Analysis of the forces in the construction of large-span steel box girder by incremental construction

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Abstract—Taking a large-span steel curved bridge in Yunnan Province as the research object, this paper focuses on the multi-point jacking construction technology and construction control points, which provides the basis for the limited jacking construction planning and reasonable arrangement of working procedures in Yunnan Province. Taking the successful application of a large-span steel box girder on the pusher as an example, the numerical simulation of the steel pushing process is carried out by using the finite element software 3D3S, and the data analysis of the structure is summarized in this paper, which provides reference for solving similar engineering problems in the future.

1. OVERVIEW
The incremental launching method has the advantages of simple equipment, short construction period, small assembly area, and avoiding many high-altitude operations, which is well adapted to the construction under complex conditions in mountainous areas. In addition, the steel box girder is light in weight, easy to install and convenient to transport. With its unique advantages, the push method in steel structure bridges has been more and more widely used\textsuperscript{[1]}. It can be seen from domestic and foreign research that scholars have introduced few practical problems in the construction process of the jacking construction, and the mechanical analysis of the key nodes in the process of the steel box girder jacking is still not perfect. In this paper, the structural force data of the steel box girder is obtained by calculation, combined with actual engineering problems, to provide reference for similar engineering problems in the future.

2. PROJECT SUMMARY
The bridge is located at a certain section of the Shangri-La-Lijiang Expressway. In consideration of topography, geomorphology, and hydrology, the upper structure of the bridge uses 63.71+70+63.71 meters of continuous composite steel beams.

The plane of the bridge is located on the left turn curve of $R=2077.96\text{m}$, $L_s=225\text{m}$, the longitudinal slope of the bridge deck is 2.7\%, and the cross slope of the bridge deck is 2\%.
Two main beams are set on a single span, solid web end beams are set at the end fulcrums, solid web middle beams are set at the middle fulcrum position, and a cross brace and cross-connection between the boxes are set every 5 meters between the spans. The horizontal joints and the horizontal bracing in the box are all open-web truss structures. The detailed structure is shown in Figure 1.

Figure 1. Cross-section view of steel beam

3. PREPARE YOUR PAPER BEFORE STYLING
This paper will mainly study the pushing process of the right side of the bridge. The steel bridge between piers 0–3, the assembly area is arranged at the tunnel opening behind pier 3. The line shape is a flat curve, and the radius of curvature is 2077.957 to the left. The total weight of a single jack is about 810t. The front end is equipped with a guide beam, and the walking type pushes the installation in place. The steel beam has a trough section and weighs about 4.05t per linear meter.

The guide beam is composed of two welded H-shaped beams. The two guide beams are supported and connected by a tie rod, and the web of the guide beam is opened to reduce its own weight. The guide beam is divided into 3 sections in the longitudinal direction and assembled to form a whole with the steel beam longitudinal partition with high-strength bolts. The plane and lateral connections between the guide beams are connected by trusses to ensure the spatial integrity of the steel guide beams and meet the force requirements. The bottom of the guide beam is assembled into a main beam curve with a radius of 1100m. The self-weight of the guide beam used in the push of the Pai Dam Bridge is about 72t, and the guide beam is processed according to the pushing radius and cross slope. The guide beam connection truss adopts Q235B, and the rest are all Q345B; the guide beam and box beam are welded with equal strength and are fully penetrated.

The total weight of the right side of the bridge is 785 tons. Deploy walking-type jacking equipment on Pier No. 1 and No. 2 and use temporary buttresses to install walking-type jacking equipment between Pier No. 2 and No. 3 abutment. There are 6 sets of jacking equipment, each set of jacking equipment Two sets of walking jacks are provided. It is planned to adopt a 400-ton walking jacking system. The vertical jack jacks of the system are 400 tons, the longitudinal jacks are 80 tons, and the correction jacks are 80 tons, which meets the requirements of on-site construction.

The Construction Process is as Follows:
(a) A 110t truck crane is used to install the platform brackets and walking-type jacking equipment brackets between No. 0 abutment and No. 1 pier, between No. 2 pier and No. 3 abutment, and a car crane is arranged at the position of No. 3 abutment. The support foundation uses an excavator to trim the platform and tamp it, and tie the steel bars to pour the concrete foundation.

(b) The steel guide beams are assembled on the ground in sections, and the steel guide beams are installed on two sets of jacking equipment between the No. 2 pier and the No. 3 abutment using a 220-ton truck crane.

(c) Use walking-type jacking equipment to adjust the guide beam to the empty steel beam assembly position, and assemble the second and third steel beams.

(d) The walking-type jacking equipment is used to push the guide beam and steel beam forward by 11.01 meters, vacating the assembly position of the fourth section of the steel beam, and assemble the fourth section of the steel beam.

(e) Repeat the above steps until the steel girder is assembled from the second section to the nineteenth section, and pushed forward in sequence. Because it does not affect the construction of the 0# abutment, in order to ensure the safety and stability of the push, no push is adopted. In the first section, when the top of the steel guide beam is about to reach the 0# abutment, use a truck crane to remove the guide beam in sections.

(f) After all the steel beams are pushed in place, install the unloading jack, prepare to drop the beam, and unload the steel beam to the designated position. After the second to nineteenth sections of steel beams are dropped to the designated position, the first section of steel beams are installed by hoisting by a car, and the steel beams are all installed.

