Sensitivity Analysis of Factors Affecting down Deflection of Long-span Continuous Rigid Frame Bridge

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Abstract. In order to deeply analyze the factors affecting the excessive mid-span deflection of the long-span continuous rigid frame bridge in service, this paper uses the Shaanxi A Bridge as the supporting project and uses the finite element analysis software Midas Civil to establish the bridge model. Put forward the factors that may affect the deflection, adopt a sensitivity analysis method that controls the value of a single factor while other factors remain unchanged, and repeatedly adjust the model parameters to obtain the deflection calculation results. According to the results, determine whether the factor is the main influencing factor of deflection. The research results show that structural stiffness, prestress loss, environmental temperature, and concrete shrinkage and creep are the main factors affecting the deflection of rigid frame bridges. The degree and direction of their influence on deflection are different. The research results can provide reference and guidance for actual engineering.

1. Introduction

The long-span prestressed concrete continuous rigid frame bridge is due to the consolidation of piers and beams, good overall structural performance, no need for system conversion, no need for large tonnage bearings, large clearance under the bridge, low material economical cost, and high piers. The characteristics make the bridge’s longitudinal thrust rigidity small, and the statically indeterminate structure will not crack due to excessive secondary internal forces under the effects of temperature, shrinkage, and creep. These advantages make the continuous rigid frame in the form of long-span bridges used widely [1, 2]. The mid-span deflection of continuous rigid frame bridges increases continuously with the passage of time, which has become one of the most significant problems of continuous rigid frame bridges at home and abroad. After several years of use, the deflection of some bridges has reached tens of centimeters in the middle of the span, resulting in unsightly shape of the bridge and uneven bridge deck, which affects high-speed traffic [3].

What is the reason for this common problem in long-span rigid frame bridges? In order to analyze and study this problem in depth, a finite element model was established with Bridge A as the supporting project, and the sensitivity calculation and analysis method was adopted to control the change of a single factor. Determine the main influencing factors and degree of influence [4].
2. Project Overview
The main bridge of Bridge A is a prestressed concrete continuous rigid frame bridge of 110+2100+110 meters, the box girder of the main bridge is C50 concrete, and the piers are C40 concrete. The start date of the bridge was September 2002 and the completion date was November 2005. It has been in operation for nearly 10 years.

The main bridge is constructed by the cantilever casting method, using 6 sets of diamond-shaped hanging baskets of 1500kN. The box girder prestress construction is a post-tensioning method. The 0# box girder has a large volume and is poured in two times. The closing sequence of the main bridge is to first close the side spans of piers 7# and 8# and piers 10# and 11#, and finally close the two mid-spans. The closing temperature of the side and middle bridges should be carried out in an environment where the temperature is lower than 21 degrees. The piers are up to 98 meters high and will be constructed in a single section of 3 meters.

Figure 1. Bridge elevation.

3. Finite element model
The finite element analysis software Midas Civil was used to establish a bridge model A. The bridge piers and main girder of the model adopt beam elements, and the pier girder adopts elastic connection-rigidity to consolidate the pier girder. There are 460 longitudinal prestressed steel strands. The whole bridge has 356 units and 363 nodes. Each side of the T-shaped beam is divided into 0#~28#, a total of 29 sections, and the whole bridge is divided into 97 construction stages.

Figure 2. A bridge calculation model.

Figure 3. Full bridge bending moment diagram.
4. Sensitivity Analysis of Influencing Factors of Deflection
Select the side spans on both sides of the 8# pier and the section sections of the main span to calculate the corresponding deflection values.

4.1. Structural stiffness
The stiffness of the bridge section is determined by the elastic modulus of the material and the section parameters. The section size parameters are generally not changed after the design, but concrete is a material with time-dependent characteristics, and the elastic modulus is the easiest to change. For a statically indeterminate structure, due to the existence of secondary stress, the modulus of elasticity has a greater influence on the result of structural deflection. In addition, with the continuous development and diffusion of cracks in the later operation of the structure, the stiffness of the structure will also decrease, resulting in an increase in the mid-span deflection. The structure model is used to reduce the elastic modulus of the structure to simulate the decrease of the overall stiffness of the structure [5, 6].

