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Design of the V-shaped Lower Tower Column Support for Tuojiang Bridge on Jinjianren Expressway

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Abstract

Tuojiang Bridge on Jinjianren Expressway is a single-tower double-plane cable-stayed bridge with the space curve and hexagonal section steel inclined tower. As the urban landscape bridge, it is an important channel connecting the north and south directions of Chengdu city area. Based on the structural characteristics of the main tower of Tuojiang Bridge and the construction process, the design and optimization of the V-shaped lower tower column bracing schemes of the main tower were carried out. Ultimately, the design scheme of less point supporting system was determined by comparison. In the scheme, the foundation of the nearby existing structure is used or the existing structure was avoid through setting template beams and brackets, which brings out lower costs. By welding steel cushion blocks on the V-shaped leg segment, it is conducive to segment hoisting and the structure alignment. Meanwhile, by using finite element software to simulate the construction process, the reaction forces acting on the bracket are analyzed during the construction of the V-shaped lower tower column, which are used as the loads in the calculation of the V-shaped lower tower column support to ensure the reliability of the finite element analysis and the economical efficiency of the support. The less point supporting system program can not only meet the functional requirements of hoisting, assembling and adjusting the shape of the main structure, but also reduce the construction difficulty and cost of the structure, and enable the successful implementation of this project, which can provide a reference for the design of similar projects.

Keywords

Tuojiang Bridge; Main Tower; V-shaped Lower Tower Column; Support.

1. Introduction

Tuojiang Bridge on Jinjianren Expressway is the world's largest suspension single tower cable-stayed bridge with the asymmetrical curved and twisted cable plane. The bridge has the world's tallest inclined bridge tower and the world's widest bridge deck with four spans of 45+185+238+45m, which is shown in Figure 1. As an important channel connecting Deyang Zhongjiang County in the north and Meishan Renshou County in the south, and also joining the Hi-tech Zone Airport New City, Tianfu International Airport, Jintang County, and Jianzhou New City, Jinjianren Expressway project meets the needs of the growing regional traffic, leading to vital effect in the north-south direction of Chengdu's "eastward" area [1]. Regarding as an important node of Jinjianren Expressway, the bridge is located in the river with only 1m loose pebble layer shallow cover.Besides, the west bank side of the terrain is complex, accompanied by most of the water operation. Tuojiang Bridge is 64m~86.7m in width, whose weight of the steel structure installation of each extension meter reaches 78.45 tons,

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vertical height of the main tower reaches 173.3m and tilt angle is 18°. As a whole, the main tower structure has a spatial inclined curve variable cross-section. The steel tower and steel-box girder segments have large weight, inducing many difficulties from manufacturing, installation equipment selection, high precision control assembly requirements. Apart from that, the spatial inclined cable plane, the complicated structure, and interference among stayed cable, assembled support of the main tower and the tower cranes give rise to many problems.

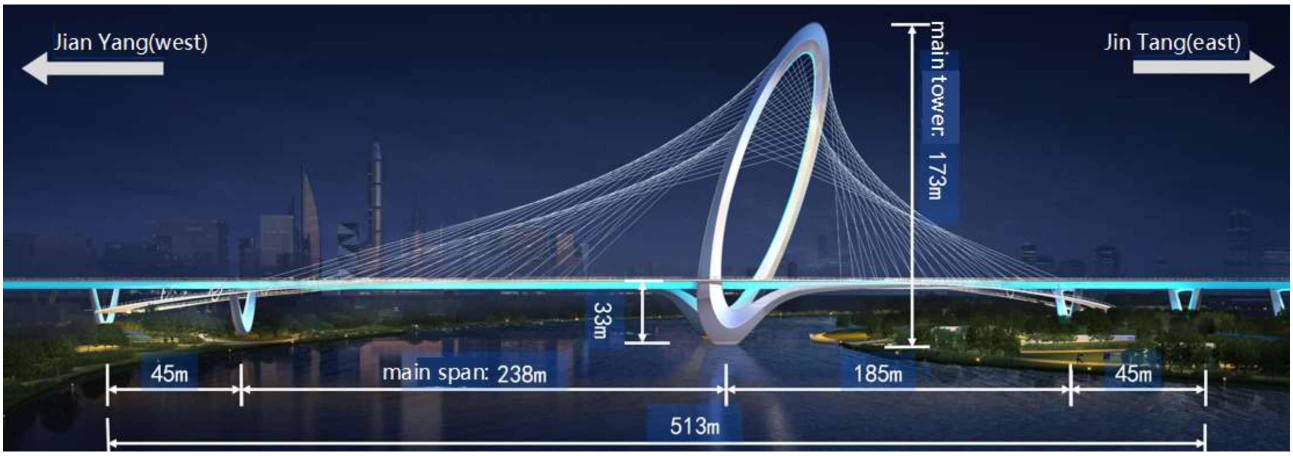

Fig. 1 The elevation arrangement of Tuojiang Bridge

2. Design Scheme Selection

The double V-shaped lower tower columns of the main tower need block hoisting due to lifting weight restriction, and in order to facilitate the construction of V-shaped tower columns in upstream and downstream, it is necessary to set up the assembling support. However, it is hard to analyze and design the supporting system, so the linear control of the installation process needs to be taken into account. From this, three schemes are proposed and compared for the tower column assembling support, which are listed in the following table.

