Sensitivity Analysis of Cantilever Construction Process of Long-Span Continuous V-Structure Composite Bridge

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Abstract. As a large and complex structural system, each change of physical parameters will have a certain degree of influence on the whole structure. Taking the navigable hole bridge of the main bridge of Yueqing Bay No. 1 Bridge in Zhejiang Province as an example, the influence of concrete bulk density, temperature change, elastic modulus, prestress tensioning, shrinkage plus creep of concrete on the bridge deformation is considered, that is, the sensitivity analysis of parameters. Thus, the parameters together with their effects which have a great influence on the structure in the process of bridge construction are determined and adjusted in time to ensure the linear smoothness of the bridge, the safety of the structure, and the improvement of the driving comfort and the aesthetics of the bridge.

1. Foreword

Long-span continuous rigid frame bridge has some advantages and has been built a lot at home and abroad. In particular, the latest popular short-line method construction has many unique advantages. Therefore, some large-span continuous beams and continuous rigid frame bridges built in China are constructed by short-line method.

Bridge is a large and complex structural system. The change of each physical parameter will have a certain degree of influence on the force of the whole structure. The purpose of parameter sensitivity analysis is to determine the parameters together with their effects which have a great influence on the structure during the construction of the bridge, to make timely adjustments to ensure the smooth alignment and structural safety of the bridge, and to improve the comfort of driving and the aesthetics of the bridge. However, due to the influence of such factors as concrete bulk density, temperature change, elastic modulus, prestress tension, shrinkage and creep of concrete, it is easy to cause the construction control based on the theoretical calculation results to be not in good agreement with the actual deformation of the structure. Moreover, the difference may affect the linear and internal force distribution after completion of the bridge, and if the gap between the final state of the bridge and the design state is too large, it will affect the safety and durability of the bridge. Therefore, according to the selected construction plan, each construction stage should be calculated in detail and the reasons for the deviation between the measured value and the design value should be analyzed in time, so as to determine the best adjustment scheme for the control parameters in the next construction stage. It is
necessary to provide parameters for construction control in time to ensure that bridge alignment is within a reasonable range."

2. Research status at home and abroad:

2.1. Short line method
Yang Shaobin et al [7] used Sutong Bridge as an example of construction process, compared and analyzed the advantages of short-line matching construction method with other construction methods, introduced the construction technology of short-line method, emphasized the significance of correct measurement, precise construction and timely adjustment of line shape for short-line method. Chen Zihang et al [8] compared the two prefabricated beam methods of long-line with short-line methods, introduced the principle of linear control of the short-line method, and used the internal approach bridge of the north side of the Taohuayu Yellow River Bridge as an engineering example. The bridge box beam was transformed from the simple-span system to multi-span continuous systems. The length error correction method in the pouring process is given, and the operability of the method is verified. Taking a 13-mesh 70m span prestressed concrete continuous rigid frame bridge as an example, Shi Gang introduced the linear control process of the bridge, also completed the adjustment of the prefabricated line shape based on the nonlinear least squares method, and controlled the axis deviation and elevation deviation within 20mm, verifying the superiority of the short-term method. Fang Shujun et al. [11] analyzed the influence of shrinkage and creep of concrete on the construction of short-span bridges with a four-span and one-span simple continuous-construction rigid-frame bridge, and calculated the influence of the storage period on the deformation of the bridge structure. The long-term effect of shrinkage and creep after forming a bridge is considered to be the main reason for the internal force redistribution after structural system transformation.

In this paper, for a long-span continuous rigid frame bridge, the sensitivity analysis of the cantilever segment deflection in the maximum cantilever construction stage is carried out, mainly considering the concrete bulk density, concrete elastic modulus, prestressed pipe friction coefficient and local deviation coefficient, segment storage time and the influence of temperature load. So it could provide guidance for the construction monitoring of the bridge and a useful reference for the construction monitoring of the same type of bridge.

3. General situation of Engineering and FEM
The Yueqing Bay Bridge and wiring project in Zhejiang Province starts from the south of Wenling City. The starting point is K202+050, which is connected to the proposed Taizhou Bay Bridge and wiring project. It passes through Yumeng Shamen and Lupu and crosses Yueqing Bay through Maoji Island and ends in Yueqing City, Nantang, connected to the Yongtaiwen Expressway, which has been completed and opened to traffic, has a terminal number of K240+197 and a total length of about 38 km. The design of the vehicle load grade is highway-class I.

The K230+965–K231+435 section of Yueqing Bay No.1 Bridge is a navigational hole bridge with a bridge span of 85+2×150+85. The upper structure is a prestressed concrete continuous rigid frame, while the lower structure main pier body adopts a V-shaped pier. The main pier foundation cap is made of integral round octagonal caps, and each cap is provided with 18 diameter 2.5m bored piles.