4. **Finite Element Calculation**

4.1. *Calculation Content*
The finite element software 3D3S is used for model calculation and analysis. Mainly calculate the pressure of guide beams and steel box beams on temporary piers and supports during the jacking construction process, and whether the strength and rigidity of guide beams and steel box beams meet the requirements of use. According to the analysis of the construction process of the steel box girder jacking\cite{3}, the working conditions of the important stage are selected\cite{4}, as shown in Table 1.

| Working Condition | Head The construction status |
|-------------------|-----------------------------|
| Stage one         | When LG2 of steel box girder is assembled |
| Stage two         | When the guide beam is approaching L2 |
| Stage three       | When the guide beam is 20m above Pier L2 |
| Stage four        | When the guide beam is 50m above Pier L2 |

According to the parameters of each component\cite{5}, the steel box girder, guide beam and support system model are established, as shown in Figure 2 and Figure 3.
4.2. Analysis of Calculation Results

4.2.1. Analysis of Supporting Force: Piers L2 ~ L3 are the pier columns that participate in the most force in the jacking construction stage, and the loads of these pier columns mainly come from the pressure and friction force of the guide beam and steel box beam section on the support system, and the support reaction force of the jacking cylinder. As well as the self-weight of the support system, these factors constitute the reaction force at the top of the pier. Therefore, controlling the supporting reaction force at the top of the pier is an important factor for the success of the jacking. With the change of the pushing stage, the supporting reaction forces of the L2 and L3 piers are also constantly changing. The changes are shown in Figure 4.
Figure 4. Change trend graph of L2 and L3 pier support reaction force

It can be seen from Figure 4 that during the process of stage 1 to stage 2, the supporting reaction force of L3 gradually increases because the guide beam and steel box beam are in a cantilever state, and the L2 pier does not participate in the force. The status is mainly concentrated on the L3 pier. When the construction progressed to the second stage, the supporting reaction force of the L3 pier reached its maximum value of 1639kN. At this time, the entire main beam and guide beam structural system was in the maximum cantilever state. When the construction progresses to stage 3, that is, after the guide beam reaches the top of L2 pier and exceeds 20m, the supporting reaction force of L2 pier reaches 374kN, indicating that the load on the pier top starts to transfer from pier L3 to pier L2 after the guide beam reaches pier L2. Therefore, the supporting reaction force of L3 pier gradually decreases, while the supporting reaction force of L2 will gradually increase. As the construction continues, when the progress reaches stage 4, L2 will reach the maximum value of 1422kN during the pushing process, and the supporting reaction force of the L3 pier will gradually decrease until the steel box girder is pushed to the top of the steel box girder. After being pushed in place, the supporting force of the L2 and L3 piers is basically the same. This also means that the force on both ends of the steel box girder is uniform and the structure is in a stable state.

4.2.2. Deflection Analysis: In the process of jacking construction, an important characteristic value that can reflect the thrust conditions is the displacement value of each structure. Therefore, the displacement of each structure must be controlled during the pushing process. According to the model analysis results, the deflection results of the front end of the guide beam and the steel box girder are extracted, and the deflection changes with the construction stage during the pushing process can be obtained. As shown in Figure 5.
It can be seen from Figure 5 that when the top thrust reaches stage 2, the deflection of the overall structure reaches the maximum value, the maximum value is 806mm; it can be seen that the deformation of each member when the entire structure system is in the maximum cantilever state Reach the maximum value, and the structural strength and rigidity meet the requirements during jacking. If the deflection is too large during the jacking construction process, on the one hand, it will be very difficult to change the pier on the guide beam, which greatly increases the difficulty of jacking construction; on the other hand, the excessive deflection during the construction process makes the entire structure extremely dangerous and directly damages the overall stability of the bridge structure. Excessive deformation of the cantilever free end of the guide beam causes large deflection and deformation of the beam, making the contact between the main beam and the slideway very uneven, and will also affect the local safety of the structure.

4.2.3. Stress Analysis: The stress ratio of the entire structure changes during the jacking construction process, as shown in Figure 6. It can be seen from Figure 6 that when the jacking construction reaches stage 4, that is, after the steel box girder reaches the L2 pier, the stress ratio reaches the maximum, and its value is 0.728. Therefore, this stage is also the main safety control section of the entire construction process. The stress ratio of the steel structure is less than 0.85 in the safe range. Therefore, the strength and rigidity of the entire structure meet the requirements.
4.3. Anti-overturning Check

According to the pushing procedure, it is known that the guide girder of the drainage bridge is about to go up to the L2 pier as an unfavorable working condition, and the anti-overturning performance under this working condition is calculated.

State 2: The guide beam is about to go up to the L2 pier, the front overhang is the largest.

Overturning moment:

\[ M_k = 74 \times 40 + 86.5 \times 10.6 = 3877 \, \text{t.m} \]  \hspace{1cm} (1)

Anti-overturning moment:

\[ M_k = 217 \times 26.5 + 42 \times 50 = 8000 \, \text{t.m} \]  \hspace{1cm} (2)

The length of the counterweight is 10m and the weight is 50t.

Anti-overturning coefficient:

\[ \frac{M_k}{M_q} = \frac{8000}{3877} = 2.1 \geq 2 \]  \hspace{1cm} (3)

Fulfil requirements.

5. Conclusion

In this paper, through the safety control of the whole process of pushing the steel box girder of a large-span steel concrete curved bridge in Yunnan Province, the following conclusions are obtained:

(a) The use of finite element software for numerical simulation analysis can carry out pre-safety control of important components. The control indicators include: support reaction force, tolerance and stress ratio\(^6\).

(b) The optimal design principle is that at the beginning of the component design phase, the stress state of the structure during the construction phase and the use phase should be considered at the same time\(^7\). When the most unfavourable working conditions are known, the site construction plan should be modified in time and check calculations.
(c) Through the combination of finite element analysis and on-site construction operations, the force analysis of the entire structure during the pushing process is better considered to ensure that the structure is in a safe state during the construction process, and the feasibility of the structural design can also be verified.

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