Design and Construction

Adaptability Analysis of the Main Girder and Materials of a Partial Ground-anchored Suspension Bridge

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Abstract: Although partial ground-anchored suspension bridges provide economical and feasible technical solutions when constructing ground suspension bridges under soft-soil geological conditions, the main girder bears a relatively large stress under anchor force. In this paper, analyzing the specific steel box composite beam with the Ultra High Performance Concrete (UHPC) bridge deck, we investigate the adaptive capacity of the main beam of the partially ground-anchored suspension bridge. Through the analysis of ground anchor forces, the maximum ground anchor force within the allowable stress range of the pavement layer is determined. This provides a basis for determining the corresponding cable forces, anchor forces, and anchor dimensions, offering valuable insights for the design of partially ground-anchored suspension bridges.

Keywords: Self-anchored suspension bridge; ground-anchored suspension bridge; partial ground anchor; UHPC; adaptability

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1 Introduction

Traditional ground-anchored suspension bridges have strict geological requirements, and bulky anchorages can reduce their economic performance. The presence of creep-slip in the soil threatens the safety of superstructures, and the mechanical properties of extra-thick soft foundations can even lead to questions about the validity of the suspension bridge scheme. In the coastal area of the Yangtze River Delta, as represented by Shanghai, soft soil is widely distributed. Soft soil itself has a weak bearing capacity and exhibits obvious settlement, which has an adverse effect on the design, construction, and operation of bridges in this area. Due to the weak bearing capacity of soft-soil foundations, for thrust structures such as ground-anchored suspension bridges and thrust-arch bridges, bulky anchorages or abutments must be constructed to withstand horizontal forces, and the resulting project costs are considerable, seriously affecting the economics of bridge construction [1]. Due to the large deformation of soft-soil foundations under loading, the soil is prone to creep and slip under long-term loading, threatening the safety of the superstructure. Therefore, the use of thrust structures for bridges built on soft-soil foundations should be avoided. Self-balancing systems have become the main bridge forms across rivers in soft-soil foundation areas. Although cable-stayed bridges with self-balancing systems are the main form of bridges across rivers in soft-soil foundation areas, in recent years, with the rapid development of self-anchored suspension bridge theory, cable-stayed bridges are no longer the only choice.

As proposed by Professor Xiao from Tongji University, the partial ground-anchored suspension bridge [2] combines a self-anchored suspension bridge with a ground-anchored suspension bridge. During construction, the main cables are initially laid using ground anchors. Subsequently, the main beam is lifted using the main cables (The main beam is lifted either for the entire span or, except for the navigational clearance section.). At this stage, the tension in the main cables is transferred to the anchorages, with the passive earth pressure of the anchorages bearing the load. After the main girder is closed, some of the anchor cables can be released to convert part of the main cable force to the pressure of the main girder, creating a self-anchored beam configuration. The cable force of the anchor cables is adjustable during the construction stage and the use stage, which allows the inclusion of the passive earth pressure in the slip resistance check calculation of the anchorage, thus reducing the demand on the anchorage gravity. This study provides a new concept for bridge structure design. The main cable and anchor cable force and the main girder load need to be comprehensively considered during the construction stage and use stage. In the adjustment process of the anchor cable force and the later use process of the adaptive anchored suspension bridge, the load-bearing effect on the main girder is different from that of the existing suspension bridge main girder structure system, with the most prominent manifestation in the case of the main girder deck structure due to the concrete used, which is required to adapt to a larger stress amplitude to meet the needs of an adaptive system.

The performance advantages of Ultra-High-Performance Concrete (UHPC) are that good load-bearing performance can be obtained at the expense of a relatively small increase in dead weight, and because UHPC has good ductility and fatigue resistance, under the combination of dead and live loads, the performance of the bridge deck is better than that of a steel bridge deck. Compared with a general concrete bridge deck, the UHPC pavement is thinner and offers better tensile performance. Due to its good Peaceability, the UHPC layer is also very convenient for paving during the construction stage. Therefore, traditional steel or concrete main girders [3]-[5] can be replaced by UHPC–steel structure main girders.

