

# Process Comparison and Stress Analysis of V-Shaped Structure of Continuous Girder Bridge in Construction Stage

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**Abstract:** Based on the first steel-concrete hybrid continuous beam bridge with V-shaped structure in China, this paper studies the construction technology and stress of V-shaped structure. The results show that: (1) Considering the construction period, construction difficulty, weather and other factors, the optimal construction technology of the V-shaped structure of the bridge is joint construction of cable and framing; (2) The stress characteristics of the V-shaped structure are analyzed by using the general finite element program ABAQUS. Under the most unfavorable conditions, the lower chord of the V-shaped structure is under overall compression and the upper chord is under overall tension. The maximum tensile stress is 2.2 MPa located at the top of the column, and the maximum compressive stress is 5 MPa located in the web at the root of the lower chord; (3) Reducing the number of large and small mileage temporary cables from 7 to 4, and increase the initial tension from 3000 kN to 5000 kN, so as to optimize the construction measures.

## 1. Introduction

With the improvement of bridge aesthetics and the requirement of lightweight structure, the hollow prestressed concrete continuous girder bridge emerges at the historic moment. Compared with the ordinary continuous girder bridge, the continuous girder bridge with V-shaped structure has better mechanical performance<sup>[1]</sup>, greatly improved structural stiffness<sup>[2]</sup>, and has the advantages of smaller structural size and relatively economic cost<sup>[3]</sup>. The section forms of V-shaped structure, however, are varied, the design is complicated, and the construction is difficult. In the process of construction, the lower chord of V-shaped structure is prone to produce excessive tensile stress, which causes cracks in the concrete structure. After the construction is completed, the lower chord of the V-shaped structure is in a state of compression, and the stress change process exists in the V-shaped structure under the two working conditions. If improper control is carried out, it will have a great impact on the later operation<sup>[4-6]</sup>. At present, the stress distribution of V-shaped structure is not yet clear<sup>[7-8]</sup>, thus the construction technology and stress analysis of V-shaped structure have become an important topic in the design and construction of such bridges<sup>[9-11]</sup>.

This paper takes the first steel-concrete hybrid continuous beam bridge with V-shaped structure in China (Fig. 1) as the engineering background. The main span of this bridge is 240 m, which is the largest span of steel-concrete hybrid continuous girder bridge in China. Through numerical simulation analysis, the stress state in the construction process is clarified, the stress characteristics and the stress distribution information of the key parts are grasped, which provides a reference for the design of V-shaped structure of continuous girder bridge and promotes the further development of this kind of bridge.

## 2. Project Profile

In this paper, the upper girder of the main bridge of a bridge adopts the continuous girder structure of hollow system, and the 96m steel box girder is used in the mid-span. The rest of the bridge adopts the prestressed concrete structure, and the section is of a single box with double chamber, with longitudinal, transversal and vertical prestressed cables installed. The girder height of

the main V-shaped structure (Fig. 2) is 3.8 m at the support position corresponding to the upper chord of the hollow part, and the girder height is gradually increased by using the parabola shape twice to both sides. The vertical height of the lower chord is 4.5 m. It transitions with the column through a circular arc with a radius of 1 m at the support position. The section height of the column is 4m, and the width of the column is shrunk 0.2 m on both sides of the upper chord bottom plate.



Fig.1 Main V-Shaped Structure of a Bridge

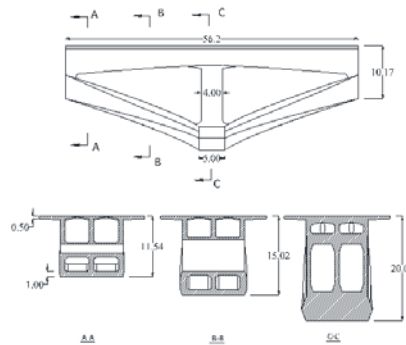


Fig.2 Dimensions of Main V-Shaped Structure Schematic Diagram (Unit: m).

### 3. V-Shaped Structure Process Comparison and Selection

#### 3.1 The Main Construction Method of V-Shaped Structure

##### (1) Full framing construction

The full framing method is a construction technology that is built at a certain interval in the bridge location and cast-in-place through scaffolding and supporting formwork. The V-shaped structure of the main bridge of Fuzhou Wanbian grand bridge is constructed by full framing method. This method has the advantages of simple erection and short construction period, but the cost of full framing is expensive and the flood resistance capacity is weak, which may cause potential safety hazards<sup>[12]</sup>.