After analyzing the advantages and disadvantages of different schemes, it can be seen that Scheme 3 saves 564t of steel and 20 days of construction period compared with Scheme 1, at the same time the corresponding technical problems can be solved through setting operation platforms for the supports, designing and processing the matching steel connectors by plants, and adjusting the construction technology. Considering the tight construction period of the project and the overall structure stability of the V-shaped tower column support, Scheme 3 is recommended as the construction scheme [2].

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Table 1. The scheme comparison of the V-shaped lower tower column supports for the main tower

programme	Scheme 1 Multi-point support hoisting method	Scheme 2 Single point support hoisting method&Temporary prestressed support hoisting Method	Scheme 3 Less point support hoisting method&Temporary prestressed support hoisting Method
vantages	1.The effect of the structural assembling linear control is better; 2. The segments can be matched quickly by positioning measures of matching connectors and three-way jacks and other adjustments, construction efficiency is relatively fast; 3. V-shaped tower column support can be used as an operating platform, without additional platform.	1.tower beam solidification section use the supports, and other parts are hoisted by matching connectors inside of the support, leading to less steel amount.	1.The steel amount of the support can be saved, and the assembling linear control is relatively easier.
disadvantages	1. Relatively long construction period. 2. A large amount of temporary works.	1.The number of rows of the support columns is less, and they are connected only by parallel connections and inclined struts with poor stability.	1. the temporary connection and fixation for a single section hoisting needs to be completed before removing the hook of the crawler crane, so the work efficiency is relatively slow; 2.There are many steel tower segment matching connectors with high strength and precision requirements; 3. A temporary operating platform needs to be made; 4.Connectors are set up inside of the section, but the operation space is limited.
project amount	Steel: 991t Concrete: 100m^3 Total construction period: about 120d	Steel: 213t Concrete: 100m^3 Total construction period: about 100d	Steel: 427t Concrete: 100m^3 Total construction period: about 100d

3. Structure Design

3.1 Overall Arrangement

The assembling support for the V-shaped tower column consists of Ø800×10 steel pipe piles, Ø800×10 steel columns, Ø426×6 parallel connections, 2[25a/Ø 426×6 inclined struts, Ø426×6 vertical braces, and 3HM588×300 brackets to form the support structure. The bottom of some steel pipe piles is in the form of bored cast-in-place piles. The steel pipe piles and steel columns are connected by Ø426×6 parallel connections and 2[25a/Ø426×6 inclined struts. Above the steel pipe piles, 2HM588×300/3HM588×300 main beams and 3HM588×300 template beams are arranged, which are connected by 2HM588×300 linking beams. Part of the steel pipe piles are welded with plates for local reinforcement. The steel columns are supported on the foundation slab, template beams or on the side wall of the tower base through brackets respectively, together with 3HM588×300 main beams above. 2HM588×300 longitudinal beams which are connected with HM588×300 linking beams are set up under some of the main beams, and paved with surfacing to form the operation platform. Cushion blocks are welded at the joints of the bottom V-shape sections of the main tower, and three-way jacks are set between the cushion blocks and the main beams. Compared with the scheme selection stage, the structure design is optimized and adjusted as follows:

(1) Since the pile positions of the support for the V-shaped tower column are close to or overlap with the pile positions of the proposed trestle bridge and platform, and some of the piles also interfere with the steel sheet piles of the cofferdam, the utilization of the pile positions of therestle bridge and platform firstly should be considered while designing supports. The cast-in-place pile foundation of the nearby trestle bridge and platform is connected to the support through parallel connections, and the part of the support foundations are still designed as driven piles. Because of the poor geological condition, the supports on the upstream and downstream sides still need several cast-in-place pile foundations in order to improve the overall stability of the support. For the piles that cannot be avoided, the interfering piles are moved to the new position by means of template beams to ensure that the support points of the V-shaped segments remain unchanged. In this way, the overall stability of the support is improved and the number of cast-in-place pile foundations is optimized, which saves cost and shortens the construction period.

(2) Combined with the construction process of the V-shaped tower columns, for each section to be supported, the support point is set at the spacer plates of the V-shaped segments, which facilitates the downward force transmission of the segments, reduces the local force at the contact position between the V-shaped segment and the support, and avoids affecting the linear shape of the V-shaped columns

(3) Considering the degree of difficulty in precise alignment while hoisting the curved V-shaped segment, the bottom of the V-shaped segments and steel-box girders are designed to be welded with the cushion blocks that are horizontal at the bottom and tilted at the top to ensure that the segments can be stably placed on the jacks which are on the top of the support while they are hoisted. It greatly simplifies the complexity of the force on the support when the segment is hoisted and adjusted. Besides, the support can only bear the force from the horizontal direction of the segment, which is easier to analyze and calculate.

(4) In order to avoid the steel sheet piles of the cofferdam on the upstream side, it is necessary to set up a row of inclined columns whose legs fall on the tower base, and the brackets which are fixed on the tower base through the embedded parts as the support point of the columns to solve the problems of the limited space of the foundation slab resulting in hard arrangement of the columns.

