Design and Analysis for Reliability Comparison Test of Bridge Hanging Basket Automatic Monitoring System

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Abstract. Aiming at the problems that the manual comparison method corresponding to some monitoring items of the automatic monitoring system in the specification is not perfect and comprehensive, and the range of comparison deviation is not clear, the finite element analysis is used to determine the monitoring items, optimized the location and number of monitoring points. By means of the reliability comparison test design of the hanging basket automatic monitoring system, the wire displacement meter and the vibrating wire strain gauge are compared by the total station and the strain gauge respectively, and the results are analyzed by the method of single factor variance and regression analysis. The results show that the automatic monitoring and manual monitoring results are consistent. The results of single factor variance analysis show that there is no significant difference between the two, and the fitting correlation coefficient in the regression analysis is very close to 1.

Keywords: hanging basket; automated monitoring; finite element analysis; comparison test.

1 Introduction

With the advancement of urbanization in various places, all kinds of beam and arch combined bridges are favored by bridge designers due to their clear forcing and beautiful shape. In the construction of beam bridge, the most common and economical construction method is cantilever cast-in-place construction. The construction technology uses the completed part of the bridge structure as the force system, which can complete the construction without affecting the traffic under the bridge. Rhombus hanging basket is a more commonly used structural form, with few components, reasonable force, high bearing capacity, and the working coefficient can range from 0.3 to 0.6. In the construction process of the hanging basket, if the stress of the bar exceeds the allowable stress or the displacement of the bar is too large, the elevation of the formwork and the ultimately line type will be affected[1-2]. The calculation and analysis of some the hanging basket structures are neglected and monitoring of some hanging basket on-site is not paid attention to which may lead to the failure of the hanging basket structure and cause accidents. It has become bridge constructer s' consensus to strengthen the monitoring of various indicators of hanging basket struc-

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ture (including structural mechanics indicators and environmental indicators) [3-5]. At present, the corresponding hanging basket monitoring system has been developed on the market [6-9]. Some monitoring system with advanced Internet of things technology realize the automatic monitoring and wireless transmission focusing on "people, structure, environment, management" total factor monitoring. Monitoring technology has been a breakthrough. However, further research on the reliability verification of the hanging basket monitoring system needs to be done[10-13]. Domestic and foreign research in this area is slightly insufficient and lagging behind.

In terms of reliability verification, it is generally carried out by manual comparison and relevant guidelines are also given in the specification, such as the definition of comparison in the Technical Specification for Automatic Monitoring of Water Transport Engineering. The definition indicated that the process of the test comparing can compare different methods and different equipment basing on satisfying the test accuracy. Automatic monitoring technology specification for foundation pit engineering states that it is appropriate to use manual monitoring for comparison according to the frequency of every month to two months during the process of automatic monitoring. When abnormal sensor changes, important construction process and special construction methods appear, comparative measurement should be carried out immediately. At the same time, the specification states that if the vertical displacement is monitored by static force level, the level should be used for comparative measurement.[7]It also states that clear physical quantity changes should be given when it's easy to carry out and check whether the measured value has corresponding changes.

However, there are still some problems in the specification. The specification only lists some corresponding comparison methods. However, there is no corresponding comparison method and suggestion for stress monitoring. The specification does not specify how much the difference between automatic monitoring and manual monitoring is reasonable either. Considering the above problems, the hanging basket reliability verification test is designed and analyzed based on the construction of the bridge in Wanzhou, Chongqing. Firstly, the preload load and maximum segment load are analyzed by MIDAS software to determine the monitoring items and monitoring points. Based on this, single factor variance analysis and regression analysis are used to compare the process data to verify the reliability of the automatic monitoring system of the bridge hanging basket so as to ensure the accuracy and reliability of the data by the corresponding manual monitoring.

2 Finite element modeling

According to the size of hanging basket, the finite element model of hanging basket is established. Steel Q235 is used for the rear truss beam and steel Q355 is used for other component. The displacement and stress of each component under the preload condition and the maximum load condition are analyzed to provide reference for the layout of the measuring point. The hanging basket finite element model is shown in Figure 1.

