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Study on the Closing Sequence of Asymmetric High Pier Multi-Span Continuous Rigid Frame Bridge

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Abstract: In order to study the influence of different closing schemes on the non-symmetrical high-pier multi-span continuous rigid frame bridge, this paper uses Midas/Civil finite element software to simulate the vertical displacement of main beam, stress of main beam, horizontal displacement of pier top and bending moment of pier bottom under four different closing schemes. The results show that the vertical displacement of the main beam is small when scheme 3 is adopted. The stress of the main beam and the bending moment of the bottom of the pier are smaller after adopting the scheme 4 closing scheme. The maximum horizontal displacement of the top pier is smaller after the closure of scheme 1 and Scheme 3. After comprehensive consideration, it is suggested that the closure of Hegou Bridge should be carried out in scheme 4.

Keywords: Rigid Frame Bridge; Finite Element; Stress; Bottom Moment of Pier.

1. Introduction

Continuous rigid bridge is a common form of bridge structure [1], which has the advantages of large span, high stiffness, and strong bearing capacity [2], and thus is widely used in bridge engineering.

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In recent years, more and more scholars have researched the merging of continuous rigid bridges. Among them, Qian Zhiquan [3] et al. took 5-span continuous rigid bridge as the research object and analyzed the influence of with or without top thrust on the displacement of bridge structure, and the study showed that when the abutment was high, the bridges with or without top thrust merging were in a safe state. Wu Haishan [4] and others proved that hanging baskets casting side spans and merging sections at one time can reduce the force and deflection of the main girder in the middle span through the simulation study of pre-stressed continuous rigid bridge. Huang Zhuo [5] et al. proved through software simulation that the top thrust can improve the abutment deflection. Guo Weifeng [6] and Li Guo [7] et al. studied the temperature of continuous rigid bridge merging and showed that the top thrust at merging can reduce the horizontal displacement of the pier top and the bending moment of the pier bottom after the bridge is completed, and the top thrust force also needs to be adjusted according to the actual temperature, which is used to offset the horizontal displacement of the pier top caused by the temperature difference effect. Chen Wenbo [8] and other continuous rigid bridge mid-span joining construction technology optimization, used to improve the effectiveness and quality of the joining section of the rigid bridge buttress.

Although there are more in-depth researches on continuous rigid bridges, there are fewer researches on asymmetric high pier multi-span continuous rigid bridge merging scheme.

Based on the previous research, this paper takes the actual project of Hegou Bridge as the research object, and compares the vertical displacement of the main girder, the stress of the main girder, the horizontal displacement of the top of the pier and the internal force at the bottom of the pier under different merging programs by Midas/Civil finite element software to determine the optimal merging program in accordance with the construction of the Hegou Bridge, so as to provide the theoretical basis for the construction of the Hegou Bridge.

2. Project Overview

This paper takes the actual project River Gorge Bridge as the background, the length of the bridge is 798m, and the superstructure has three couples with spans of (30+30) m+(65+4×120+65) m+3×40m, of which the starting section of the first bridge and the third couples use post loading box girders, and the intermediate section adopts the pre-stressed continuous steel structure. The substructure adopts column abutment, and the rigid column adopts lattice pier. The joint position and pier number are shown in Fig. 1, and the joint sequence is shown in Table 1.

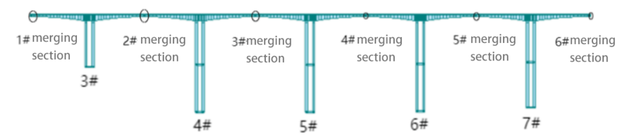

Figure 1. Schematic diagram of joining section

Table 1. Sequence of the different options for the merging program

Closing program	order of merging		
	First merging	Second merging	Third merging
Program 1	1#,6#	2#,5#	3#,4#
Program 2	3#,4#	2#,5#	1#,6#
Program 3	2#,5#	3#,4#	1#,6#
Program 4	1#,6#	2#,3#,4#,5#	