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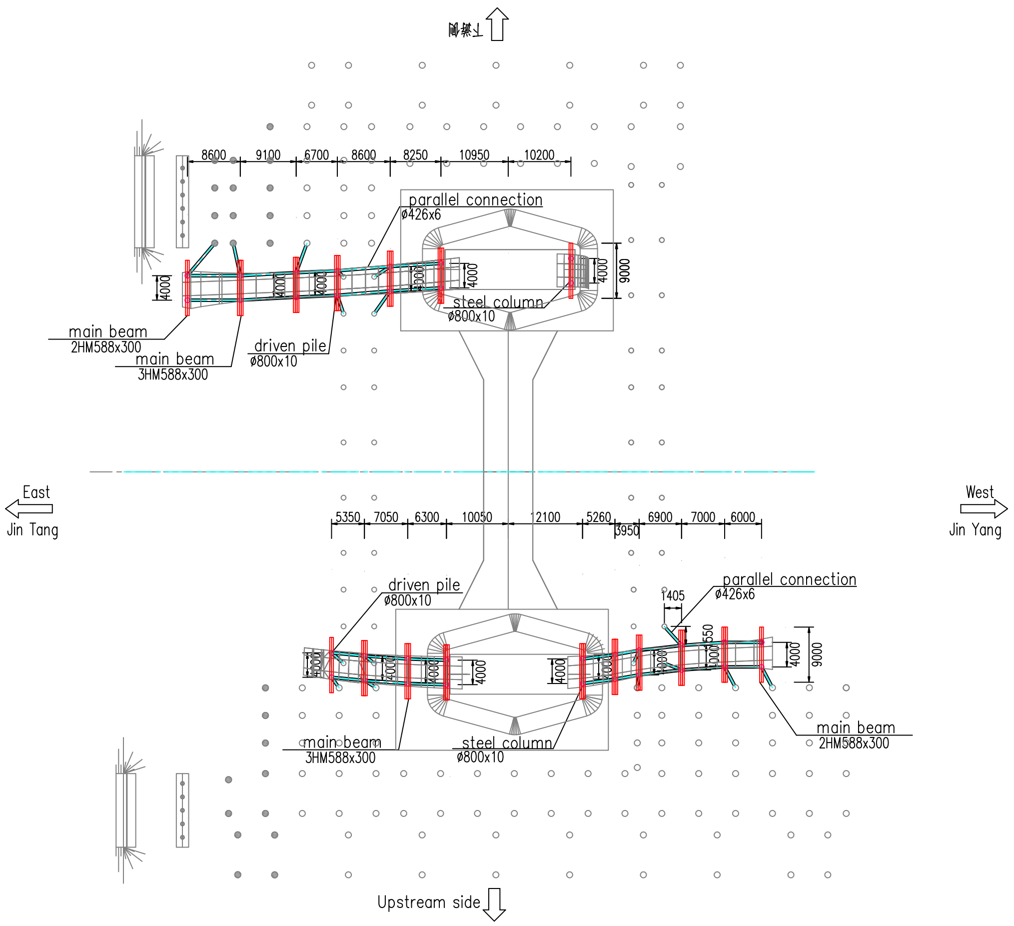

Fig. 2 The layout of the assembling support of the V-shaped lower tower columns

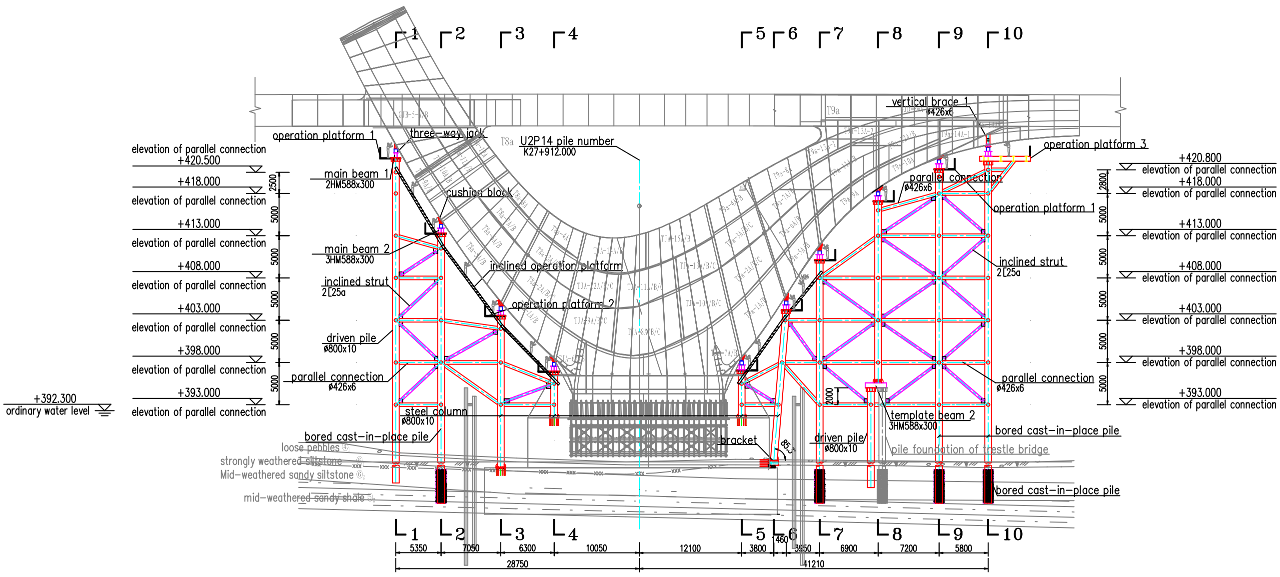

Fig. 3 The elevation layout of the assembling support of the V-shaped lower tower columns on the upstream side