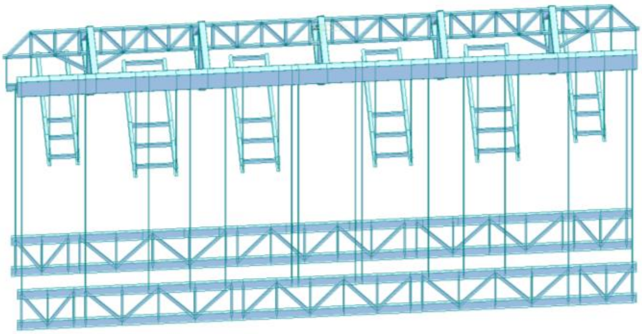

Fig. 1. Hanging basket finite element model.

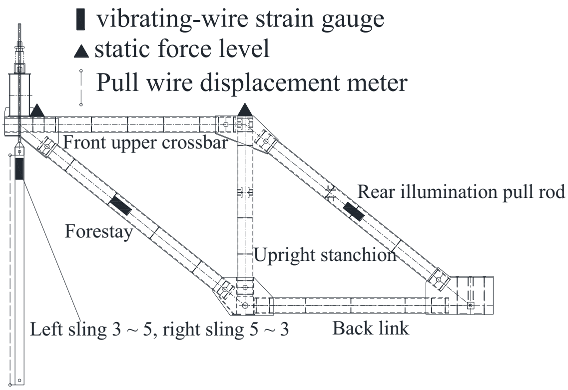

Fig. 2. Layout of typical section measuring point.

Table 1. Preloaded class of each jack.

Jacks' position	Load class (kN)		
	First load class	Second load class	Third load class
Left first piece truss	224.5	449.0	898.0
Left second piece truss	417.8	835.6	1671.1
Middle piece truss	421.9	843.8	1687.6
Right second piece truss	417.8	835.6	1671.1
Right first piece truss	224.5	449.0	898.0
Total load	1706.5	3412.9	6825.8

In order to eliminate the virtual displacement of the hanging basket system and provide more accurate data for the elevation of the vertical mold, the pre-load test process is designed. The detailed loading level and loading system are shown in Table 1. The reaction frame is uniformly embedded on the longitudinal ribs of the single box four rooms and the five reaction frames in the longitudinal ribs correspond to the five pieces of trusses on the bridge deck. At the same time, the maximum segment load of 902.4 t construction condition is analyzed.

Table 2. warning values of each level from different parts of the hanging basket

Monitoring item	Monitoring site	Warning level	Warning value
Stress	Steel sling	First level	105 MPa
		Second level	131 MPa
		Third level	153 MPa
		Fourth level	191 MPa
	Primary truss	First level	72 MPa
		Second level	92 MPa
		Third level	236 MPa
		Fourth level	295 MPa
Relative vertical displacement	Primary truss	First level	11.2mm
		Second level	14.0mm
		Third level	20.0mm

After calculation and discussion, the designer and the user of the hanging basket set the indicators of each part and the warning value of the hanging basket as shown in Table 2. According to the finite element analysis results, the stress and deformation of each rod are within the range of the warning value.

3 Arrangement of the key monitoring points of the hanging basket monitoring system

According to the above analysis results, the hanging basket automatic monitoring point layout is designed. A total of 12 vibrating wire strain gauges are arranged at the fore-stay, back stay, left and right slings 3~5 of the main trusses of the middle and secondary main trusses, which are used to monitor and calculate the strain at the position with the maximum stress. A total of 7 static force level are arranged at the upright stanchion and beam ends of the middle and secondary main trusses, which are used to monitor relative vertical displacement of the main truss. One of them is arranged at the position of upright stanchion of the side truss as the reference point. A total of 6 cable displacement sensors are arranged at the upper and lower ends of the left and right slings 3-5, which are used to monitor the elongation of the sling and check the elevation of the bottom basket formwork. The detailed layout of measuring point is shown in in Figure 2. The sensors installation in site is shown in Figure 3.