In this study, the suspension bridge at the section of the Jiasong Highway across the Huangpu River was taken as an example. The load-bearing process of the suspension bridge was analyzed to obtain the load-bearing control indicators of the main bridge deck through simulation. Provide a reference indicator for the overall performance of the bridge from the two dimensions of structure and material. As a result, the main girder, especially the bridge deck design parameters of the adaptive anchored suspension bridge, was determined [6,7]. Specifically, high-performance concrete is combined with specific steel box composite girders and bridge decks to ensure that the stresses and deformations of the stiffened girders and bridge decks during large adjustments of the anchor cable forces are within safe and controllable limits. That is, an adaptability study of the UHPC–steel structure, as a stiffened main girder structure, was carried out to meet the load-bearing requirements of the stiffened box girder structure under changes in the cable force during the construction and use stages to reduce the difficulty of stress control in the overall structural system and to achieve self-adaptation of the main girder load bearing. The actual construction process of the self-anchored suspension bridge was different from that of the simulation; the relevant conclusions can only be used as a reference for a constrained self-anchored suspension bridge.

2 Comparison of Self-anchored Suspension Bridge Schemes

Worldwide application of self-anchored suspension bridges began at the end of the 19th century, they developed rapidly in the 1930s and spanned kilometer-level extra-long spans. In a self-anchored suspension bridge, the main cable is directly anchored to a stiffened girder, thus canceling the bulky anchorage. In view of the specific conditions of the Jiasong Highway crossing the Huangpu River in the background project, a single-span crossing was used, and a self-anchored suspension bridge was arranged. The main bridge pylons are arranged outside the abutments on both sides, longitudinally symmetric, and adopt a double-cable arrangement. The main beam has a uniform height cross-section, with a relatively low structural height, reducing the bridge's self-weight. The self-anchored suspension bridge does not require the construction of large-volume anchorages, resulting in an elegant appearance. However, because the main cable is directly anchored on the stiffened girder, the girder has to withstand a large axial force. Therefore, the cross-section of the girder and the amount of steel used for the main cable need to be increased, and the construction cost significantly increases. Since the main cable and slings must be hoisted after the stiffened girder and pylon are completed, a temporary support needs to be erected to install the stiffened girder, and the construction is complicated and expensive. However, the material usage of the main pylon, foundation and stay cables is less than that of cable-stayed bridges.

After various considerations, the designer ultimately chose a self-anchored suspension bridge as the main bridge type for the Jiasong Highway across the Huangpu River. The main bridge is a self-anchored suspension bridge with twin pylons and a double-cable-plane composite deck steel box girder with a length of 130 m + 336 m + 130 m = 596 m.

2.1 Introduction to the Main Bridge Model

2.1.1 Main girder

The overall width of the main girder in the standard section is 35.6 m, and the girder height at the road centerline is 3 m. The steel girder is 2.92 m high, and the material is Q345qD. In consideration of construction transportation, the cross-section of the steel girder is a bilateral box single-cell girder. The center-to-center spacing of the longitudinal girders of the bilateral boxes is 20.7 m, the standard section of the longitudinal girders is 9 m, and a cross beam and a cantilever beam are set at 3 m intervals. The steel bridge deck is made of a 12 mm thick orthotropic plate with U-shaped stiffeners. Figure 1 shows its cross-section. The bridge deck was paved with a 60 mm thick UHPC layer.

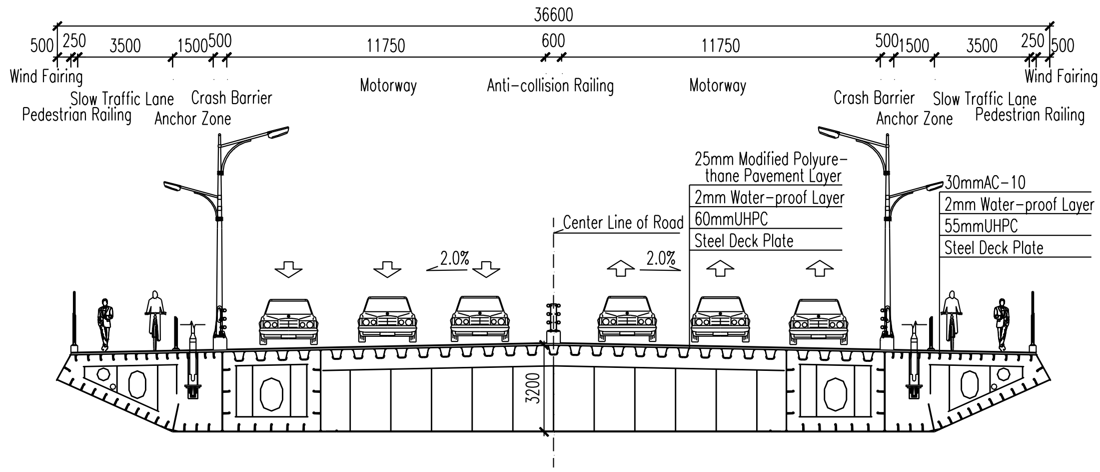

Figure 1 Cross-section of the main girder of the steel bridge deck (Unit: mm)

