Construction monitoring analysis on concrete continuous beams across Hanyi Expressway

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Abstract: The Han-Yi high-speed railway bridge is a concrete continuous beam bridge, of which the Han-Yi expressway on the upper span is a (40 + 64 + 40) m two-line continuous beam, and the crossing distance between the center of the left line and the highway is DK1254 + 228.63. The intersection angle is 85 degrees. In order to ensure that the bridge closes smoothly, this article uses the finite element software Midas / Civil to build a finite element model, adopts a cyclic feedback construction monitoring scheme, and implements the control of the cross-section stress and deflection of the main beam in real-time during construction and feedback. In the whole construction process, the main beam elevation and stress are used as the main control indicators. The elevation mainly controls the line shape to ensure that the final bridge line shape and the design line shape are consistent; the stress is mainly found in a timely manner through the regular monitoring and analysis of abnormal conditions that may exist in the construction, and early warning is provided to ensure construction safety.

1. Introduction

Roads and bridges are always inseparable. It is a truth that has never changed since ancient times. With the rapid development of railway construction, the construction of long-span bridges has entered an unprecedented period of climax. The diversification of the structure of large bridges has brought about an improvement in the level of scientific research, design, construction, supervision and management of bridge engineering, and has also driven and promoted the development of related industries. At the same time, the structural safety and reliability of large bridges has become a key issue of general concern in today's society. In the construction stage, due to the complicated force, the lack of reasonable calculation in the construction stage, and the artificial improper operation, the risk during the construction stage is relatively large [1]. A large number of engineering accident investigations show that, in both developed and developing countries, about 60% -90% of engineering accidents occur during the construction stage [2].

In order to ensure the safety, reliability, durability, and driving comfort of the bridge structure during operation, the implementation of construction process monitoring and monitoring of large continuous beam bridges has become an indispensable important link in bridge construction. Due to the complicated construction process of prestressed concrete continuous beams, the construction methods, material properties, pouring procedures, and vertical mold elevations used directly affect the alignment and stress...
of the bridge. If the deflection of the beam body is not tightly controlled during construction, the alignment of the bridge irregularities not only affect the apparent quality of the beam body, and it is difficult to close, but also affect the beam-piercing work, increase the tensile resistance of the steel beam, and even increase the beam body torque [3-4].

Through the organic combination of construction monitoring and control, adjust and control the alignment of the bridge, make the alignment of the bridge span structure as close as possible to the design [5-6] expected value, and ensure that the main control section stress value of the whole bridge is within a safe range during the entire construction process, ensuring the bridge Construction safety and normal operation.

2. Project Overview
The cross-Hanyi high-speed railway bridge is located in Guanyin Town, Shacheng District, Jingzhou City. The upper-span Han-Yi Expressway is a one-line (40 + 64 + 40) m double-line continuous beam, and the left-line center crosses the highway at DK1254 + 228.63, The intersection angle is 85 degrees. The beam body is a single-box single-chamber, variable-height, and variable-section box girder. The beam height is 5.485m at the middle fulcrum, 3.485m at the side fulcrum and midspan, and the bottom of the beam changes according to a quadratic parabola. The top width of the box girder is 11.02m, the bottom width is 6.4m, the top plate thickness is 35-60cm, the web thickness is 50-65-80cm, and the bottom plate thickness is 40-80cm.

The total length of the beam is 145.5m, the span is (40 + 64 + 40) m, the middle fulcrum beam is 5.485m high, the span mid beam is 3.485m high, and the center of the side support to the beam end is 0.75m.

3. Model and calculation
3.1 Finite element model
The calculation software uses MIDAS CIVIL to establish a finite element model of the plane rod system for calculation. The entire bridge structure is separated into 141 units with a total of 210 nodes. According to the construction procedure, it is divided into 37 construction stages and 13 construction conditions to simulate the construction process. The coefficient of friction of the channel is \( \mu = 0.25 \), the coefficient of deviation is \( k = 0.0015 \), and the retraction value at one end of the anchor is 6mm. The values of the material parameters in the model are shown in Table 1, and the discrete structure diagram is shown in Figure 2.

