A Study on Analysis of Long Span Continuous Rigid Frame Bridge

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Abstract. A case study of a large span pre-stressed concrete continuous rigid frame bridge (Ba-Mao-Chong bridge) of GUI DU high speed railway. Finite element program Midas/Civil is used to simulate the construction process and operation phase, the influence of concrete overweight, pre-stressing loss, concrete shrinkage and creep, stiffness loss and other factors that related the long-term deflection of bridge are analyzed. The calculation results show that: (1) The overweight concrete and Bridge deck pavement construction error could cause the bridge long-term deflection increases. (2) The creep coefficient, environment humidity, and other factors on the bridge have significantly influence on long-term mid-span deflection, (3) The beam stiffness reduction could lead to the bridge long-term mid-span deflection increase.

Keywords: Continuous Rigid Frame Bridge.

1. Introduction
The GUI Du highway is a fast way between Guiyang and Du-yun city, it is an common segment channel of National Highway Planning Network of Xia Men-Cheng Du, Lan Zhou - Hai Kou,Shang Hai to Kun Ming, in the middle part of the Gui-Zhou province. The highway starting point in the Huo-Shi-Po of Du-yun City, connected with Xia-Rong expressway, through the Xiao-Wei-zhai, Da-Tie-Xiang of Gui-ding County, Chang Ming Town, Long-li county and other places, The end is at Lan-Ni-Gou of Gui-yang Expressway, Cross connecting with the Guiyang city highway and the south exit road of Guiyang, the route is 80.969 kilometers.

Ba-Mao-Chong bridge is located in Gui-du expressway line, the left line of bridge beginning and end were ZK218+768 and K219+764. The span arrangement is 4×40+5×40+5×40+(80+150+80)+3×40m, bridge length is 996m; the right line of bridge beginning and end were YK218+747.792 and K219+764. The span arrangement is 5×40+5×40+5×40+(80+150+80)+3×40m, the bridge length is 1032.92m. The main span is 80+150+80m, with variable cross-section of pre-stressed concrete continuous rigid frame structure, Pre-stressed concrete T beam are used on both sides.

2. Layout of Height Measurement Point of Bridge Deck
Optical fiber sensors, demodulator, precision leveling instrument, total station instrument, dynamic load data acquisition instrument are used to monitor the bridge of Ba-Mao-Chong. The instrument and equipment are shown in table 1.

In order to ensure the continuity and effectiveness of the monitoring data of the bridge, a permanent control network for the Ba-Mao-Chongbridge is established. Point arrangement, as shown in Figure1.
Table 1. Main instrument and equipment.

| Number | Name                        | Model                        | Quantity |
|--------|-----------------------------|------------------------------|----------|
| 1      | Precision electronic level  | Leica DNA03                  | 1        |
| 2      | total station               | Leica TPS1201+               | 1        |
| 3      | Grating surface strain gauge| FBGTECH FSS0221DS            | 54       |
| 4      | Grating thermometer         | FBGTECH FST2111DS            | 16       |
| 6      | Bridge modal testing system | DHS907                       | 9        |

Figure 1. Layout of bridge elevation survey points.

Through the past 4 years (2012.10--2016.10) elevation monitoring of the Ba-Mao-Chong bridge, there is the cumulative variation curve of the bridge elevation in different observation periods was shown in Fig.2 to Fig.5.

Figure 2. Monitoring results of the left side of the left bridge.

Figure 3. Monitoring results of the right side of the left bridge.

Figure 4. Monitoring results of the left side of the right bridge.

Figure 5. Monitoring results of the right side of the right bridge.
It can be seen from the monitoring results that the deflection value of the Z17 point at the mid-span monitoring point of the Ba-Mao-Chong bridge is the largest. As the time increases, the cumulative value of the deflection increases gradually at the Z17 point.