2.1.2 Main Cable and Sling

(1) Main cable

The main cable is the main load-bearing member of the suspension bridge. There are two main cables in this bridge, which are arranged in parallel cable surfaces; the vector-to-span ratio is approximately 1/5.17. Each main cable contains 52 parallel steel wire strands, and each strand contains 127 galvanized aluminum alloy steel wires with a diameter of 5.0 mm for a total of 6604 main cables, which are arranged vertically in a hexagonal shape. The main cable is circular after being tightened, the outer diameter of the cable clamp is Φ454 mm (void ratio of 20%), and the inner diameter of the cable clamp is 449 mm (void ratio of 18%). The main cable is made of prefabricated parallel wire strands (PPWS), which are commonly used in China and are installed and erected strand by strand on a catwalk on site. The standard tensile strength σ_b is 1860 MPa, elastic modulus E is 2.0×10^5 MPa, and material strength partial factor γ_R is 1.85.

(2) Sling anchorage type and cable clamp type

Since the self-anchored suspension bridge adopts a construction sequence of girder first and cable afterward, the slings must be tensioned multiple times during the system conversion to form the suspension cable system. In self-anchored suspension bridges, the tension end of the slings needs to be set on the main girder. The vertical slings use pin-type parallel steel wire strands, with an outer layer of PE sheath. Each suspension point has two slings, and the standard spacing in the longitudinal direction is 9m. The sling strands are made of Φ7 high-strength steel wire with a standard tensile strength (σ_b) of 1770MPa. Based on the force magnitude, the standard sling types are Φ7-55 (meaning 55 strands of 7mm diameter steel wires form one sling, the same for the following). The slings near the main tower have types Φ7-91 and Φ7-73. The connection between slings and main cables uses pin-type connections, while the connection between slings and main girders uses anchor box anchoring, with anchor points located at the cantilever end.

(3) Saddle

At the top of the two main pylons, main cable saddles are installed. The main cables pass through the cable saddles and wind towards the side span. The main cables in the side span are anchored and distributed on the main girder through the dispersing cable saddles. Dispersing cable saddles are placed 7.2 m from the end of the main bridge and use a fixed type of dispersing cable saddle. Between the dispersing cable saddle and the transverse diaphragm of the main girder, tension-compression ball-and-socket steel supports are installed.

2.1.3 Boundary Conditions and Tower-Beam Connection Method

The whole bridge is a five-span continuous semi-floating system with the tower piers consolidated and the tower beam separated; the specific boundary conditions are as follows:

(1) Vertical constraint: Spherical steel bearings are set at the main pylon corbel, anchor pier and the top of side pier; two bearings are set at each side pier and the cross beam of the main pylon, for a total of 12 bearings for the whole bridge.

(2) Lateral constraint: Lateral limiting devices are set up at the main pylon and the tops of side piers to withstand the direction of wind and seismic action of the crossbridge.

(3) Longitudinal constraint: The longitudinal elastic constraint and viscous damper are set at the main pylon.

2.1.4 Design Loads And Load Combinations

(1) Dead load

Phase I dead load: 287.6 kN/m; Phase II dead load: 79 kN/m.

(2) Live load

The design load level is the Highway -I level; Consider an eccentric load factor of 1.10. The value of the vehicle braking force is selected according to the provisions in the "General Specifications for Design of Highway Bridges and Culverts" (JTG D60-2015).

(3) Temperature load

Overall temperature difference: -23~+23 °C. System temperature difference: ±15 °C temperature difference between the main cable, sling, and main girder and the main pylon. Sunshine temperature difference: The sunshine temperature difference on both sides of the pylon is ±5 °C. The temperature gradient of the steel girder cross section is taken according to the specification BS5400.