![Figure 1. Schematic diagram of the elevation position](image)
Bridge construction monitoring is a cyclic process of construction, measurement, identification, correction, advance notice, and construction. The most important purpose of construction control is to pay attention to the stress and safety of the structure during construction. The specific performance is: the deformation is controlled within the allowable range, and it has sufficient strength and stability. During construction, if it is found that the stress of the full bridge is close to or exceeds the safety control index or the linear error of the main beam is too large, the construction should be suspended, the cause should be identified, and the correction should be made in time to make both meet the requirements as much as possible.\[7\]

### 3.2 Calculation method

The vibrating wire frequency meter is used to read the frequency of the strain gage, calculate the concrete strain there according to the frequency and strain conversion calculation formula, and finally multiply the concrete elastic modulus to obtain the stress.

As the most important part to ensure the safety of bridge construction, stress monitoring is particularly important. At present, there are two types of stress monitoring: direct method and indirect method. The direct method is a method of directly sensing the internal stress of concrete through a sensor. But at present, it is limited to the compressive stress sensor invented by Carlson, and it is expensive, and it is not suitable for the requirements of multi-section and multi-point measurement of stress monitoring, so it is rarely used. The indirect method is a method of measuring the strain of concrete or steel structure through a sensor, and then converting it into stress.\[8-9\] It is also a method commonly used at home and abroad. The frequency of the strain gauge is read with a vibrating wire type meter, the concrete strain is calculated according to the frequency and strain conversion calculation formula, and finally the stress is multiplied by the concrete elastic modulus.\[10\]

### Table 1. Material properties

| Material                  | Application area | Bulk density (KN/m³) | Elastic modulus (MPa) | Linear expansion coefficient | Standard compressive strength (MPa) | Standard tensile strength (MPa) |
|---------------------------|------------------|----------------------|-----------------------|------------------------------|------------------------------------|-------------------------------|
| C50 concrete              | Main beam        | 25                   | 3.45 × 10⁴           | 1 × 10⁻⁵                    | 32.4                               | 2.65                          |
| Prestressed steel strand  | Main beam        | 78.5                 | 1.95 × 10⁵           | /                            | /                                  | 1860                          |

The section stress \( \sigma \) is obtained from the measured strain as follows: \( \sigma = E \cdot \varepsilon \)

In the formula: \( \varepsilon \) - Measured strain \( ( \varepsilon \cdot \varepsilon \cdot \varepsilon ) \);

\( E \) —— material elastic modulus (MPa).

\( \varepsilon = \frac{\Delta}{k} (F - F_0) + (b - \alpha) (T - T_0) \)

Among them: \( k \) —— the minimum reading of surface strain gauge \( (c / F) \);

\( F \) —— Real-time measurement value of surface meter \( (F) \);

\( F_0 \) —— reference value of surface meter \( (F) \);

\( b \) —— surface temperature correction coefficient \( (10⁻⁶ / °C) \);

\( \alpha \) —— the coefficient of linear expansion of the structure under test, \( (10⁻⁶ / °C) \);

\( T \) —— real-time measurement of temperature \( (°C) \);
The strain that can be measured by the strain sensor is the total strain, which can be expressed as:

\[ \varepsilon = \varepsilon_{\text{Elasticity}} + \varepsilon_{\text{Creep}} + \varepsilon_{\text{Self}} + \varepsilon_{\text{Temperature}} + \varepsilon_{\text{Shrinkage}} + \varepsilon_{\text{Initial error}} \]  

In the formula:
- \( \varepsilon_{\text{Elasticity}} \) - elastic strain caused by load;
- \( \varepsilon_{\text{Creep}} \) - corresponding creep strain;
- \( \varepsilon_{\text{Self}} \) - the volumetric strain of the material where the measurement point is located;
- \( \varepsilon_{\text{Temperature}} \) - free temperature strain, that is, thermal expansion and contraction strain;
- \( \varepsilon_{\text{Shrinkage}} \) - the shrinkage strain of the material where the point is measured.
- \( \varepsilon_{\text{Initial error}} \) - the initial error caused by the initial hydration heat at the location of the measurement point.

Among them, the sum of the last three strains is called no stress.