3. Effect of Closure Sequence on Rigid Frame Bridges

The order of joining has a certain influence on the stability of the bridge structure. In the design of the bridge, the order of the merging needs to consider the force of each part, the sequence of the merging should be conducive to the stability of the overall structure, to avoid the occurrence of uneven force or local overloading. The sequence of merging also needs to take into account the conditions of the construction site, the construction of suspension bridge towers, merging measurements and other factors, which can effectively reduce the construction difficulty and improve the construction efficiency. The sequence of the bridge has a certain impact on the quality control of the bridge, and the different sequence of the bridge may lead to different stress conditions of the bridge structure, affecting the service life and safety of the bridge. Therefore, it is necessary to strictly control the order of the merging in the process of design and construction to ensure the quality of the bridge structure.

Overall, the influence of the closing sequence on rigid bridges is multifaceted and requires comprehensive consideration of various factors during the design and construction process to ensure the safety, stability and quality of the bridge structure.

3.1. Effect of Closing Sequence on Main Girder Displacement

In order to compare the effects of different joining schemes on the deflection of the main girder of the River Gorge Bridge under the influence of constant load and prestressing load, in this section, the vertical deflection of the main girder of the different schemes when it is just joining together is compared by using the finite element software, so as to select a joining scheme that is most in line with the construction of the River Gorge Bridge, and the simulation results are shown in Fig. 2.

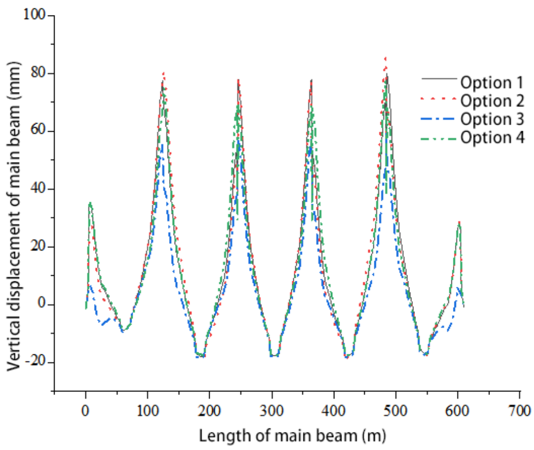

Figure 2. Vertical displacement of main beam under different schemes

As can be seen from Fig. 2, the difference in vertical deflection of the main girder after just joining under the four joining schemes is relatively small, the vertical displacement after joining using Scheme III construction scheme is the smallest, and the maximum vertical displacement of the main girder after joining under Schemes I, II, and IV is basically the same, and the maximum displacement is kept near 78mm. Therefore, only considering the vertical displacement of the main girder, it is recommended to adopt Scheme III when the river gorge bridge is merged.

3.2. Effect of Closing Sequence on Stresses in Main Girders

The main girder stress directly affects the safety of the structure, and different merging schemes will produce different stresses on the upper and lower edges of the main girder. In order to minimize the stresses at the upper and lower edges of the main girder after the bridge is merged, this section uses finite element software to compare the stresses at the upper and lower edges of the main girder under different merging schemes, and the simulation results are shown in Fig. 3 and Fig. 4, respectively.