##### (2) Hanging basket and upper chord support construction

The hanging basket and upper chord support method (Fig. 3) adopts the construction technology of “lower chord cables combined with hanging basket segment casting, and the upper chord is cast through the bracket segments”. The V-shaped structure area of the main bridge of Beipanjiang grand bridge was constructed with this method for the first time. This method avoids the interference between the upper and lower chord construction, and reduces the investment of equipment. But the cable force bears most of the weight and construction load of the upper chord box girder, the structural stability is insufficient, and the construction efficiency and safety of high-altitude support are low.

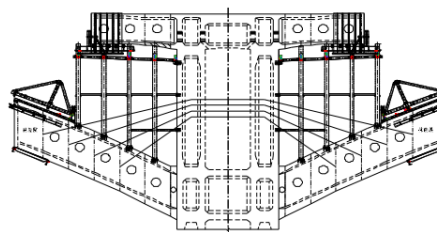


Fig.3 Schematic Diagram of Construction Method of Hanging Basket and Upper Chord Support.

### (3) Rigid skeleton combined with temporary tie rod construction

The V-shaped structure is embedded with a rigid skeleton (Fig. 4) as the bearing system, and several temporary tie rods are set on the inclined limb. The tension of the tie rod is used to reduce the bending moment at the root of the lower chord to reduce the tensile stress at the root, so as to avoid the cracks at the root of the inclined limb and the top surface of the pedestal due to excessive bending moment and tension during the construction of the V-shaped structure. However, comparing with other construction methods, the process is complex and the cost is high. The main bridge of Huangzhou bridge in Guangdong Province is a V-shaped rigid frame composite box girder bridge. The V-shaped structure area is constructed by rigid skeleton combined with temporary tie rod.

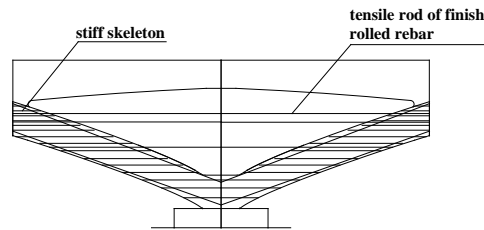


Fig.4 Schematic Diagram of Rigid Skeleton Combined with Temporary Tie Rod Construction.

### (4) T-shaped balance frame construction of universal bar assembly

The T-shaped balance frame assembled by universal members (Fig. 5) is constructed with the new support scheme assembled by steel truss beam and universal members. Taking Qingtian Tashan bridge as an example, the angle of V-shaped structure ( $75^\circ$ ) of the bridge is larger than that of similar structures, and the scale of V-shaped structure ranks first in China. Therefore, the vertical load acting on the support is larger, and the bearing capacity of the support is very high. This method is flexible and can be adjusted according to the actual situation of the construction location. However, there are many nodes in the support system, and the deformation is large under the self-weight and construction load of the structure, which affects the structural safety to a certain extent.

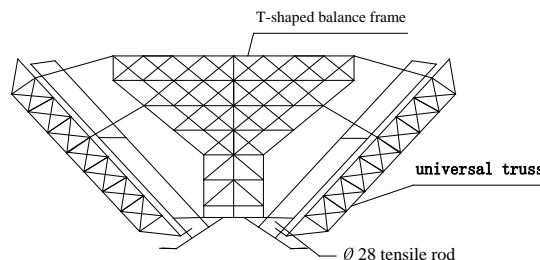


Fig.5 Schematic Diagram of T-shaped Balance Frame Assembled by Universal Members.

### (5) Joint construction of cable and framing

The joint construction of cable and framing (Fig. 6) is to add temporary cable on the basis of full support method. After the construction of the lower chord of V-shaped structure is completed, the temporary cable force is tensioned for the first time to avoid the cracking of the lower chord under excessive tensile stress. After the first casting of the lower chord, the temporary cable force is tensioned for the second time to optimize the stress distribution of the V-shaped structure. In this method, the internal force of the V-shaped structure can meet the design requirements by adjusting the tension of the cable, which can reduce the amount of the lower chord support and shorten the construction period. However, the height of the support is limited, so it is not suitable for deep valley, deep river and other areas.

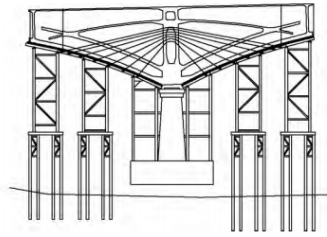


Fig.6 Schematic Diagram of Joint Construction of Cable and Framing.