In order to verify the reliability and accuracy of the automatic monitoring system, the method of manual comparison is adopted. Among them, the measured data from static force level and cable displacement meter are compared with the total station and the measured data from vibrating wire strain gauge are compared with the strain gauge at the corresponding position. The manual comparison method corresponding to the cable displacement meter and the vibrating wire strain gauge is not specified in the specification. The selection of the total station is because of the high precision of the total station and it is also the most commonly used equipment for monitoring. The selection of strain gauge is because that the principle of strain gauge is simple and the force is clear. At the same time, it is also the most commonly used method for stress testing. The reaction frame for preloading is shown in Figure 4.

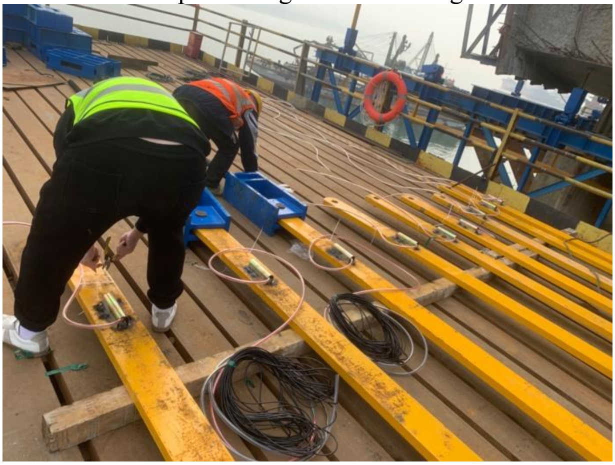

Fig. 3. The sensors installation in site.

Fig. 4. Reaction frame for preloading.

4 Comparing analysis between manual and automatic monitoring

In order to compare, the automatic monitoring curve is identified with the suffix ' A ', and the manual monitoring curve is identified with the suffix ' B '. It can be seen from Figure 5 that the automatic monitoring elongation from sling is basically consistent with the manual monitoring results. The vertical downward elongation is between-5.57 mm and-0.73 mm, showing a strong linear law in the preloading load.

Under the maximum load of 902.4 t, the elongation is slightly larger than the preloading prediction.

It can be seen from Figure 6 that the automatic monitoring stress from sling is in good agreement with the manual monitoring results. The sling stress is between 13.8 MPa and 89.4 MPa, showing a strong linear law in the preloading load. Under the maximum load of 902.4 t, the sling stress is slightly larger than the extrapolation prediction of the preloading results.

It can be seen from Figure 7 that the automatic monitoring vertical displacement from beam end is relatively consistent with the manual monitoring results, and the vertical displacement of the beam end is between-12.02~-2.13mm, which shows a strong linear law in the preload load. While under the action of the maximum load 902.4t, the displacement of the beam end is larger than that predicted by extrapolation of the preload results.

As can be seen from Figure 8, the stress of the forestay and back stay of the main truss in the automatic monitoring is consistent with the manual monitoring results. The forestay stress of the main truss is between-114.7~-20.6MPa and the back stay stress of the main truss is between 18.8~94.7MPa, which shows a strong linear law in the preload. Under the action of the maximum load 902.4t, the sling stress is larger than the prediction of the preload results.

The preloaded load is provided in the form of five concentrated forces by the reaction frame of the longitudinal ribs of the box girder and the load is mainly distributed in the bottom of hanging basket. The maximum load is distributed on the single-box four-chamber section through the entire hanging basket system. Half of the load on the bottom of hanging basket will be directly transmitted to the hardened structure without passing through the hanging basket. Therefore, the load acting on the hanging basket under the two working conditions is disproportionate. Under the maximum segment load condition, a greater proportion of load will be transmitted to the hardened structure through the hanging basket.

It is proposed in the specification that automatic monitoring should be compared with manual monitoring, but no specific evaluation methods and standards are proposed for the deviation between the two. In order to evaluate the difference between automatic monitoring results and manual monitoring results, single factor variance analysis and regression analysis were performed on the two results. The detailed results are shown in Table 3 and Table 4. Single factor variance analysis (also known as ' F test ') is a method to determine whether there is a significant difference between the two sets of data by calculating the relationship between the test value and the critical value or calculating the test probability. When the test value is less than the critical value, the hypothesis that there is no significant difference between the two groups of data is accepted under the condition of 95 % confidence. Otherwise, the hypothesis that there is no significant difference between the two groups of data is rejected, that is, there is a significant difference between the two groups of data. Or, when the test probability is greater than 5 %, there is no significant difference between the two groups of data. when the test probability is between 1 % and 5 %, there is a significant difference in the judgment data. When the test probability is less than 1 %, the difference in judgment data is extremely significant. From Table 3 ~ 4, it can be seen that through one-factor analysis of variance, the test value is much smaller than the critical value, and the test probability is much larger than 5 %. There is no significant difference between the results of automatic monitoring and manual monitoring.

