INTRODUCTION

In recent years, with the large span bridge construction prosperity and development, bridge structure and form is increasingly sophisticated, continuous rigid frame bridge has become popular because of its good capacity of span, construction convenience and low cost [1]. However, bridge deformation is too large due to the increasing traffic volume, overweight vehicle damage and the aging of structure and material, which affects the bridge structure's safety, durability and driving comfort, so the bridge structure deformation monitoring is particularly important [2].

Excessive mid-span deflection is one of the main diseases of continuous rigid frame bridge [3]. Real-time monitoring system about stress, deflection and cracking of large span continuous rigid frame bridge is studied by document [4]. Liu [5] indicated that the problem of cambering occurred at the top and the cambering was caused by the joint action of the girder span length, sun-shining, temperature variations, pre-stress tensioning, concrete shrinkage and creep [5]. Deformation monitoring of continuous rigid frame bridge are studied both at home and abroad [6-13], but most of them are used in construction control period rather than in operating period, what's more, the theoretical data and practical data has not been compared and analyzed. This paper takes a long-span continuous rigid frame bridge as an example, clears the contents and methods of deformation monitoring according to the relevant specification [14-19], calculates the theoretical values of the bridge deformation with finite element software, and then compares and analyzes the theoretical data and practical data. Finally, it shows that the bridge is under normal working condition. This paper provides the basis for continuous rigid bridge and it has good practical value.

2. PROJECT OVERVIEW

A large span continuous rigid frame bridge is located on Lurong highway of Chongqing. This bridge contains two pieces; the total length is 942 m, of which the main bridge length 612 m. The span arranged: 4×30 m (Approach)+(106 +2×200 +106) m (main bridge) +(4×30m +3×30 m) (Approach). Deck transverse arranged: 0.5m (Crash barrier) +11 m (lane) +1.50 m (medial divider) +11 m (lane) +0.5m (Crash barrier). Bridge deck sets up two-way cross slope of 2.1%.

Main bridge beam section is single box -single room section, center height of which is 3.50m, baseboard thickness is 0.28m, and roots height of which is 12m, baseboard thickness is 0.70 m. The girder baseboard width is 6.5 m and the apical plate width is 12 m. Box girder height and box girder slab thickness change at 1.8 parabola. Thickness of box girder web plate of the roots of the beam is 0.76 m and the one of mid-span of the beam is 0.41 m.

Pre-stressed concrete simply supported beam which span is 4×30.00m、3×30.00m are used in both pieces of approach superstructure.

Double-limb thin-walled hollow piers are used as the main pier in substructure, transitions are hollow thin-walled piers, bored pile foundations are used.

Double-column piers are used as approach pier, U-expanding base are used in No. 0 abutments, column abutments with pile foundation are used in No. 15 abutments, 9cm thick asphalt concrete is used in bridge deck surface layer. Bridge facade arrangement is shown in Fig. 1.

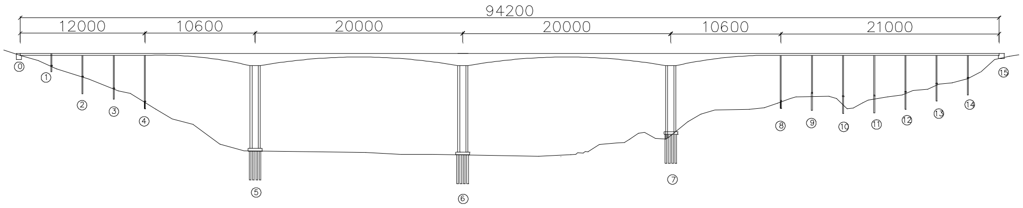

Fig. 1. Bridge elevation layout (units: cm)

3. DEFORMATION MONITORING METHODS AND MEASURING POINTS

According to the bridge situation, the study monitored the plane control network, vertical control points, bridge linear, main pier deformation and joints deformation of the bridge. The measurement systems include total station with optical prism which has the accuracy of 0.01 mm and indium-steel ruler with the accuracy of 1 mm.

3.1 Deformation Monitoring Methods

3.1.1 The plane control network

The plane control network is triangulation. The study used a total station with optical prism, directly on the middle of base, and according to the two horizontal control network technology in "Building Deformation Measurement Procedures" (JGJ8-2007) [14], we got the plane control network monitoring data by Traverse Surveying.