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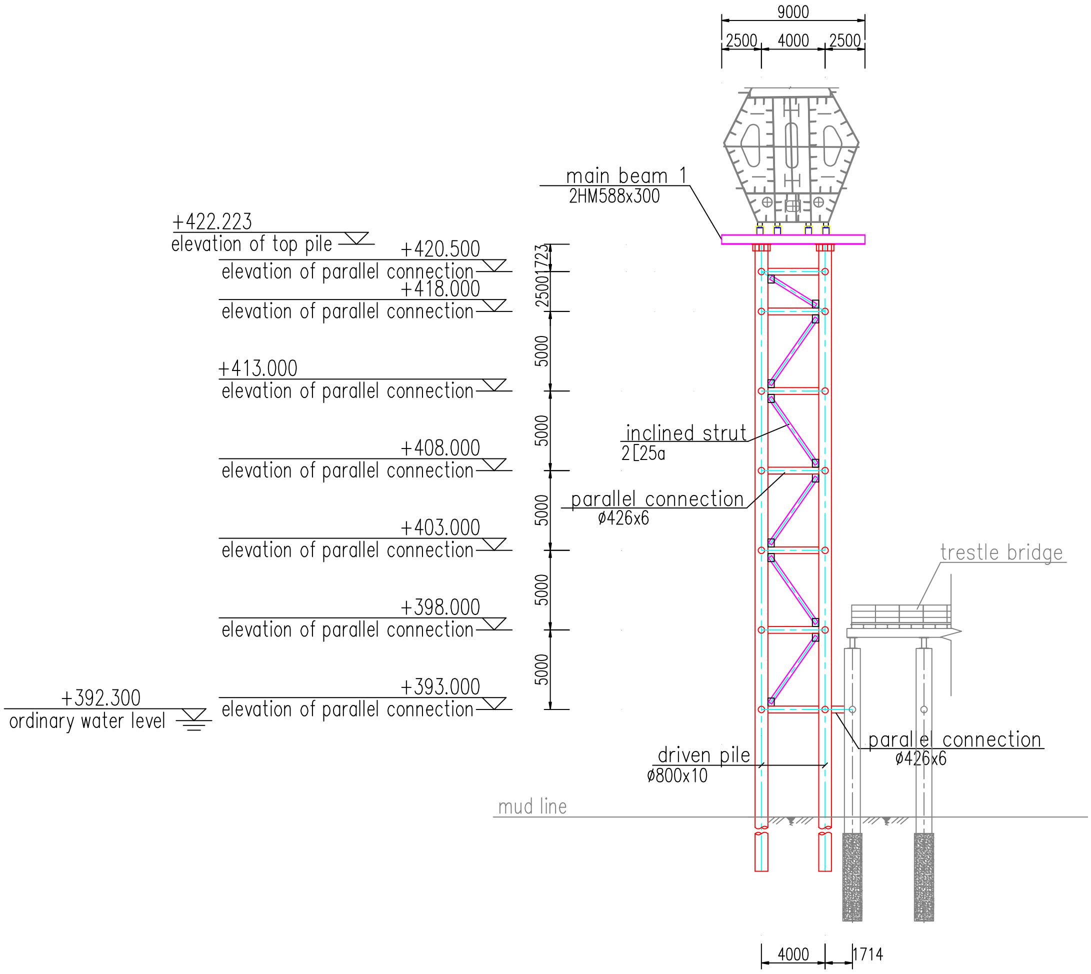

Fig. 4 The sectional drawing of the assembling support of the V-shaped lower tower columns on the upstream side

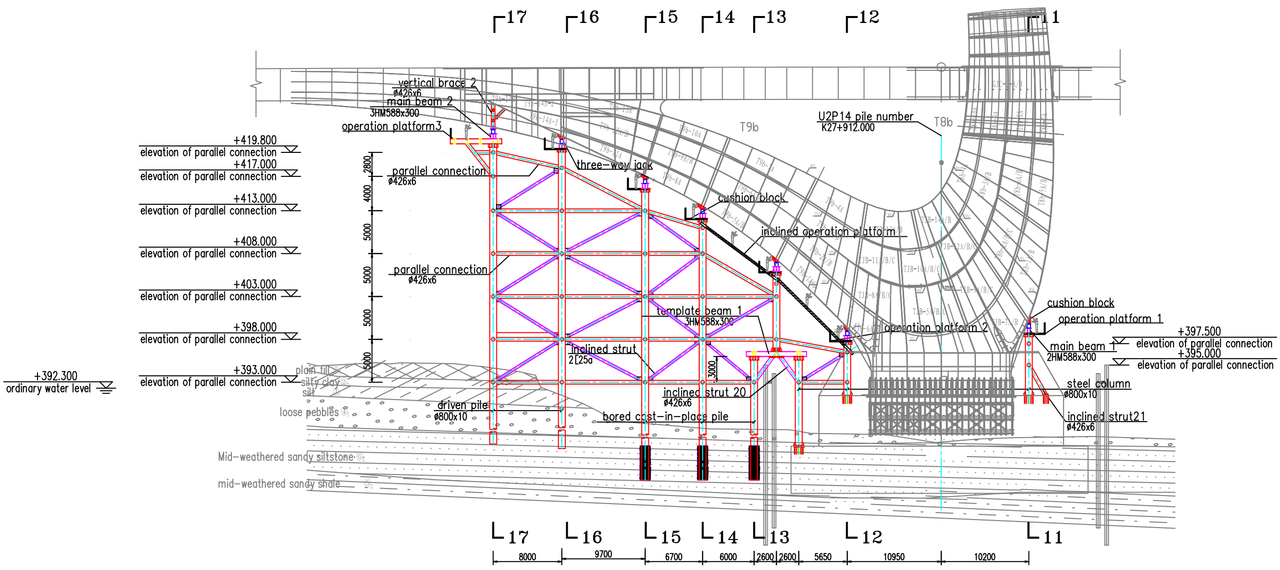

Fig. 5 The elevation layout of the assembling support of the V-shaped lower tower columns on the downstream side