Regression analysis is to calculate the regression model curve by regressing the measured value and the predicted value and obtain the fitting correlation coefficient. According to its position in the [0, 1] interval, the linear correlation between the two sets of data is judged. The closer the fitting correlation coefficient is to 1, the stronger the correlation between the two groups of data. The closer the fitting correlation coefficient is to 0, the weaker the correlation. From Table 3 ~ 4, it can be seen that the fitting correlation coefficient between automatic monitoring and manual monitoring results is very close to 1 and the correlation is very significant. Considering the linear fitting slope and intercept, it is conformed that there is a linear correlation between the measured value and the predicted value with a slope close to 1 and an intercept close to 0.

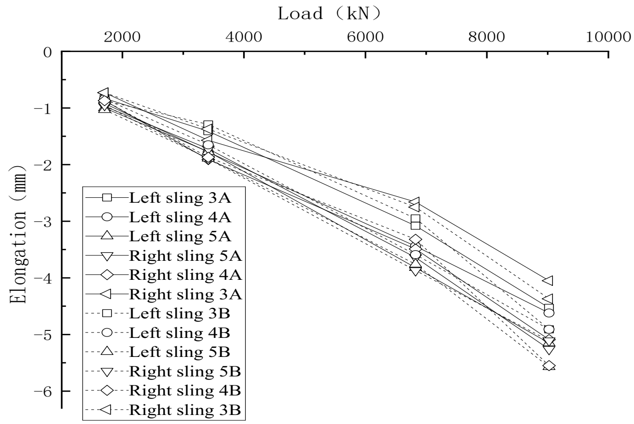

Fig. 5. Typical sling elongation curve

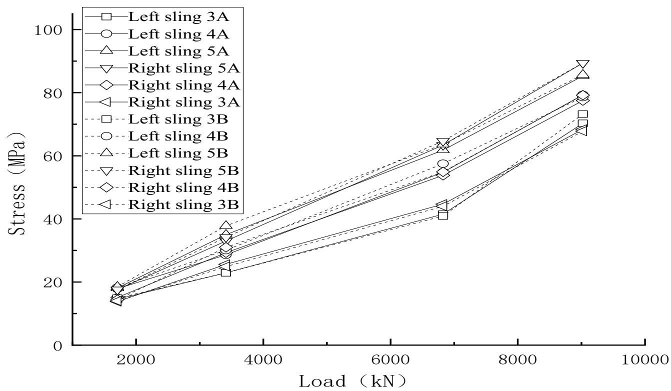

Fig. 6. Typical sling stress curve

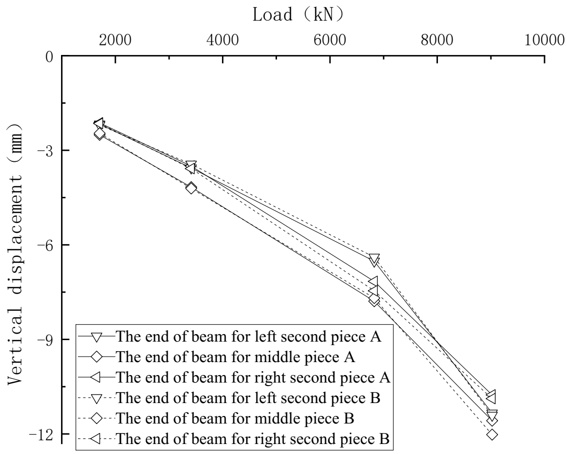

Fig. 7. Vertical displacement curve of the main truss girder end

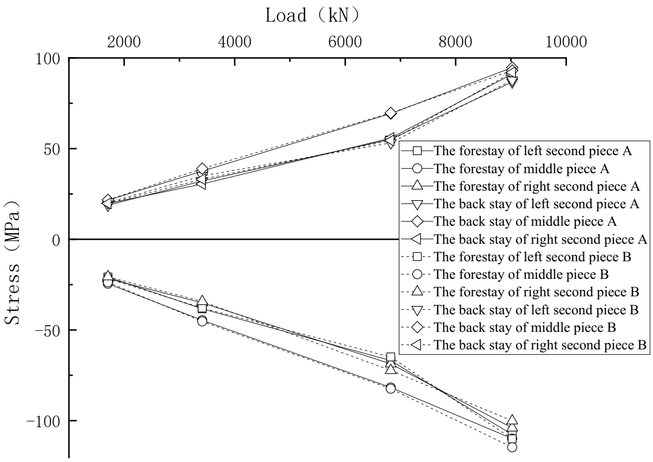

Fig. 8. Stress curve of forestay and back stay of main truss

Table 3. Comparing of stress between automatic monitoring and manual monitoring results

Member bar	Inspection value	Test probability	Critical value	Confidence	Correlation coefficient	Slope	Intercept
Left sling 3	0.001	0.972	5.987	95%	0.998	1.047	-1.111
Left sling 4	0.002	0.962	5.987	95%	0.997	0.986	1.562
Left sling 5	0.004	0.950	5.987	95%	0.998	0.993	1.725
Right sling 5	0.001	0.979	5.987	95%	0.999	0.998	0.710
Right sling 4	0.002	0.963	5.987	95%	0.999	1.028	-0.274

Right sling 3	0.001	0.979	5.987	95%	1.000	0.989	-0.029
Forestay of left second piece truss	0.000	0.994	5.987	95%	0.998	1.017	0.796
Forestay of middle piece truss	0.002	0.963	5.987	95%	0.999	1.056	2.311
Forestay of right second piece truss	0.000	0.984	5.987	95%	0.993	0.979	-0.688
Back stay of left second piece truss	0.002	0.970	5.987	95%	0.996	0.978	1.874
Back stay of middle piece truss	0.000	0.997	5.987	95%	0.999	0.973	1.572
Back stay of right second piece truss	0.001	0.981	5.987	95%	0.997	0.993	0.872