3.1.2 Vertical control points

Vertical reference points are measured by precise leveling with indium-steel ruler. According to the national second level measurement method, all observation standard routes are formed into closed ones [16].

3.1.3 Bridge linear monitoring

Indium-steel ruler is used to measure the bridge linear. According to the second level of “The National First and Second Leveling Norms” (GB / T 12897-2006) [16], the sight length of leveling, distance between the front and rear sight, and the number of precision level repeated measurements should all conform to the specification requirements for "secondary precision level". Before the measurement, horizontal angle should be adjusted at first. The reference point and the bridge linear observation point should be consisted into a closed loop, observation sequence is in accordance with the odd stop: "after - before - before - after", the even stop: "before - after - after - before", then the observation data would be adjusted.

3.1.4 Pier deformation monitoring

Total Station with optical prism is used to monitor the pier deformation. According to the secondary plane accuracy required in “Deformation measurement of building and structure” (JGJ 8-2007) [15], the polar method would be adopted for measurements.

3.1.5 Joints deformation monitoring

Joints deformation monitoring includes transverse displacement monitoring of both joints sides (Large Stake side and small Stake side) and steel gap change monitoring of the joints. a total station with optical prism are used to measure the transverse displacement monitoring of both joints sides and the steel tape are used to measure the steel gap change monitoring.

3.2 Test Point Arrangement of Deformation Monitoring

3.2.1 Bridge deck line

The bridge deck line monitoring points are make full use of the historical monitoring points, and some measuring points are added to where not meet the requirements of measurement spacing, specific arrangement of measuring points are as follows: The bridge deck line monitoring is only aim at the main line, the linear observation points longitudinal along the bridge are set in each L/2, L/4 and the fulcrums cross section of the main bridge, and according to the requirements of the stationing spacing is not more than 20 m, some linear observation points are added.

The linear observation points of transverse direction are set on the inner side bottom of the right and left of the bridge deck against wall and on the top of median concrete fence base. The bridge were divided into 4 vertical section which is left outside, left inside, right inside and right outside. (Line L, L’, R, R’). The whole bridge set 164 deck linear observation points. The observation points are made of stainless steel round head testing nails, anchorage glue are used to placement after drilling hole and red paint are used to mark. Measuring points plan is shown in Figs. 2 and 3.

3.2.2 Pier deformation

Deformation monitoring of the main pier laid 12 observation points. 4 observation points are laid at each pier which respectively arranged at the 0 # block diaphragms center of left piece outside and right piece outside of the main pier. These points arrangement plan is shown in Figs. 4 and 5.

3.2.3 Expansion joint deformation monitoring

There is 1 observation section set in each expansion joint of the main bridge in this expansion joint monitoring. Points are laterally set on the outside of the deck. There are four observation sections and eight measuring points in total. Each observation section has 2 measuring points. Measuring points plan is shown in Fig. 6.

4. DEFORMATION MONITORING RESULTS AND ANALYSIS

4.1 Theoretical Calculation of Deformation Monitoring

According to the material parameters and use conditions of the bridge, based on the relevant specification [17], the author used finite element analysis software modeling. Main beam and pier are simulated by beam elements. There are 275 nodes and 268 units in total. Because of traffic closing in the process of monitor, the model did not consider the moving load effect. The load types of the bridge model are mainly like concrete creep and shrinkage, the loss of pre-stress, uniform and gradients temperature change, etc., the discrete graph of structure model is shown in Fig. 7.

Through the calculation and analysis of the model, the theoretical values of the deck line, the pier deformation and the expansion joint deformation can be gotten.

4.2 Comparative Analysis of Theory and Measured Values

The theoretical calculation result is gotten by the model. According to the monitoring indicators and method of this bridge, the measured values of bridge deformation of the first period can be obtained in September 2012. The ones of the second period can be obtained in December 2012. In the monitoring process of bridge deck line and pier vertical displacement, the traffic is closed. In the monitoring process of main pier lateral offset and expansion joints, the traffic is unclosed. We can compare and analyze the measured values with the theoretical values. Main beam vertical deflection analysis, pier vertical and lateral deformation analysis, expansion joint deformation analysis results are as follows:

4.2.1 Comparative analysis of main beam deflection

In order to analyze the measurement results of two phases, we get the measured deflection by using the relative elevation data of the first period minus the second period one. According to the vertical displacement monitoring of the main pier, we can conclude that settlement has not happened in the main piers. Theoretical deflection data from the finite element structural model have considered the affect of temperature change, concrete creep and shrinkage, the loss of pre-stress. The comparison of the measured deflection and the theoretical deflection is shown in Figs. 8, 9.