The main girder of Bridge A is made of C50 concrete, and the standard value of elastic modulus is 3.45×10^4MPa. Therefore, the influence of the concrete elastic modulus reduced by 5%, 10%, 15%, 20%, 25%, and the other parameters on the main beam line shape are calculated respectively.

Table 1. Change value of concrete elastic modulus.

| Discount rate | 5% | 10% | 15% | 20% | 25% |
|---------------|----|-----|-----|-----|-----|
| Elastic Modulus (×10^4MPa) | 3.28 | 3.11 | 2.93 | 2.76 | 2.59 |

Calculation results:
Figure 6. The stiffness affects the deflection curve of the lower side span.

Figure 7. Deflection curve of main span under influence of stiffness.

It can be seen from the calculation results that as the stiffness decreases, the deflection of the side span and the main span also increases. When the stiffness is reduced by 25%, the deflection of side span 23# is the most significant, increasing by 2.81 cm, and the deflection of main span 23# is the most significant, increasing by 3.37 cm. It can be seen that the decrease in stiffness has a great influence on the deflection of the continuous rigid frame bridge.

4.2. Prestress loss

Bridge A adopts a three-way prestressed system, of which there are 460 longitudinal prestressed steel strands.

During the operation of the bridge, the longitudinal prestress loss gradually increases, and the pressure on the concrete gradually decreases, which causes the rigid frame bridge's mid-span deflection to increase continuously [7].

The tension control stress of the bridge's longitudinal prestress construction is 1252.5 MPa. The corresponding deflection values are calculated by deducting 10%, 20%, and 30% respectively.

| Discount rate | 10%  | 20%  | 30%  |
|---------------|------|------|------|
| Tension control stress (MPa) | 1127.25 | 1002.00 | 876.75 |

Calculation results:
Figure 8. The prestress loss affects the deflection curve of the lower side span.

Figure 9. Deflection curve of main span under influence of prestress loss.

From the calculation results, it can be seen that with the increase of prestress loss, the deflection of side span and main span greatly increase. When the longitudinal prestress is reduced by 30%, the deflection of the 22# side span is the most significant, increasing by 3.33 cm, and the deflection of the 22# block of the main span is the most significant, increasing by 2.36 cm. It can be seen that the longitudinal prestress loss has a great influence on the deflection of the continuous rigid frame bridge.

4.3. Ambient temperature
Adjust the temperature and use the model to calculate how the deflection of the continuous rigid frame bridge changes under temperature changes. Take the system temperature as -10°C, -5°C, 0°C, 5°C, and 10°C respectively.

Calculation results:

Figure 10. Deflection curve of lower side span under the influence of temperature.
Figure 11. Deflection curve of main span under the influence of temperature.

It can be seen from the calculation results that with the decrease of the ambient temperature, the deflection of the side span does not change much, while the deflection of the main span gradually increases. When the temperature drops by 20 degrees, the deflection of the side span 0# block is the most significant, increasing by 0.9cm, and the main span 28# block is the most significant, increasing by 2.47cm. It can be seen from the increase in temperature that the temperature drop has a great influence on the deflection of the main span of the continuous rigid frame bridge.

4.4. Concrete shrinkage and creep

The shrinkage and creep of concrete will increase the structural deformation. For statically indeterminate structures, the creep deformation is subject to the redundant constraints of the statically indeterminate structure [8, 9]. The internal force of the structure will change with the development of the concrete creep, that is, the creep will cause the redistribution of the internal force of the structure. The rate of creep increase is decreasing with time. Generally, the creep growth gradually reaches a limit value after 5-20 years, but most of the creep is completed within 1 to 2 years. Now the deflection values of Bridge A at the completion stage, 1 year of operation, 2 years of operation, 5 years of operation and 10 years of operation are given [10].

Calculation results:

Figure 12. Shrinkage and creep affect the deflection curve of lower side span.