The advantages and disadvantages of the above five conventional V-shaped structure construction methods (Table 1) can provide reference for the V-shaped structure construction of a bridge.

Table 1 Advantages and Disadvantages of V-Shaped Structure Construction Methods

Construction method of V-shaped structure.	Construction period.	Advantages.	Disadvantages.
Full framing construction.	Short.	The support erection process is simple and the construction period is short.	The support formwork consumption is large, the support cost is high, and the flood resistance capacity of full framing is weak.
Hanging basket and upper chord support construction.	Long.	The upper and lower chord segments can be constructed synchronously, which has little impact on the construction period.	Structural stability is insufficient; support construction efficiency and safety is low.
Rigid frame combined with temporary tie rod Construction.	Longer.	Avoiding the cracking of the root of inclined limb and the top surface of pedestal due to excessive bending moment and tensile force.	Expensive.
T-shaped balance frame construction of universal bar assembly.	Long.	The members can be assembled flexibly, and can be assembled into ideal shape at will, which is not limited by the structure itself.	Large deformation affects the safety of the structure.
Joint construction of cable and framing.	Shorter.	Optimizing the stress distribution of V-shaped structure, reducing the amount of lower chord support and shorten the construction period.	The height of the support is limited.

### 3.2 Structure Process Comparison and Selection

Considering the construction period, the construction period of the other three methods is longer than that of full support construction and cable support joint construction; Considering the hydrological conditions, on the one hand, the construction site of a bridge project across the river belongs to subtropical maritime monsoon climate, with abundant rainfall, and the river section is in the transition section of runoff and tide, so the adverse effects of water flow and flood on the construction process should be avoided as far as possible. On the other hand, the geological layer of the river fluctuates greatly, and the steel pipe pile foundation is prone to uneven settlement, so it is not suitable to use full support construction; Considering the economics, the joint construction of cable and framing can reduce the amount of support by more than 30% compared with the full support method under the condition of ensuring the reasonable stress of V-shaped structure in the construction stage, and ensure the V-shaped structure in the construction stage. Considering the mechanical performance, the most unfavorable stage is before the closure of the upper chord, and the finite element model is established to compare the normal stress of the roof section of the lower chord of the V-shaped structure (Fig. 7). The results show that, compared with the full support, the joint construction method of cable framing can significantly reduce the tensile stress at the top plate of the lower chord, especially at the intersection of the lower chord root and the column; the overall tensile stress of the lower chord in the construction of hanging basket and upper chord support is

significantly increased; the setting of temporary tie rod can make the whole lower chord tension, but there is a large stress mutation at the connection between the tie rod and the lower chord, which is unfavorable to the structure stress. Comprehensive comparison shows that the joint construction of cable and framing can significantly reduce the tensile stress of the lower chord, and the mechanical performance of the structure is the best.

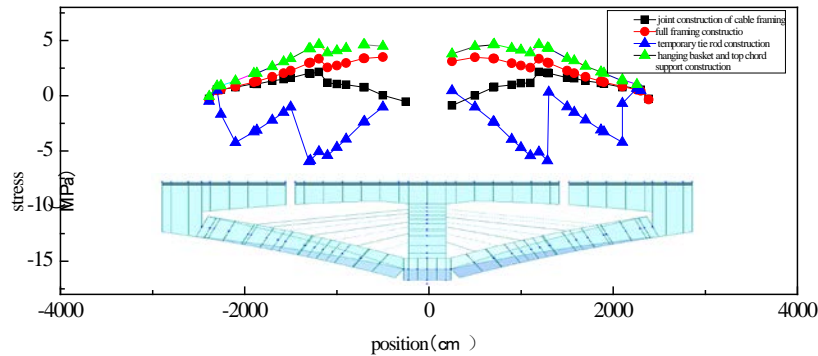


Fig.7 Comparison of Normal Stress of V-Shaped Structure

lower chord roof with different construction methods.

#### 4. Stress Analysis of V-Shaped Structure in Construction Stage

##### 4.1 Finite Element Simulation

(1) concrete and prestressed reinforcement simulation

The upper and lower chords of the V-shaped structure are made of C55 concrete, and the corresponding tendon areas are given according to the prestressed tendon groups. The embedded element method in ABAQUS is used to simulate the interaction between concrete and reinforcement in reinforced concrete structure, and the mechanical relationship between them is established by displacement coordination condition. Simulation of concrete and prestressed tendons is shown in Fig. 8.