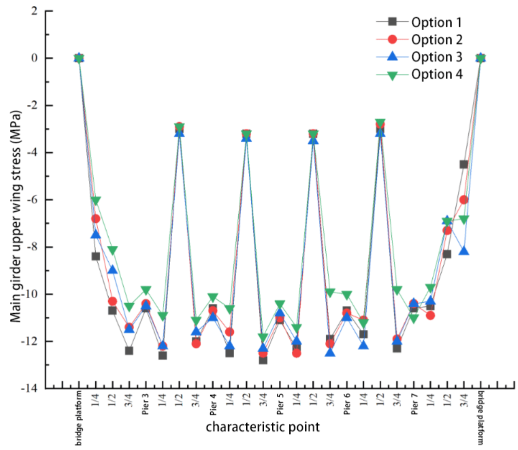

Figure 3 Stresses at the upper edge of the main beam

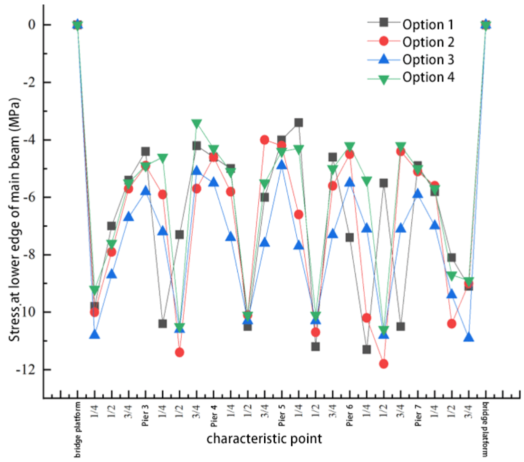

Figure 4 Stresses at the upper edge of the main beam

For the main girder top edge stress, it can be seen from Fig. 3 that the four different merging schemes have roughly the same influence on the main girder top edge stress, and the stress reaches the minimum value in the middle section of the side spans, the middle section of the sub-side spans and the middle section of the middle spans, and the stress in the main girder top edge of scheme 4 is smaller.

For the main girder lower edge stress, it can be seen from Fig. 4, four different solutions for the main girder lower edge stress influence law is more or less the same, under different programs the main girder lower edge stress in the pivot point to reach the minimum value, the program four main girder lower edge stress is smaller.

It can also be seen in Fig. 3 and Fig 4 that the upper and lower edges of the main girder cross-section are in a pressurized state when the four different schemes are merged, so the main girder cross-section is pressurized in the full cross-section.

Therefore, in order to minimize the stresses on the upper and lower edges of the main girder after joining, it is recommended to adopt the scheme 4 joining plan for the joining of the River Gorge Bridge.

3.3. Influence of Hopping Sequence on Horizontal Displacement of Pier Top

Due to the different heights of the piers of the River Gorge Bridge, the height of the piers is higher. Different merging order will inevitably lead to different horizontal displacement of the pier top, in order to study the horizontal displacement of the pier top after merging of different programs, the use of finite element software to compare the horizontal displacement of the top of the pier under different merging programs, the simulation results are shown in Fig 5 (offset to the right is positive).

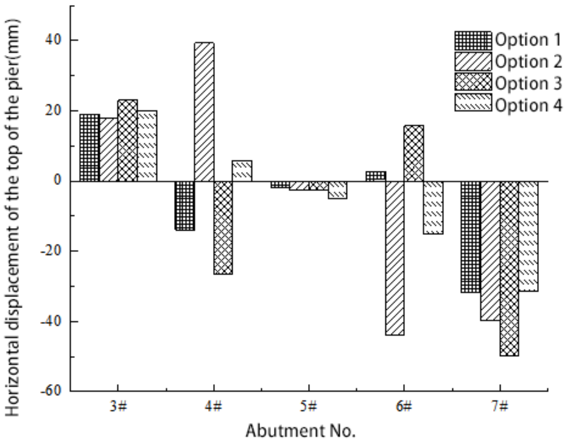

Figure 5. Horizontal displacement of pier top under different schemes (mm)

As can be seen in Fig 5, different merging schemes have different effects on the horizontal displacement of the pier tops of the piers. For pier No. 3, all the four schemes move the top of the pier in the direction of the bridge, for piers No. 5 and No. 7, all the four schemes move the top of the pier in the reverse direction, and for piers No. 4 and No. 6, the different schemes cause the top of the pier to move in different directions. The horizontal displacement of the top of pier 5 is less affected by the four merging schemes.

It can also be seen from Fig. 5, the fourth plan has less effect on the horizontal displacement of the pier, especially for pier 2, compared with the other three plans, the effect of plan four is significantly reduced. Therefore, only from the perspective of reducing the horizontal displacement of the top of the pier, the preferred option is to choose the fourth scheme of the merging program.