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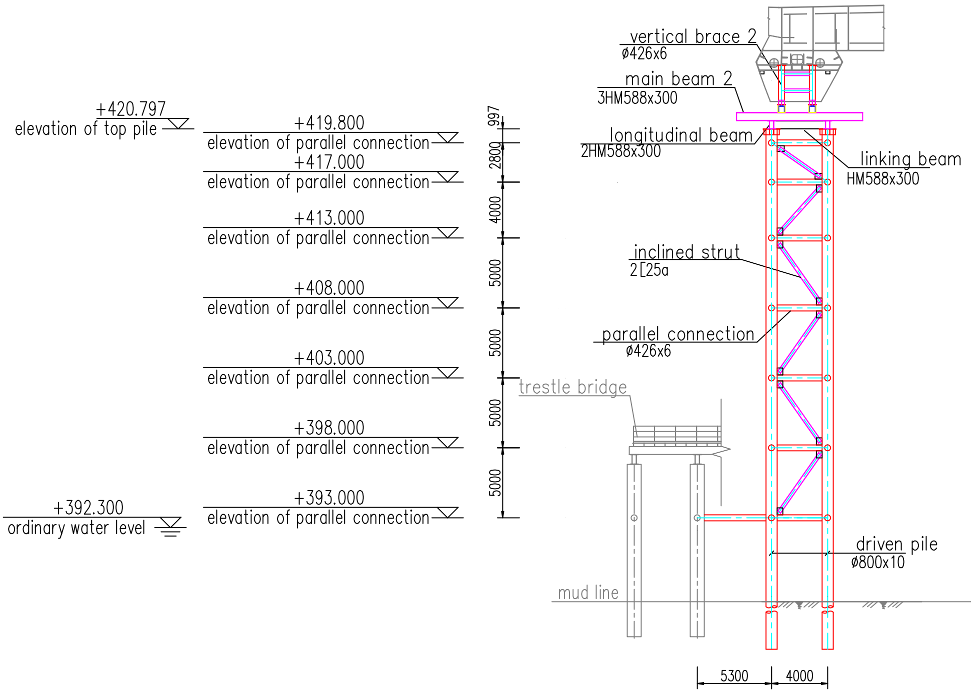

Fig. 6 The sectional drawing of the assembling support of the V-shaped lower tower columns on the downstream side

3.2 Structure Load Values

The main loads to be considered for the support include: (1) Self-weight of the structure are calculated by the finite element software. (2) Self-weight of some V-shaped segments and steel-box girder segments are considered. According to the hoisting and installing process of V-shaped segments, and combining with the modeling calculation results of the construction stage of V-shaped segments , it considers the influence of some V-shaped segments and upper steel-box girder segments on the support, considering the variation coefficient of 1.2 during the placement process. Some V-shaped segments and steel-box girder segments has 39 blocks with the weight of 14.63t~77t on the upstream side and 29 blocks with the weight of 18.18t~74t on the downstream side separately. (3) Construction loads are considered at 2.5kN/m^2. (4) The horizontal force generated from adjustment is considered as 10% of the weight of the V-shaped segments. (5) Wind load. Design wind speed v is 20. 7m/s, which is calculated according to the specification, and basic wind pressure w_0 is 0.3kN/m^2 . (6) Flow force. The maximum flow velocity is 2.218m/s. According to the specification, the flow force F_w of steel pipe piles is 14.4kN, the flow force F_w of parallel connections is 0.76kN/m, and the flow force F_w of inclined struts is 1.43kN/m.

In terms of the structure construction process, there are two working conditions to be considered for the support. The non-working condition is that when the support has been completed, under the design wind conditions, the support is installed in place with no V-shaped segments placed. The working condition is considered that when the support has been completed, V-shaped segments and box girder segments are installed in blocks under design wind conditions.

3.3 Structure Analysis

First of all, the external force transferred to the support during lifting construction of the V-shaped segments should be analyzed. The finite element model is established on the basis of the construction process to simulate the actual construction process through the construction stage analysis. The V-shaped tower column connects with the support rigidly to ensure their coupling relationship, simulating lifting construction of the V-shaped segments in the form of node load, which can verify the reliability of segmentation and force deformation of the V-shaped tower column. As a result, the reaction force acting on the top of the support from the V-shaped tower column is extracted as the

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load of the support calculation. The schematic drawing of the blocks and simulation of construction process are shown in Fig.7 and Fig.8.