The relationship between the coefficient of linear expansion and temperature is shown in equation (1).

$$T = \frac{A_P \sigma_P}{E_P \alpha} \quad (1)$$

Where T is cooling temperature,  $E_P$ , Elastic modulus of prestressed steel strand,  $\alpha$ , material expansion coefficient,  $A_P$ , Area of prestressed steel strand, and  $\sigma_P$ , prestressing. Taking  $\alpha = 1.2 \times 10^{-5}$ ,  $E_P = 1.95 \times 10^8$  kN/m<sup>2</sup>. According to equation (1), the temperature of 1395 Mpa prestress should be reduced by 554 °C by editing the predefined field.

(2) full framing simulation

The truss element is used to simulate the full framing (Fig. 9). After the geometric model is established, the MPC constraint is created to interact the full framing rod end with the concrete surface area. The MPC type is tie. The rigidity of full framing is  $2.4 \times 10^6$  kN/m.

(3) cable simulation

The cable is simulated by truss element. After establishing the geometric model, the embedded region is used to interact with the concrete area. The initial tension is applied by setting the initial stress.

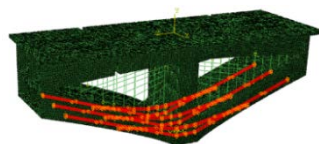


Fig.8 Simulation of Concrete and Prestressed Tendons.

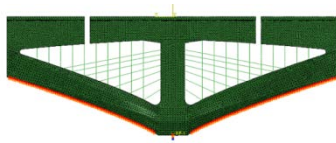


Fig. 9 Simulation of Full Framing At the Bottom of Lower Chord.

(4) analysis step settings

Because there are many interactions between truss element and solid element, the type of analysis step is set as implicit dynamic analysis, and geometric nonlinearity is introduced.

(5) boundary condition setting

Because of the temporary consolidation of the support under the V-shaped structure in the construction stage, the six degrees of freedom at the support of the V-shaped structure solid finite element model are set to zero. The two ends are free boundary and no load is applied.

#### 4.2 Force Analysis

The main stress distribution of V-shaped structure in the most unfavorable construction stage (pouring upper chord concrete) is shown in Fig. 10 and Fig. 11. The tensile stress is positive and the compressive stress is negative.

(1) Because the prestressed steel tendons have not been tensioned at the upper chord, there is a large range of tensile stress at the top slab of the upper chord, and the maximum tensile stress is 2.2 MPa, which is located at the top of the column. The results show that the bottom plate of the upper chord is basically in the compression state; the intersection of the upper chord and the lower chord also has a large range of tensile stress, and there is a sudden change of tensile stress at both ends of the section. The stress of the upper chord web is relatively uniform, mainly in the compression state, and the maximum compressive stress is not more than 2 MPa.

(2) The main tensile stress of 2.5 MPa appears in the section area of the middle roof buckle in the lower chord, and the bottom of the lower chord is basically in three-dimensional compression state. The compression stress of the lower chord web is larger than that of the upper chord web, especially there is a maximum principal compression stress of 5 MPa at the web at the root of the lower chord.

(3) Because most of the dead weight of the beam is borne by the full support and temporary buckle, the compressive stress of the column is relatively balanced, and the stress situation is similar to that of the bridge in the operation stage. The top of the column is in three-dimensional compression state, and the maximum compressive stress is 3 Mpa. There is a three-dimensional tensile area at the connection between the bottom of the column and the support, and the maximum tensile stress is 2 MPa.

(4) The residual cable force of the temporary buckle is still about 3000 kN, which is consistent with the finite element simulation results of the bar system, indicating that the buckle still has sufficient cable force reserve.

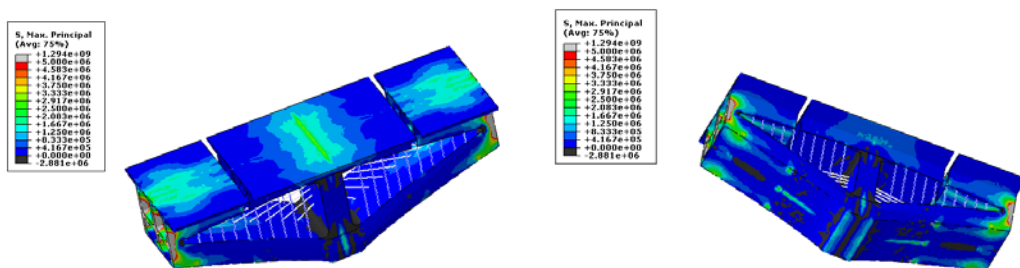


Fig.10 Cloud Chart of Main Tensile Stress of V-Shaped Structure in Construction Stage.