For the calculation of \( \varepsilon_{\text{Creep}} \), the calculation formula in the standard "Design Code for Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts" issued by the Ministry of Communications will be used in this system.

\[ \varphi(t, \tau) = \beta_a(\tau) + 0.4 \beta_d(t-\tau) + \varphi_f[\beta_f(t) - \beta_f(\tau)] \]  

In the formula: \( \beta_a(\tau) = 0.8 (1 - R_r / R_\infty) \)  

Use the fitting formula: \( R_r / R_\infty = -1.206 \tau^{0.264} + 1.184 \)  

From formulas (3) and (4):  

\[ \beta_a(\tau) = \begin{cases} 0.9648 \tau^{0.264} & \text{if } 0 < \tau \leq 100 \\ -0.1472 & \text{if } \tau > 100 \end{cases} \]  

\[ \beta_f(t) = \text{alg}^2 t + b \cdot \text{lng} + c \]  

\[ \varphi_f = \varphi_{f1} \cdot \varphi_{f2} \]  

\[ aH^2 + bH + c \text{ for } H \leq 1300 \]  

\[ 1.12 \text{ for } H > 1300 \]  

3.3 Monitoring and control measures

In the construction process of continuous beam bridges, first of all, attention should be paid to the elevation error of the vertical mold; secondly, attention should be paid to the size error of the concrete section of the main beam and the influence of the environmental temperature during construction and measurement.

Of course, during the construction process, errors are inevitable. When the linear error of the main beam can be controlled within the accuracy range under each working condition, it is not necessary to adjust. When this error exceeds the control accuracy range or the cumulative error of each working condition is not allowed, it must be adjusted. During the adjustment, the elevation of the vertical mold is used as the main adjustment method, and the elevation of the main beam is used as the main control target [11].

In addition, due to the different construction control of continuous beam bridges, arch bridges, cable-
stayed bridges, etc., it is not possible to adjust the line shape of the main beam by cable force. It can only be adjusted by adjusting the vertical mold elevation of the next beam segment during construction. The adjustment of the mold elevation is limited, otherwise the main beam may appear a broken line, and it may change the structural stress and affect the structural safety. Therefore, to ensure that the continuous and continuous beam bridges have the same alignment and design alignment, the main design calculation parameters need to be adjusted based on field measurements and calculation identification to ensure that the theoretical calculation of the vertical elevation of each beam segment is as accurate and consistent as possible, actual.

4. Calculation results and conclusions

4.1 Monitoring results and analysis

Stress monitoring is mainly carried out in combination with the stress characteristics of the continuous beam cantilever construction and the purpose and requirements of construction control. Considering that it is suitable for long-term construction process observation and can guarantee sufficient accuracy, a long-term, stable, high-precision embedded vibrating wire concrete strain gauge and a supporting vibrating wire reader are used for stress testing.

The monitoring data is compared with the previous calculation results. As shown below:

![Stress value](image1)

Figure 3  0 # small mileage stress value

![Stress value](image2)

Figure 4  0 # large mileage stress value

![Stress value](image3)

Figure 5 4 # Small mileage stress value

![Stress value](image4)

Figure 6 4 # Large mileage stress value

The stress state displayed by the structure during the construction process is basically consistent with the theoretical calculations and design requirements, and both meet the design and specification requirements. The final measured stress state of the structure is within the allowable range of the general prestressed concrete bridge. requirements.

4.2 Results of displacement and deformation monitoring

In order to ensure the bridge alignment and construction quality of the bridge, the elevation and deflection of each beam segment needs to be detected during the entire construction process to provide a basis for the box beam elevation adjustment and control.

The elevation of the positioning point of the hanging basket in the beam section is measured with a
precision level. By measuring the elevation of the vertical mold before the concrete is poured, and then measuring the change of the elevation of the control point of the beam top in the subsequent working conditions, the absolute elevation of the control point of the beam section in each working condition is finally obtained. The main beam deflection monitoring is performed with a total station and a prism.

Comprehensive analysis of hanging basket pre-compression experiments, vertical mold height control data, section size data, and measured displacement data of cantilever construction sections. Through comparative analysis of design, monitoring requirements and theoretical calculation values, the results are shown below.

![Figure 7: Linear shape after the entire bridge is shaped](image)

**5. Summary**

During the construction of the Dongjin No. 2 double-line super bridge (40 + 72 + 40) m prestressed concrete double-line continuous beam bridge, the various tasks of the monitoring unit were smoothly and effectively implemented, and the monitoring work was well completed. Provides favorable technical and data support. The quality of the project has reached the qualification standards, and the internal force and structural deformation of the main beam have been well controlled. The bridge's structural stress monitoring performance is good, and the structure is linear and smooth. In summary, the construction process of the (40 + 72 + 40) m prestressed concrete double-line continuous beam bridge of the Dongjin No. 2 double-line super bridge is in a controlled state, and the structure completion indicators of the bridge perform well and meet the acceptance conditions.

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