Figure 13. Deflection curve of main span under the influence of shrinkage and creep.
The calculation results show that as the operating time increases, the deflection of the main span is greatly affected by shrinkage and creep within 1 to 2 years. As the operating time increases, the deflection of the main span continues to increase, while for the side span, its deflection continues to decrease over time, but the degree of change is not as large as that of the main span. After 10 years of operation of the bridge, the upper deflection of the side spans 19# to 21# was the most significant, both increased by 1.3cm, and the 28# of the main span was the most significant, with an increase of 5.62cm. The calculation results of the integrated side span and main span clearly show that with the increase of operating time, the change in deflection caused by shrinkage and creep becomes smaller and smaller, and gradually stabilizes. It can be seen that shrinkage and creep have a great influence on deflection.

5. Conclusion
According to the calculation and analysis results, the selected four influencing factors are all the main influencing factors, and the conclusion is:

(1) Structural rigidity: With the decrease of structural rigidity, the deflection of side span and main span also increases continuously, and the deflection tendency of side span and main span is basically the same, and the deflection changes of 16#~26# block are the most obvious.

(2) Prestress loss: The longitudinal prestress loss causes the deflection of the side span and the main span of the structure to increase greatly, and the deflection of block 8#~26# changes significantly.

(3) Ambient temperature: As the temperature drops, the deflection of the side span and main span increases to varying degrees. It has obvious impact on the 0#~12# of the side span, 13#~28# has little impact, and has a significant impact on each section of the main span, and the impact level is similar.

(4) Shrinkage and creep of concrete: The shrinkage and creep of concrete cause the side span to bend upward and the main span to bend downward. The influence on the deflection of the main span of the structure is greater than the influence on the side span. Shrinkage and creep have a great impact during the first to two years of operation. As time increases, the impact gradually decreases and stabilizes.

Due to differences in bridge design parameters, construction methods, maintenance levels, environment, etc., various influencing factors change to varying degrees, so that the deflection correction value cannot be given quantitatively. However, according to the sensitivity analysis results, it can be seen that structural stiffness reduction, longitudinal prestress loss, environmental temperature drop, and concrete shrinkage and creep have all caused the increase in mid-span deflection. Therefore, corresponding countermeasures can be given for these four factors. Reduce the problem of excessive deflection in the middle of the span.

6. Suggest
This paper studies the sensitivity analysis of single factor to the deflection of long-span continuous rigid frame bridges, but there are still shortcomings, specifically as follows:

(1) The deflection calculation is only carried out for single factor changes. However, in actual engineering, the changes of various factors that affect the bridge's mid-span deflection affect each other and should be combined reasonably, taking into account the deflection changes under the influence of multiple factors.

(2) Only theoretical calculation and analysis were done, and no comparison with actual bridge monitoring data was made to verify the accuracy of the conclusion. Comprehensive bridge monitoring and monitoring data should be collected, and the fluctuation value of each factor and the change value of deflection should be determined separately for comparative analysis.

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References
[1] Fan Lichu. Bridge Engineering [M]. Beijing: People's Communications Press, 2012.
[2] Ye Jianshu. Principles of Structural Design [M]. Beijing: People's Communications Press, 2005.
[3] JTG D62-2004, Code for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts [S].
[4] Zou Liqun. Long-term deflection analysis of long-span continuous rigid frame bridges caused by concrete shrinkage and creep [D]. Beijing Jiaotong University, 2010.
[5] Yao Qiang. Research on long-term deflection control method of long-span continuous rigid frame bridge based on load balance method [D]. Chang'an University, 2009.
[6] Thomas, N, Sveinson. Temperature effects in concrete box girder bridges. The University of Calgary, 2004.
[7] Wang Peijin. Discussion on long-term deflection prediction of prestressed concrete box girder of long-span continuous rigid frame bridge [J]. Highway and Transportation Science and Technology, 2007, 24 (1): 87-89
[8] Mohsen, A, Issa. Investigation of cracking in concrete bridge decks at early ages. Journal of bridge engineering, 1999.
[9] Luo Chunlin. Research on the Causes and Countermeasures of Deflection of Long-span Continuous Rigid Frame Bridges [D]. Southwest Jiaotong University, 2008.
[10] Ge Junying. Guide for bridge engineering software Midas Civil [M]. Beijing: People's Communications Press, 2013.