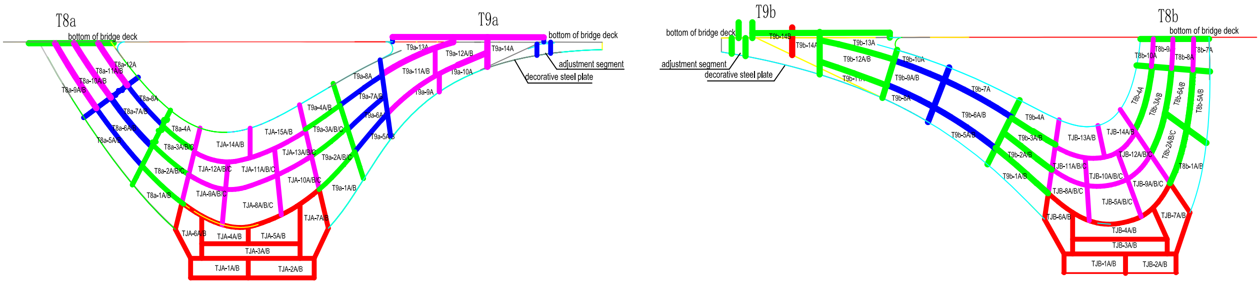

Fig. 7 Schematic drawings of the blocks of the V-shaped lower tower columns on the upstream and downstream sides

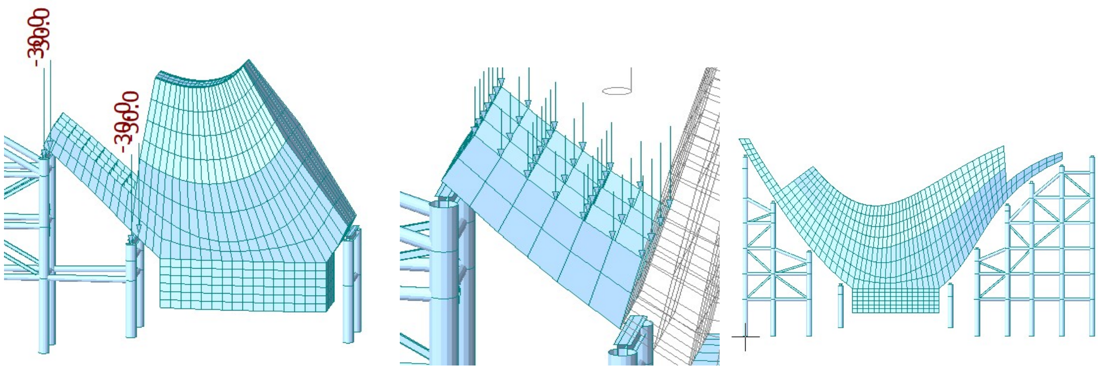

Fig. 8 Finite-element simulation of construction process and loading method

According to the structure arrangement of the support and the calculation results in modeling the construction stage of the V-shaped tower columns, the finite element software is used to establish the model of the assembling support. The steel columns, steel pipe piles, parallel connections, inclined struts, and main beams are simulated by beam units. The main beams and template beams are articulated with the steel columns or steel pipe piles, the steel columns are fixed at the foot of the columns and articulated at the brackets, and the steel pipe piles are articulated at the bottom of the pile. Considering the horizontal constraints on the pile foundation from the soil, the soil constraints are simulated by soil springs [3]. The overall computation model of the assembling supports shows in Fig. 9.

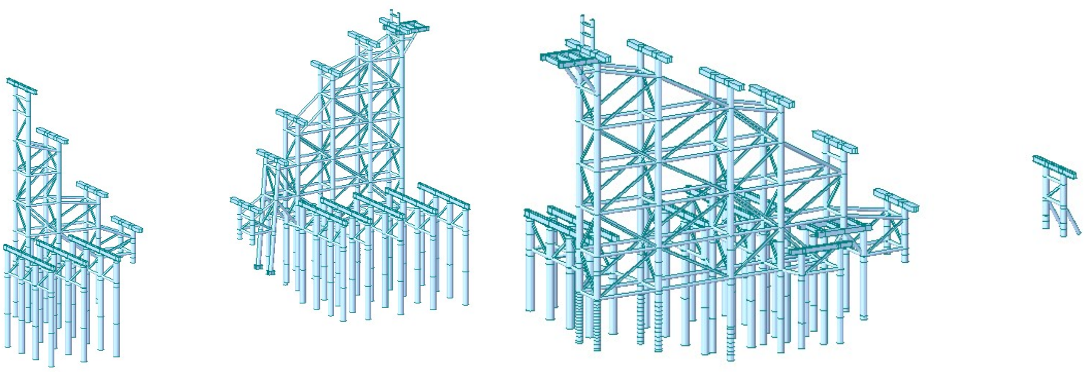

Fig. 9 The Overall computation model of the assembling supports for the V-shaped lower columns on the upstream and downstream sides

Through analyzing and calculating, the maximum combined stress of the member is $\sigma_{\max} = 191\text{MPa} < f = 215\text{MPa}$, the maximum shear stress is $\tau_{\max} = 105\text{MPa} < f_v = 120\text{MPa}$, the maximum value of the vertical displacement of the support is 3.79mm<10.0mm, and the maximum value of the horizontal displacement is 59.2mm<233mm. Based on the specification calculations, the coefficient of stability of ∅800×10 round tubes is 0.80, 0.93 for ∅ 426×6 round tubes, and 0.69 for 2[25a]. The eigenvalue coefficients of first- to third-order buckling modes of the overall structural stability calculation results of the support are 17.3~24.0, all of which are greater than 4. Therefore the stability of the components and structure meet the requirements. In summary, the strength, stiffness and stability of the support meet the design specification requirements [4]. On the basis of the calculation, the maximum pressure design value of driven piles is 1816kN,while the maximum pressure design value of bored cast-in-place piles is 2144kN. In the place of deep cover, considering 6m embedded depth of pile foundations, and considering reaching 2.5m and 1.5m depth of pile foundations into the soil and rocks respectively in the place of shallow cover layer with bare rocks, the compressive bearing capacity of steel pipe piles can satisfy the requirements.