Table 4. Comparing of elongation and displacement between automatic and manual monitoring results

Member bar	Inspection value	Test probability	Critical value	Confidence	Correlation coefficients	Slope	Intercept
Left sling 3	0.001	0.974	5.987	95%	0.990	1.091	0.181
Left sling 4	0.002	0.965	5.987	95%	0.999	1.113	0.246
Left sling 5	0.008	0.930	5.987	95%	0.993	1.063	0.057
Right sling 5	0.002	0.966	5.987	95%	0.992	0.968	-0.152
Right sling 4	0.002	0.965	5.987	95%	0.989	1.094	0.204
Right sling 3	0.002	0.963	5.987	95%	0.994	1.121	0.220
The end of beam for left second piece truss	0.000	0.990	5.987	95%	0.999	1.009	0.093
The end of beam for middle piece truss	0.001	0.978	5.987	95%	0.998	1.045	0.212
The end of beam for right second piece truss	0.002	0.964	5.987	95%	0.999	1.016	-0.039

5 Conclusion

Based on the results and discussions presented above, three main conclusions are obtained:

(1) Using finite element analysis method to assist the selection of hanging basket monitoring types and the layout of monitoring points can effectively enhance the pertinence of monitoring, reduce the blindness of hanging basket monitoring, and effectively guide the on-site monitoring work.

(2) For the problem that the comparison methods of the cable displacement meter and the vibrating wire strain gauge are not provided in the specification, the total station and the strain gauge are used for comparison measurement respectively. The measured data of the two are in good agreement. The results of one-factor analysis of variance show that there is no significant difference between the two and the fitting correlation coefficient in the regression analysis is very close to 1.

(3) When analyzing the reliability of automatic monitoring, the standard does not specify the deviation range between the automatic monitoring results and the manual monitoring results. It is suggested that the results of one-factor analysis of variance should meet the requirements of no significant difference and meet the requirements that the fitting correlation coefficient of regression analysis results is greater than 0.9.

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