In order to further analyze the influence of different jointing schemes on the maximum horizontal displacement of the top of the pier, the maximum horizontal displacement of the top of the pier under four different jointing schemes is now included in Table 2.

Table 2. Absolute value of maximum pier top horizontal displacement (mm)

Option 1	Option 2	Option 3	Option 4
32	40	50	31

From Table 2, it can be seen that the maximum horizontal displacement of the top of the pier is the largest, 50mm, when the River Gorge Bridge is constructed by Option 3 combined scheme, and the maximum horizontal displacement of the top of the pier is the smallest, about 31mm, when it is constructed by Option 2 method, and the maximum horizontal displacement of the top of the pier is between Option 3 and Option 4. Therefore, only considering the maximum horizontal displacement of the top of the pier, it is recommended to use Scheme I and Scheme IV combined dragon program construction.

Considering the horizontal displacement of the top of the pier and the maximum horizontal displacement of the top of the pier, it is recommended that the River Gorge Bridge be constructed using the Option 4 Hopping Scheme.

3.4. Influence of Hopping Sequence on the Internal Force at the Base of the Pier

In order to study the change rule of each bending moment at the bottom of the bridge abutment under different programs, this section uses finite element software to simulate and analyze the bending moment at the bottom of the bridge abutment, and the comparison results are shown in Fig. 6 respectively.

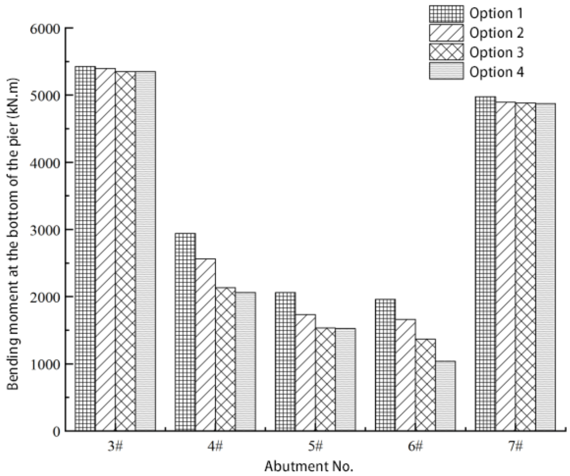

Figure 6. Bending moment at the bottom of the pier

As can be seen in Fig. 6, the bottom bending moments of piers 3 and 7 are approximately the same when four different jointing schemes are used for jointing, but for piers 4, 5, and 6, the bottom bending moments of the piers are significantly smaller than those of the other three schemes when scheme 4 is used for jointing.

Therefore a large difference in the bottom bending moment of the intermediate abutment occurs when different schemes are used for merging. Therefore, in order to reduce the bending moment at the bottom of the pier, it is recommended to use the scheme 4 hinge plan when the hinge is used.

4. Conclusion

(1) For the vertical displacement of the main girder after joining, the vertical displacement of the main girder is minimized after adopting scheme III joining. For the stress of main girder, the stress in the span of the upper edge is the smallest, and the stress at the pivot point of the lower edge is the smallest, and the stress at the upper and lower edges of the main girder is smaller than that of the other solutions after scheme four is adopted.

(2) For the maximum horizontal displacement of the top of the pier, the maximum horizontal displacement of the top of the pier is kept near 31mm by using Scheme I and Scheme IV combined, and the maximum horizontal displacement of the top of the pier is larger by using Scheme III combined.

(3) For the bending moment at the bottom of the pier, the bending moment at the bottom of the pier is significantly

smaller than the other three schemes when using Scheme IV combined dragon.

(4) Considering the vertical displacement of main girder, stress of main girder, maximum horizontal displacement of top of pier and bending moment of bottom of pier under different schemes, the River Gorge Bridge is proposed to use Scheme IV (first side-span joining, and finally sub-middle-span and middle-span joining at the same time) for joining

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