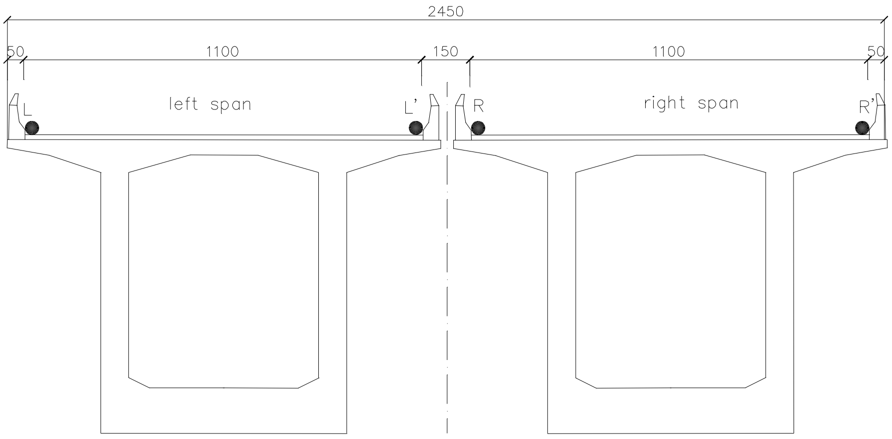

Fig. 2. The deck arrangement of measuring points in alignment profile (unit: cm)

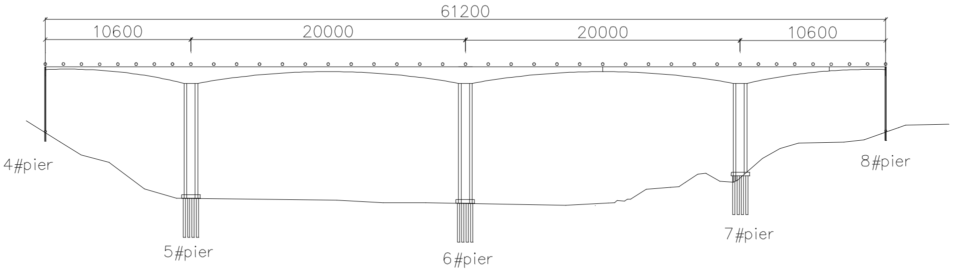

Fig. 3. The deck arrangement of measuring points in alignment profile (unit: cm)

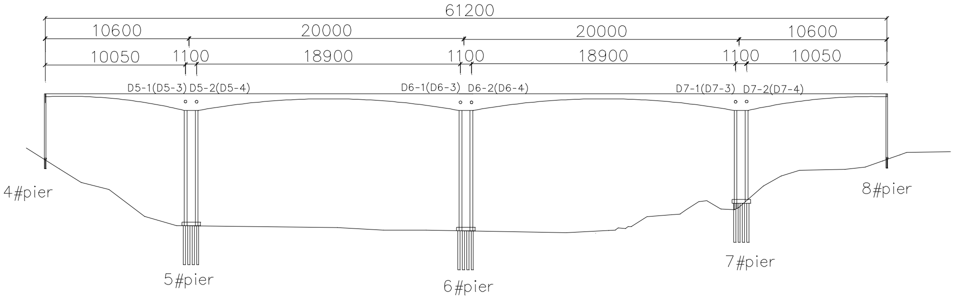

Fig. 4. Longitudinal measuring point on deformation of main pier (units: cm)

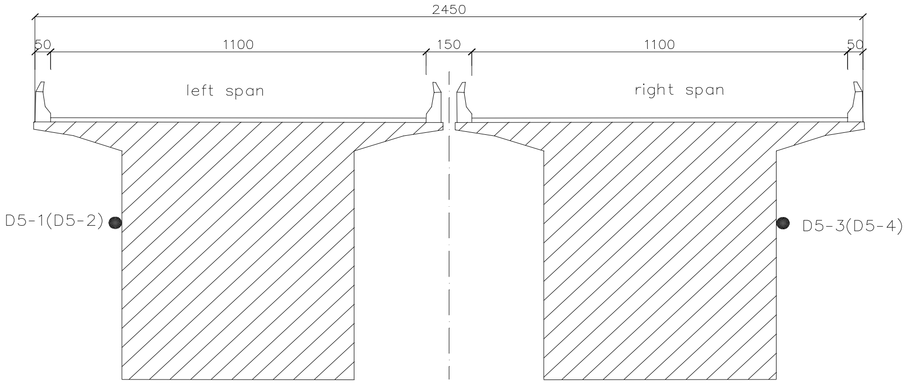

Fig. 5. Horizontal measuring point on deformation of main pier (units: cm)