2.1.5 Main Cable Anchorage Area

To ensure the implementation of the main cable anchorage area and provide sufficient side pier ballast weight, the main cable anchorage scheme with a concrete beam is adopted in the main cable anchorage area. The angle between the main cable and the main girder is approximately 18°. The main cable enters the inside of the box room structure through the hole in the roof at the anchoring end of the main girder, passes through the loose cable sleeve, spreads out into a single cable strand, and is anchored on the large cross beam at the beam end. The scatter range of the main cable is approximately 11 m, and the maximum scatter angle of the cable strands is approximately 12.5°.

2.1.6 Bridge Model

The suspension bridge was modeled by Bridge Doctor V4 software, and the obtained model is shown in Figure 2. Where the calculation specification is selected from the "Specification for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts" (JTG 3362— 2018).

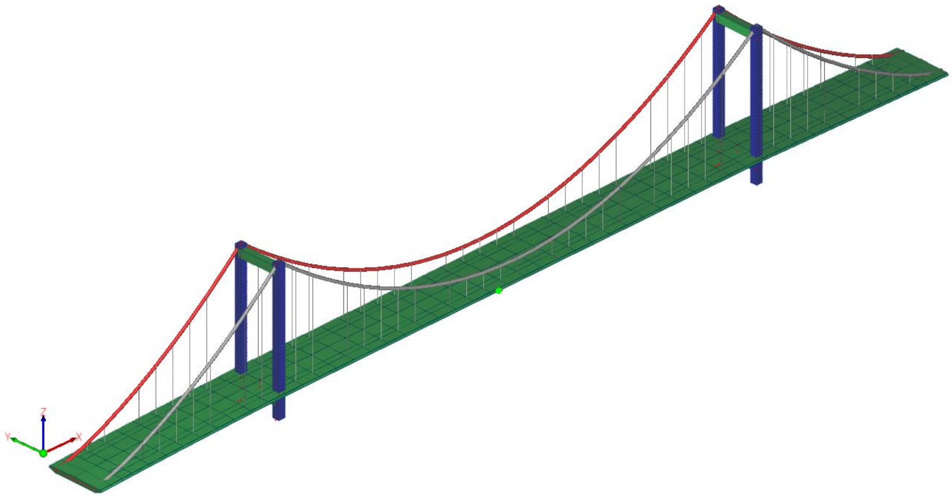

Figure 2 Model of main bridge

2.2 Stress State of Main Girder

Since this paper mainly conducted adaptability analysis on the main girder, due to space limitations, only the main calculation results of the main girder are listed here for comparative analysis, which is described later. The stress diagrams under various conditions are shown in Figures 3 to 7.

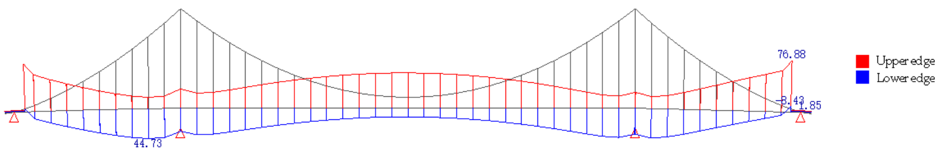

Figure 3 Normal stress of upper and lower edges of the steel main girder under dead load (Unit: MPa)

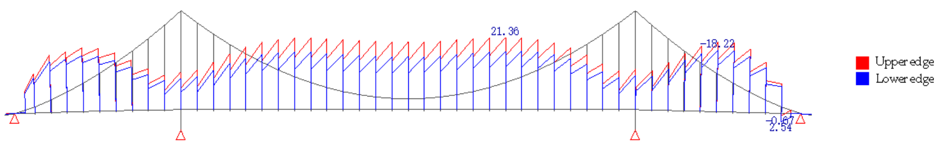

Figure 4 Normal stress of upper and lower edges of the steel main girder under the maximum vertical live load (Unit: MPa)

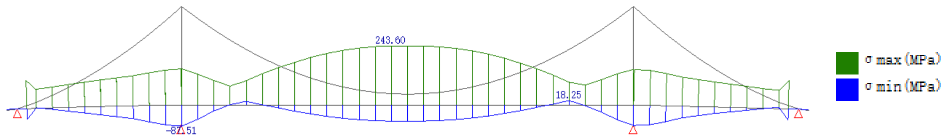

Figure 5 Normal stress diagram of the steel main girder under the basic load combination (Unit: MPa)