3.4 Detail Design

According to the calculation results, the joints of the steel pipe pile with more horizontal connections on the downstream side are under greater stress, and need to be strengthened locally by cover plates. The structure of the steel pipe pile after strengthening is as follows:

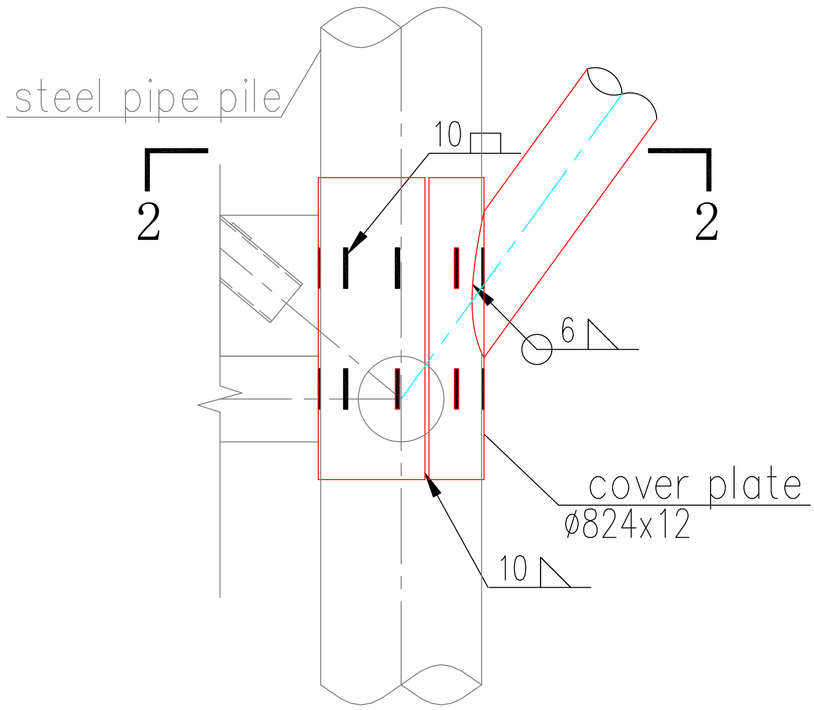

Fig. 10 The structure diagram of the steel pipe for local reinforcement

The axial force design values of the parallel connections, inclined struts and pile are extracted: F1=-123.2kN, F2=-93.1kN, F3= -80.3kN, F4= -774.5kN, F5=-499.4kN, F6=-527kN. Midas FEA is used to calculate the joint force by local modeling for the connection between the parallel connections, inclined struts and steel pipe pile. The steel pipe pile is fixed at the bottom of the pile, and the model is established as follows:

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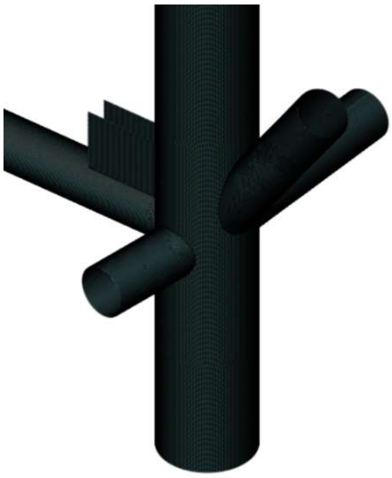

Fig. 11 The local model diagram of the steel pipe pile

After analysis, the maximum stresses of Q235B members are $\sigma_{\max} = 210MPa < f = 215MPa$, $\tau_{\max} = 92.5MPa < f_v = 125MPa$, the local structure of the steel pipe pile meets the requirements [5].