As Figs. 8, 9 shown, for the left outside deck, the maximum deflection value is 18.76 mm which appeared at the of 0.417L section of 5#span. For the left inside deck, the maximum deflection value is 18.76 mm which appeared at 0.417L section of 6#span. For the right outside deck, the maximum deflection value is 13.86 mm which appeared at 0.417L section of 6#span. For the right inside deck, the maximum deflection value is 13.60 mm which appeared at 0.333L section of 6#span.

The curve of measured deflection is relatively smooth with no mutation. The measured deflection coincide well with the theoretical deflection. The measured values are less than theoretical values except individual non-critical points.

4.2.2 Comparative analysis of main pier vertical displacement

In order to know piers settlement situation and its affect to bridge linear in monitoring cycle, we measured the vertical displacement of pier. Comparison results of measured values and theoretical values are shown in Table 1.

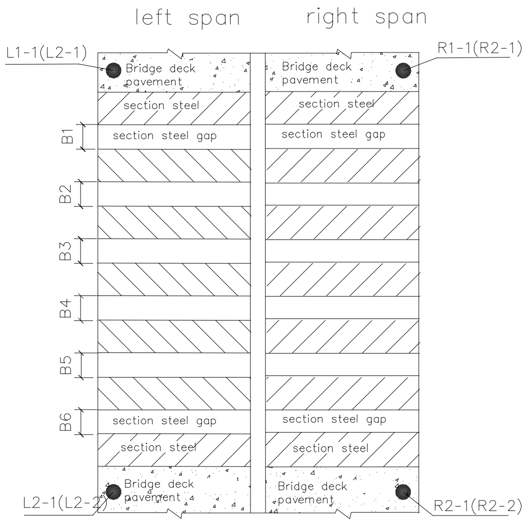

Fig. 6. Monitoring point arrangement on expansion joint deformation

Fig. 7. Discrete graph structure model

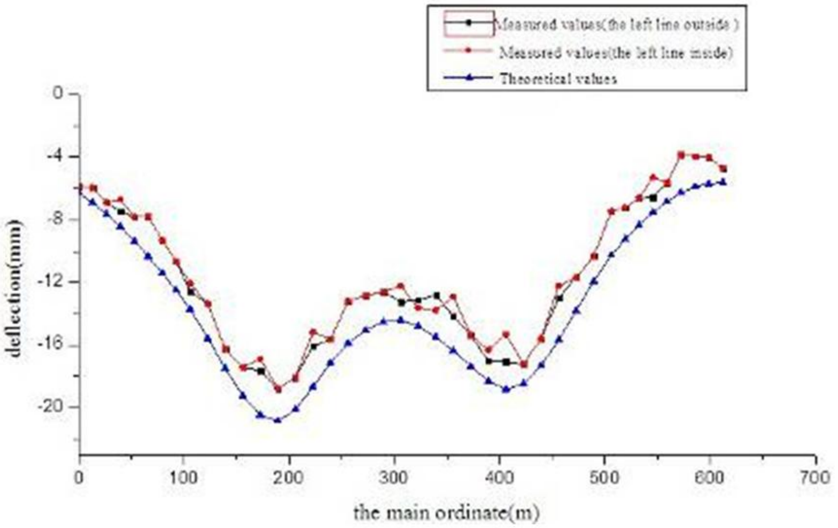

Fig. 8. The inside and outside measured deflection values compared with the theoretical calculation values on left side of the bridge