The results of the Fourth measurement is different from the third for the left side of the left bridge, is 14.75mm. The result of the ninth measurement is quite different from the result of the eighth measurement, which is 15.22mm. The results of the first and third monitoring were similar. And the results of tenth, ninth, fifth and sixth were similar. The difference between the third and the fourth measurements on the right side of the left side is very different, and the ninth and the eighth monitoring results is large difference. The maximum deflection value of the cumulative of Ba-Mao-Chong bridge is 87.26mm. The results of the third and fourth monitoring were different, The difference between the two is 7.5mm. The difference between the eighth measurements and the ninth measurements is 6.06mm, and the first times and second times are similar, second times, eighth times and sixth times are similar, fifth times and tenth times are similar. The maximum ZY17 value of the right side bridge deflection is 87mm, the difference between the third and the fourth monitoring results is larger, 15.83mm, and the deflection and time of the other points increase linearly.

3. Numerical Simulation

3.1. Calculation Model

The finite element program Midas/CiviL is used to establish the finite element model, as shown in Fig.6. The three main girders of the “T structure” consist of 28 cantilevers. The whole bridge is divided into 139 units and 144 nodes. The main girder is divided into 123 units, the main span piers are double thin-walled piers, the 1 pier is divided into 8 units, and 2 pier is divided into 8 units.

Figure 6. Calculation model of Ba Mao River Bridge. The constraints of the calculation model of the pendulum bridge are shown in Table 2.

| Constraint node number | Constraint position | Dx | Dy | Dz | Rx | Ry | Rz |
|------------------------|---------------------|----|----|----|----|----|----|
| 1                      | Support of side span| ×  | √  | √  | ×  | ×  | ×  |
| 124                    | Support of side span| ×  | √  | √  | ×  | ×  | ×  |
| 141                    | Bottom of piers of 1#| √  | √  | √  | √  | ×  | √  |
| 142                    | Bottom of piers of 1#| √  | √  | √  | √  | √  | √  |
| 143                    | Bottom of piers of 2#| √  | √  | √  | √  | √  | √  |
| 144                    | Bottom of piers of 2#| √  | √  | √  | √  | √  | √  |

In Table 1, Dx, Dy, and Dz are translational degrees of freedom in the direction of the X, Y, and Z axis, Rx, Ry, Rz are rotational degrees of freedom in the direction of the X axis of the whole coordinate system, respectively.

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3.2. Comparison between Numerical Simulation Results and Measurement Results

In order to analyze the change characteristics of the monitoring points along the time, ZZ17 (middle span) ZZ29 (third span) and ZZ33 (endpoint) are selected for analysis. Fig 7 is the deflection characteristic diagram of the left Ba-Mao-Chong bridge of the left side.

**Figure 7.** The relationship of Vertical deflection and time for left side of left bridge.

It can be seen from fig.8, that the vertical displacement increases with time, and generally shows a downward trend. The monitoring point ZZ17 vertical displacement increases with the time, in general, the decline trend. The vertical displacement of the second cross span is the largest. The measured deflection is 82.42mm. and The calculated results are in good agreement with the measured results. The comparison of ZZ29 points shows that the calculated results are slightly larger than the measured results, but the deformation trend is consistent. It can be seen from 9 that the calculated results are larger than the monitoring results by 25mm in the middle span of Shi Men Kan bridge. Up to the time of measurement, the maximum deflection is 151mm of the left bridge in the middle span ,and the maximum deflection is 148mm in the middle span of right. Both of the two are less than the theoretical deflection value 264mm.

The comparison between Fig. 7 and Fig.8 shows that the calculated results are slightly larger than the measured value. Therefore, the latter analysis is more secure.

3.3. The Influence of Self Weight

**Figure 9.** Influence of bridge weight increase on long term deflection of bridge.

Based on the calculation model of the Ba-Mao-Chong Long Bridge, assuming that the weight of the main girder is 1%, 2%, 3% and 4% respectively, the deflection under different overweight ratios is calculated as shown in Fig.9.