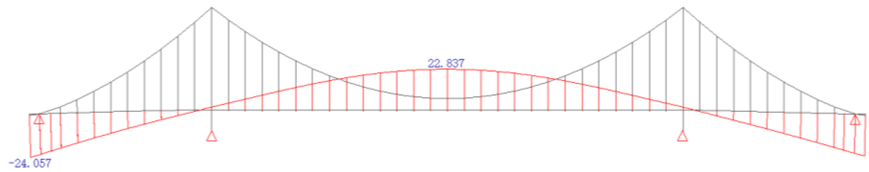

Figure 6 Vertical displacement of the steel main girder under a temperature increasing (Unit: mm)

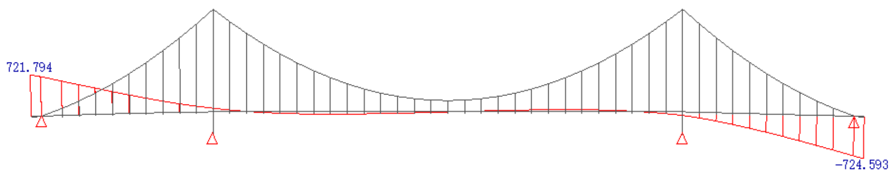

Figure 7 Lateral displacement of the steel main girder under the maximum live load along the lateral direction (Unit: mm)

3 Force Analysis of a Self-anchored Suspension Bridge With Partial Constraints

During the operation of a self-anchored suspension bridge, the bridge will be subjected to a considerable deck load in the horizontal direction due to the dynamic and braking loads of vehicles. If ordinary steel–concrete composite girders are used for load-bearing calculations, the demand for larger concrete cross-sections will increase due to the weaker tensile capacity of the concrete, which in turn increases the thickness of the concrete bridge deck and increases the load-bearing capacity of the hangers, and increases the steel beam fatigue [7]. On the other hand, when the braking load combination is the most unfavorable combination, the bridge deck may crack due to tension. UHPC has very good strength properties, especially tensile and ductility properties. After the main girder material is replaced by a UHPC–steel composite girder, the bridge deck can adaptively adjust when subjected to the most unfavorable load [8]. Moreover, during the tensioning and anchoring of slings, due to the different cable forces of the slings, the stress in the main girder will be affected to different degrees during the tensioning process. In the construction process of the cable before the girder, each hoisting of the main girder of each segment will cause stress changes on the whole bridge. During the construction of the girder first and the cable afterward, the large change in the cable force at the time of system conversion will also cause large changes in the normal stress and bending moment of the main girder.

To enable the compressive, flexural and shear strengths of the main girder to meet the needs of larger stress changes during the construction process, studying the self-adaptation capability of the main bridge is also essential. Building upon the aforementioned self-anchored suspension bridge scheme, constraints are applied at the girder ends to simulate the stress state of the main girder. The constraints at the girder ends can be considered as anchor cable forces. Through analysis of the stress state of the main girder, the final anchor dimensions, construction stage cable forces, and the retained cable forces in later stages for the adaptive suspension bridge are determined. Accurate conclusions can only be obtained by fully simulating the construction process, where the cables are tensioned before the beams.

3.1 Effect of UHPC on the Self-adaptation Capability of the Main Bridge

3.1.1 Effect of UHPC on the Stresses at the Upper and Lower Edges of the Main Girder Under a Dead Load

A comparison of Figure 3 and Figure 8 shows that when the main bridge is under the action of a dead load, the stress at the upper edge of the main bridge with the steel structure as the main girder is significantly greater than that of the main bridge with the UHPC-steel hybrid girder as the main girder. These results show that, under the action of structural gravity and the second-stage dead load of the bridge deck, UHPC with a thickness of only 60 mm can effectively reduce the normal stress at the upper edge of the steel girder; in this example, the reduction rate reaches 31.0%. For the lower edge of the steel girder, the normal stress also has a certain reducing effect. UHPC bridge deck plays a key role in the adaptive ability of the normal stress at the upper edge of the main bridge.