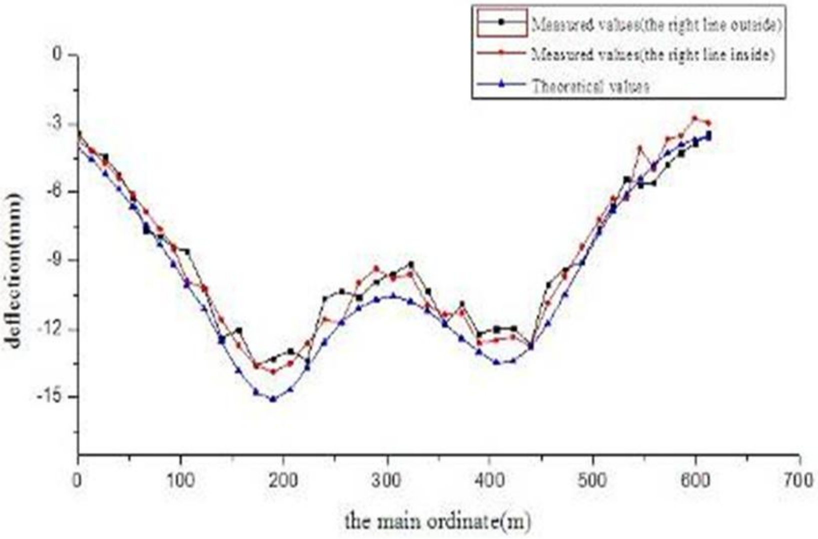

Fig. 9. The inside and outside measured deflection values compared with the theoretical calculation values on right side of the bridge

Table 1. Comparison on theoretical and practical vertical displacement value of main piers (units: mm)

No.	Location	Relative altitude of 1st phase	Relative altitude of 2nd phase	Measured vertical deformation	Calculated vertical deformation
1	Left span 5# pier top	100.96795	100.95540	-12.55	-13.70
2	Left span 6# pier top	99.60651	99.59328	-13.22	-14.39
3	Left span7# pier top	96.02002	96.01257	-7.45	-10.25
4	right span 5# pier top	101.44560	101.43571	-9.89	-10.05
5	right span 6# pier top	100.08538	100.07561	-9.77	-10.54
6	right span 7# pier top	96.51525	96.50806	-7.19	-7.79

From the test results of vertical displacement of the main pier we can get the following results: when the left piece under the conditions of cooling 16.4. The vertical deformation of 5#pier is 12.55 mm, which is less than theoretical value of 13.7 mm. The vertical deformation of 6# pier is 13.22 mm, which is less than theoretical value of 14.39 mm. The vertical deformation of 7# pier is 7.45 mm, which is less than theoretical value of 10.25 mm. When the right piece under the conditions of cooling 11.7ºC, the vertical deformation of 5#pier is 9.89 mm, which is less than theoretical value of 10.05 mm. The vertical deformation of 6# pier is 9.77 mm, which is less than theoretical value of 10.54 mm. The vertical deformation of 7# pier is 7.19 mm, which is less than theoretical value of 7.79 mm.

The above analysis shows that the vertical deformation of main piers is less than theoretical values, then we can determine that main pier settlement did not occur significantly.

4.2.3 Comparative analysis of main pier offset

In order to know piers offset situation and its affect to bridge linear in monitoring cycle, we measured the main pier offset. Comparison of results of measured values and theoretical values is shown in Tables 2, 3.

The offset of main piers of both pieces is shown in Figs. 10, 11.

From the test results of the main pier offset, we can get the following results: when the left piece under the conditions of cooling 17.4ºC, the offset of 5#pier is 42 mm, which is less than theoretical value, the offset of 6#pier is 9mm, which is less than theoretical value, the offset of 7#pier is 22 mm, which is less than theoretical value. When the right piece under the conditions of cooling 18ºC, the offset of 5#pier is 45 mm, which is less than theoretical value, the offset of 6#pier is 10 mm, which is less than theoretical value, the offset of 7#pier is 22 mm, which is less than theoretical value.

4.2.4 Comparative analysis of expansion joints

Compared the theoretical values with the practical values of 4 expansion joints, the result is shown in Table 4.