The main beam adopts a single box single-chamber variable beam high prestressed concrete box girder. The top plate is provided with a 2% one-way cross slope, which is formed by the height difference between the inner and outer webs of the box girder, and the lower edge of the bottom plate of the box girder is kept horizontal. The single box beam has a width of 16.05 m and a cantilever length of 3.5 m. The height of the box girder is 3.6 to 9.0 m, and the curve at the bottom of the beam is 1.8 parabola. The continuous rigid frame main bridge assembled in sections is counted according to the “V” structure. There are 3 standard “V” structures in the single frame. The pre-casting of the pier top is 28m. The number of prefabricated segments of the single “V” structure is 30.
According to the design documents, the main parameters of design calculation and the construction time assumed in design calculation are adopted to establish the model of construction monitoring and calculation by using Midas/Civil. The rigid connection between the main pier and the main beam restrains the displacement and rotation of the main beam in three directions. According to the modeling and analysis of the construction stage, the model diagram and the main beam element are divided as shown in Fig. 2-1.

Figure 1. Cross-sectional drawing of box girder

Figure 2. Segment partition diagram of continuous rigid frame
In this section, the sensitivity of vertical displacement at both ends of a V structure to concrete bulk density, temperature change, elastic modulus, prestress tensioning, shrinkage and creep of concrete is analyzed. In order to provide accurate parameters for bridge closure, the difference between the vertical deformation of one V structure and the vertical deformation of another V structure in the cantilever assembly stage is analyzed. If the vertical deformation at both ends of a V structure is not consistent, the height difference between the V configuration and the other V structure will occur.

4. Effect of concrete bulk density

When concrete segments are prefabricated, the weight of each stage will be different due to the deviation of material density or geometric size of concrete. Through fine precast construction, the weight deviation should be controlled within 3%. For Yueqing Bay No.1 Bridge approach Bridge, the design value of concrete bulk density $\gamma$ of main girder is $326 \text{kN/m}^3$, the deflection of the main beam in the maximum cantilever stage of V structure is compared and analyzed when the bulk density of concrete is respectively taken from $\gamma$ to 1.05 $\gamma$.

4.1. Bulk weight deviation

In the construction phase, consider the five possible cases where all the assembled segments are 1%, 2%, 3%, 4%, 5% more than the theoretical assembly segments due to the selected materials and other errors, and the maximum cantilever of the main beam. The effect of the vertical displacement of the stage is shown in the Figure 4 below.

The figure above shows that when the overall weight of the structure increases by 5%, the maximum downward deflection of the continuous rigid frame is 21.3 mm, while the maximum reverse arch is 2.4 mm. The former is 4.3 mm larger than the theoretical state, while the latter is reduced by 1.9 mm.

From the numerical point of view, when the overall weight is increased by 5%, the vertical displacement of the two beams does not increase much. Moreover, the displacement of the V-structure is a symmetrical change, and no height difference will occur in the closing phase. Therefore, if the density of the concrete of the hanging beam section is constant during the whole construction stage, or...
the prefabricated weight of the section assembled at the same time of the cantilever end is the same, the influence on the vertical displacement is not large, while the height difference is not generated in the closing stage.

The 5% self-weight deviation is a special limit case, and the probability of exceeding this error range is small. Therefore, the theoretical calculation limit is considered for analysis, and the self-weight deviation is analyzed as 1%, 2%, 3%, 4%, and 5%, respectively. It is summarized in the following table. The height difference of the continuous rigid frame is 0.9, 1.7, 2.6, 3.4, and 4.3 mm, respectively. It can be seen that the overall weight increase of the structure has little effect on the deformation of the continuous rigid frame.

| Deviation | 1% | 2% | 3% | 4% | 5% |
|-----------|----|----|----|----|----|
| Height difference (mm) | 0.9 | 1.7 | 2.6 | 3.4 | 4.3 |

4.2. Partial beam bulk density deviation

During the construction phase, due to occasional construction errors, the weight of the symmetrical suspension beam segments is inconsistent, and an elevation difference will be generated at both ends of the closed section. This section is based on the idea of calculating the limit of the calculation, focusing on the analysis of the maximum cantilever beam section due to construction errors resulting in asymmetrical weight difference of 1%, 2%, 3%, 4%, 5% of the five cases, the vertical configuration of the V Displacement. Using the segment number in the design diagram, only half of the V-shaped main beam is shown in the figure, the cantilever end on the left and the 0# block (the top of the pier) on the right. The closed section is on the outside of the cantilever end and is not shown in the figure. The last piece of the continuous rigid frame is 15# block.