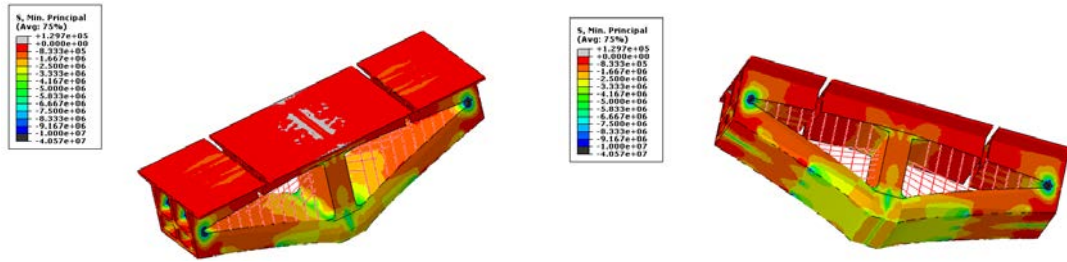


Fig.11 Cloud Chart of Main Compressive Stress of V-Shaped Structure in Construction Stage.

### 4.3 Optimization of Construction Measures

In the process of V-shaped structure using the joint construction method of cable and framing, the weight and construction load of the upper chord are transferred from the bracket to the lower chord. In order to avoid excessive load on the lower chord and the full support of the lower chord, the pretension is applied to the temporary buckle between the lower chord and the column. According to the results of finite element analysis, the initial tension of temporary cable can be increased appropriately to reduce the number of temporary cable tension.

According to the finite element analysis of the bar system, the number of the first tensioning buckles in the construction stage is 7 at the large and small mileage sides, and the initial tension is 3000 kN, which can be reduced to 4 at the large and small mileage sides. When the initial tension is still 3000 kN, due to the decrease of the total tension, it can be seen that the tensile stress of the lower chord increases obviously, and the tensile stress appears at the top plate of the root of the lower chord. When the initial tension is increased to 5000 kN, it can be seen that the stress of the top plate of the lower chord is basically the same as that of the tensioning 7 buckles. Therefore, the scheme of reducing the number of tensioning buckles by appropriately increasing the tension of buckles is proposed. The optimization of the construction measures not only ensures the reliability of the structure construction stage and the completed bridge operation stage, but also improves the economy and simplifies the construction process. The comparison of the lower chord stress of different construction measures is shown in Fig. 12.

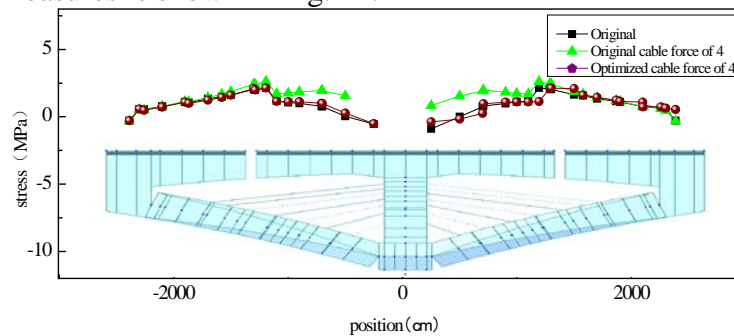


Fig.12 Comparison of Chord Stress under Different Construction Measures.

## 5. Conclusion

(1) According to the actual situation of a bridge, joint construction of cable and framing is the optimal construction technology after comparing the five construction technologies based on various factors.

(2) At the construction stage, the lower chord of the V-shaped structure is under overall compression, while the upper chord is under overall tension. The maximum tensile stress is 2.5 MPa, the maximum compressive stress is 5 MPa; The uniform force of the column indicates that the design of hollow column is economical and reasonable.

(3) This paper proposes an optimization scheme for temporary cable: Reducing 7 cables at large and small mileage sides to 4 at each side, and increase the initial tension from 3000 kN to 5000 kN. Improving the economy and simplify the construction process while ensuring the reliability of the structure in the construction stage and the operation stage of the bridge.

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