Table 2. Comparison on theoretical and practical offset of main piers on left side (units: mm)

No.	Location	Measured axial displacement	Measured axial average displacement	Theoretical axial displacement
1	small Stake side of Pier 5	43	42	44.61
2	large Stake side of Pier 5	41		
3	small Stake side of Pier 6	9	9	11.17
4	large Stake side of Pier 6	9		
5	small Stake side of Pier 7	-21	-22	-22.14
6	large Stake side of Pier 7	-23		

Table 3. Comparison on theoretical and practical offset of main piers on right side (units: mm)

No.	Location	Measured axial displacement	Measured axial average displacement	Theoretical axial displacement
1	small Stake side of Pier 5	44	45	46.32
2	large Stake side of Pier 5	46		
3	small Stake side of Pier 6	10	10	11.57
4	large Stake side of Pier 6	10		
5	small Stake side of Pier 7	-22	-22	-23.06
6	large Stake side of Pier 7	-22		

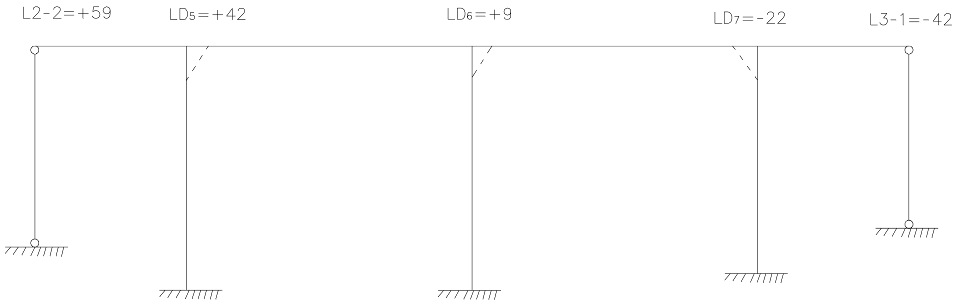

Fig. 10. Sketch about offset of main girder on left side of bridge

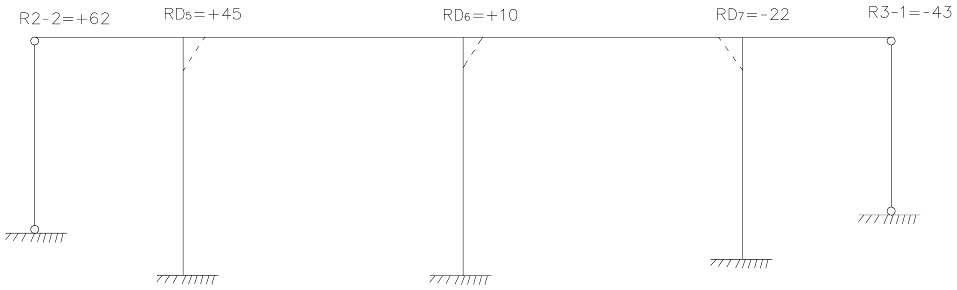

Fig. 11. Sketch about offset of main girder on right side of bridge

Table 4. Comparison on theoretical and practical expansion joint clearance of main piers (units: mm)

Pieces	Expansion joint No.	Total station measurements	Ruler measurements	Theoretical deformation
The left piece	L2#	69	69	72.38
	L3#	51	51	54.98
The right piece	R2#	71	71	74.88
	R3#	53	52	56.88

From the expansion joint measurement results, the width of each expansion joint is expanded under the condition of cooling. When the left piece under the conditions of cooling 17.4ºC, the 2# expansion joint had an expansion of 69 mm, less than the theoretical value of 72.38 mm. The 3# expansion joint had an expansion of 51 mm, less than the theoretical value of 54.98 mm. When the right piece under the conditions of cooling 18ºC, the 2# expansion joint had an expansion of 71 mm, less than the theoretical value of 74.88 mm. The 3# expansion joint had an expansion of 53 mm, less than the theoretical value of 56.88 mm. Showed that each expansion joint in normal working condition in the monitoring period.

5. CONCLUSION

Through the results of comparing and analyzing the theoretical data and practical data, we can get conclusions as follows:

(1). Measured deflection variation of the beam is consistent with the theoretical deflection curve. The curve of measured deflection is relatively smooth with no mutation and all of them are less than the theoretical value.
(2). The vertical deformation and the offset values of main piers are all less than the theoretical values. It can be initially determined that no settlement deformation of each main pier has happened during the monitoring period.
(3). In the field of environmental conditions, deformation values of expansion joints are less than theoretical values. So that expansion joints are in normal working condition.
(4). The indicators of monitoring large span continuous rigid frame bridge are completed and the convenient evaluation methods of the working condition of large span continuous rigid frame bridge are put forward.

This paper assesses the structural performance through structure static deformation and has not considered the deformation under the moving load condition. We can do a comprehensive assessment of the bridge structure by building a bridge health monitoring system to get information about the structural conditions and environmental factors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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