**Figure 10.** Effect of humidity on deflection of bridge in different stages.
As shown in Figure 9, the Maximum deflection caused by deadweight of main girder In the early stages of bridge construction With the increase of the time, the deflection of bridge caused by deadweight is reduce. 20 years after the bridge was built, When the weight of the main beam increases by 4%, the increase of the span deflection of the bridge is 51mm.

3.4. Humidity Influence
After the concrete is poured, it has been exposed to the nature for a long time, and humidity has a significant influence on the performance of concrete. According to the climatic conditions in Gui-zhou area, the relative humidity of 30% , 60% and 90% are calculated in this paper. The effect of humidity on the mid-and long-term deflection of Ba-Mao-Chong Bridge at different times was studied. From figure 10, it is known that the greater the relative humidity, the smaller the long span deflection of the bridge. When the bridge is 20 years old, and the humidity is 30% and 60%, the deflection is bigger 17.94% and 11. 1% respectively than the relative humidity is 90%. Under the same conditions, with the passage of bridge completion time, the larger the humidity, the smaller the ratio of deflection increase.

3.5. Impact of Pre-stressed Loss
In order to investigate the effect of pre-stress loss on bridge span deflection, in this paper the pre-stressed loss is simulated by the pre-stress reduction in the software. Assuming that the longitudinal pre-stressed of the bridge is reduced by 5%, 10%, 15%, 20% respectively, the maximum deflection of bridge in different service time is calculated. The calculation results are shown in Figure 11.

![Figure 11. Relationship between pre-stress loss and mid-span deflection.](image)

![Figure 12. Effect of stiffness reduction on mid-span deflection of bridge.](image)

The completion of the bridge from 5 years to 20 years, when the pre-stress decreases by 2%, the mid span deflection increases 3.3mm of the Ba-Mao-Chong bridge. After 20 years of the bridge foundation, the pre-stress loss is 2%, the maximum deflection of the middle span of the bridge increasing is 4~5mm.

3.6. Effect of Beam Cracking on Long Term Deflection of Bridge
When the pre-stressed can’t counteract the tensile stress produced by external loads, the beam will experience cracking, and the bending moment of inertia will be reduced after the cracking of the beam, so the stiffness of the beam will reduce. The stiffness is proportional to the strength of the concrete, so the effect of the cracking of the beam on the long-term deflection of the bridge is calculation through the reduction of the compressive strength. The stiffness reduction of the main beam is 10%, 20%, 30%, and the deflection of the bridge in different periods, as shown in Figure 12.
From Figure 12, it can be seen that with the increase of main girder cracks, the overall stiffness gradually decreases, and the maximum deflection of the bridge increases gradually. The increase of deflection is basically linear relationship with the time and stiffness.

4. Conclusion
In order to analyze the growth of the deflection of the Ba-Mao-Chong bridge, The finite element program Midas/CiviL is used to simulate the construction process and the operation stage. The influence of overcapacity, pre-stressed loss, shrinkage, creep and stiffness loss on deflection of long-span concrete continuous rigid frame bridge is analyzed. The following conclusions are obtained:(1)In the process of bridge construction, the increase of self weight caused by the overweight of concrete and the error of bridge deck pavement construction will cause the long-term deflection to increase. Therefore, it is necessary to avoid the construction irregularity in bridge construction, resulting in the excessive deflection of the middle part of the girder and the excessive deflection.(2)The influence of ambient humidity on the Long Span Rigid Frame Bridge is remarkable. Pre-stress loss has significant influence on long term deflection of long-span continuous rigid frame bridge. From 5 to 20 years, the mid-span deflection of Bam Chong Bridge increases about 3.3 mm when the pre-stress decreases by 2 mm.(3)The girder beam stiffness reduction has great influence on the long-term mid-span deflection of the bridge, from the Bridge construction completion to the bridge 20 years of service, When the stiffness of the main beam is reduced by 10%, the mid span deflection is increased by about 5mm.

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