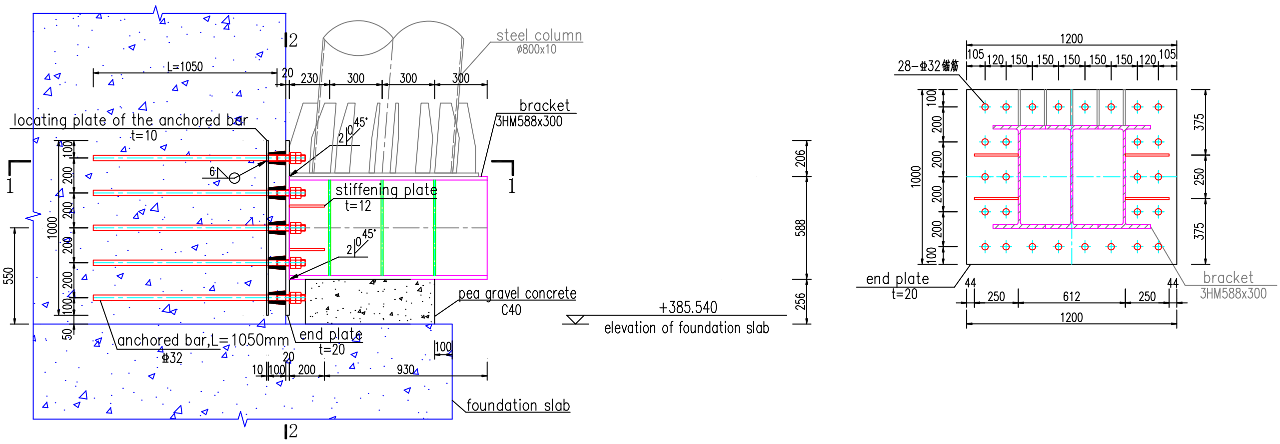

Fig. 12 Structure diagram of the bracket's embedded parts

On the upstream side, the adverse reaction forces of embedded parts of 3HM588×300 brackets is $N = 152kN$ (**pressure**), $V = 1684kN$, $M = 926kN \cdot m$ (working condition two, the basic combination of values). After calculation, it is necessary to set 28Φ32 steel bars($A_{s0} = 22519mm^2$), and the anchorage length is 1050 mm, which meets the design and specification requirements. In addition, after the installation of the embedded parts on the side of the tower base, C40 concrete is poured at the bottom of the brackets to reduce the shear effect of the column foot on the embedded parts.

4. Construction Requirements

The quality of the structure should be strictly controlled during the construction process, and the construction should be carried out according to the drawings. Regarding the characteristics of the structure itself, a few precautions should be given in the construction process [7]:

(1) The embedded depth of Ø800×10 steel pipe driven piles in the area with cover layer on the bank side shall not be less than 6m, and the depth into the holding layer shall conform to the specification requirements; the depth of Ø800×10 steel pipe driven piles into the soil in the area with shallow cover

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layer shall not be less than 2.5m and the depth into the rock shall not be less than 1.5m, or else it shall be constructed in the form of cast-in-place piles. The diameter of bored cast-in-place piles shall not be less than 1m, and the depth of cast-in-place bored pile into rocks shall not be less than 4m.

(2) Before installing the V-shaped column of the main tower, the cushion blocks shall be welded on the V-shaped segments, and their bottoms shall keep horizontal. The installation work shall not be carried out under high wind conditions.

(3) After the bottom segment of the V-shaped lower tower column is adjusted and fixed, it is welded firmly to the previous segment. A steel block is used between the cushion blocks welded on the segment and the beam, and then the three-way jack is removed.

(4) No lifting operation shall be carried out when the wind speed is greater than 13.8m/s, and corresponding wind-resistant measures shall be added when the wind speed is greater than 20.7m/s.

5. Summary

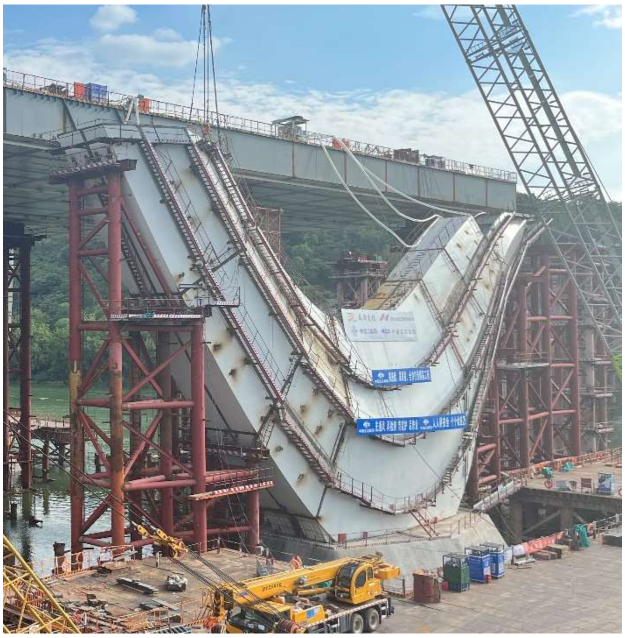

Fig. 13 Field operation of the V-shaped lower tower column support

By comparing the design schemes of the three kinds of supports, the V-shaped lower tower columns of Tuojiang Bridge on Jinjianren Expressway is determined to adopt the design scheme of hoisting method with less point support system, and it is successfully built up and used. The site construction situation is shown in Fig. 12. Under the unfavorable conditions of complex structure with a spatial inclined curve variable cross-section and difficult installation and control of V-shaped column linear shape, the design scheme of hoisting method with few point support system provides some reference, and accumulates some experience for similar projects.

(1) The design of the support takes full consideration of the utilization of the piles of the surrounding trestle bridge and platform, and adopts the foundation form of the combination of steel pipe driven pile and bored cast-in-place pile. Considering the geological circumstance, the bored cast-in-place pile foundation of the nearby trestle bridge and platform is connected with the steel pipe driven piles of the support for the V-shaped tower column. Only parts of the bored cast-in-place pile foundations are set up, which not only optimizes the number of the bored pile foundations, shortens the construction period and saves the cost, but also enhances the overall stability of the support.

(2) For the case of interference with the existing structure, the problem is skillfully solved by increasing the template beam or setting the bracket on the tower base in the principle of ensuring that the support points of the V-shaped column remain unchanged.

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(3) The bottom of V-shaped segments and steel-box girders in contact with the support are welded with a certain number of steel cushion blocks to ensure that the curved segments can be stably placed on the jacks on the top surface of the support during hoisting and adjustment, which reduces the difficulty of the segments in hoisting and accurate adjustment to a certain extent, simplifies the complexity of the support force during adjustment, and makes the simulation analysis and calculation of the structure clear and reliable.

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