When the continuous rigid frame is in the construction process, due to the error of the concrete mix ratio or the unknown factors such as the expansion template, the 15# block on one side is biased by 1%, 2%, 3%, 4%, 5%, respectively. The deformation is shown in the table below. The results show that when the 15# beam segment produces a 5% deviation, the height difference between the ends of the V-structure reaches 16 mm.

| Deviation | 1% | 2% | 3% | 4% | 5% |
|-----------|----|----|----|----|----|
| Height difference (mm) | 3.2 | 6.4 | 9.6 | 12.8 | 16 |

In summary: when the weight of the cantilever balanced V beam is not the same at the same time, there will be obvious height difference, which indicates that it is very important to control the weight of the concrete stage in the construction process.

5. Elastic modulus of concrete

If the elastic modulus of concrete is not consistent with the specification, the deformation will be affected. The calculated results when the elastic modulus is reduced by 10% are as follows: the maximum deflection and inverse arch of continuous rigid frame are 17.3mm and 4.4 mm respectively, the former increases 0.3 mm compared with the theoretical value, while the latter decreases 0.1 mm. It shows that the variation of elastic modulus has little effect on the deformation of continuous rigid frame.
6. Prestress parameter

6.1. Influence of pipe friction coefficient on vertical deformation
When the pre-stressed pipe friction coefficient is reduced by 10%, it is reduced from the original 0.17 to 0.173. The deformation of the V-structure before closing is shown in the figure below. The results show that when the coefficient of friction of the pipe is reduced by 10%, the effective pre-stress will increase. At this time, the return arch value at both ends of the V-structure is 4.6 mm, which is 2.2 mm larger than the theoretically calculated return arch value of 2.4 mm. It shows that the pipe friction system has a certain influence on the deformation of the V-structure.

6.2. Influence of local deviation coefficient on deformation
When the local deviation coefficient of the prestress is reduced by 10%, it is reduced from the original 0.0015 to 0.00135. The deformation of the V-structure before closing is as shown in the figure below. The results show that when the local deviation coefficient is reduced by 10%, the effective pre-stress will increase. At this time, the return arch value at both ends of the V-structure is 4.6 mm, which is 2.2 mm larger than the theoretically calculated return arch value of 2.4 mm. It shows that the local deviation system has a certain influence on the deformation of the V-structure.
7. Shrinkage and creep of concrete (storage time of beam)

The storage time of beams was considered as 90 days. Due to the construction progress of the lower structure, the storage time of the beam may actually change greatly. This calculation considers the various conditions of the deposit for 45 days, 60 days, 90 days, 120 days, 180 days and one year. The results show that the absolute value of the deformation of the short beam time is large, and the maximum difference of the V-frame deformation of the continuous rigid frame is 1.6 mm when the pre-staged beam period is 45 days and 365 days. Therefore, the influence of beam time on deflection deformation is not obvious.

8. Temperature load

Since the bridge is in the natural environment, the temperature difference effect of the bridge with statically indeterminate structure can also act as a load effect on the structure, so that the bridge structure under the bridge state will produce temperature difference deformation and temperature difference stress. The bridge deck pavement is 100mm, while the temperature difference according to the specification is 14°C-5.5°C-0°C. Due to its location in the subtropical zone and the environmental temperature is difficult to estimate, this section is intended to calculate the temperature difference from 20°Cto 6.7°Cto 0°C . The specific calculation results are shown in the figure below.
The results show that when the temperature gradient is 20℃ - 6.7℃ - 0℃, the inverse arch of the cantilever end of the continuous rigid frame is 1.1 mm, which is 3.4 mm lower than the original inverse arch 4.5 mm. The results show that the temperature gradient will increase the deflection at the end of the cantilever and have a great influence on the deformation of the structure. It is necessary to measure the temperature field in the process of monitoring and modify the temperature gradient in the model.

9. Conclusion

The sensitivity analysis of V-structure deformation is carried out by using Midas/Civil software. The influencing factors include concrete bulk density, temperature change, elastic modulus, prestress tensioning, shrinkage and creep of concrete and so on. The analysis shows that:

1. The self-weight of the concrete beam section has obvious influence on the deformation of the V-structure. Especially when the V-structure is suspended, if the mass of the two symmetric suspension beam sections is not equal, the V-structure will be inclined and a large height difference will occur. It is the main reason for the large difference in the height of the closed section. The construction unit shall attach great importance to the precise positioning of the template and the identity of the materials during the construction process, do a good job in the weighing of the beam sections, and notify the relevant units in a timely manner. If there is a large asymmetry deviation in self-weight, it should be adjusted in time.

2. The temperature gradient is more obvious for the deformation of the V-structure. It is necessary to measure the temperature field of the Yueqing Bay Bridge in real time and correct the calculation model to improve the accuracy of construction monitoring.

3. The beam-holding time and elastic modulus of the prefabricated beam section have little effect on the deformation of the V-structure, but they cannot be ignored. The pre-stressed pipe friction loss and the pipe deviation coefficient have no obvious influence on the deformation of the V-structure. However, engineering practice shows that its effective prestressing effect on the structure is obvious and cannot be ignored.

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