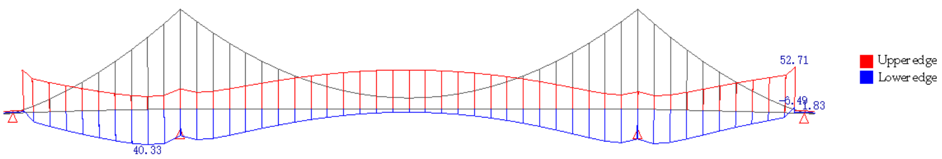

Figure 8 Normal stress diagram of the upper and lower edges of the steel–UHPC composite beam under a dead load (Unit: MPa)

3.1.2 Effect of UHPC on the Stresses at the Upper and Lower Edges of the Main Bridge Under Live Loads

Under the action of a live load, the comparison of Figure 4 and Figure 9 shows that after the addition of UHPC, the normal stress in the upper flange under live load decreases significantly by approximately 29.0% in this example, while for the lower flange, the normal stress also shows a decrease of approximately 4.0%. Because UHPC has a high elastic modulus and compressive strength, UHPC bridge decks can collaborate with steel beams through shear connectors to reduce compressive stress on the upper flange. Simultaneously, this approach can decrease the tensile stress on the lower flange. therefore, UHPC can effectively enhance the self-adaptation ability of the main bridge under the action of a live load.

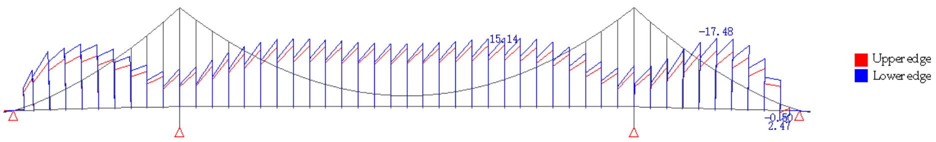

Figure 9 Normal stress diagram of the upper and lower edges of the steel–UHPC composite beam under live loads (Unit: MPa)

3.1.3 Effect of UHPC on the Normal Stress in the Full Cross-section of the Main Bridge

By comparing Figure 5 and Figure 10, during the normal stress checking calculation of the full cross-section, the addition of the UHPC layer significantly reduced the cross-section normal stress at the end and effectively improved the normal stress state of the full bridge cross-section. The normal stress of the cross-section at the main pylon is reduced by nearly 6%, reducing the risk of local instability of the steel girder.

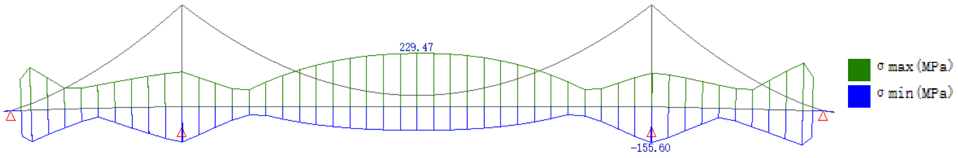

Figure 10 Normal stress of steel–UHPC composite beam under the basic load combination (Unit: MPa)

3.1.4 Effect of UHPC on the Displacement of the Main Bridge Under the Action of Temperature Change

A comparison of Figure 6 and Figure 11 reveals that under the action of temperature change, UHPC has basically no effect on the nodal line displacement of the main girder. The reason is speculated to be that the linear expansion coefficients of the UHPC and steel structures are similar. Therefore, the addition of UHPC does not significantly improve the self-adaptation ability of the main bridge under the action of temperature change.

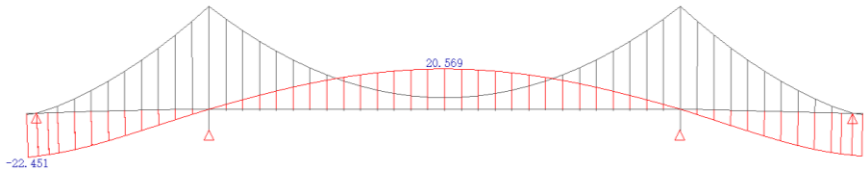

Figure 11 Displacement of the nodal lines of the steel–UHPC main girder under the influence of temperature increase (Unit: mm)

3.1.5 Effect of UHPC on the Displacement of the Main Bridge Under the Action of the maximum Lateral Live Load

Because it is a semi-floating system with a separated tower beam–consolidated tower pier, the deck of the main bridge will undergo horizontal displacement under the action of lateral live loads, such as vehicle braking loads. When ordinary steel beams are used, large end displacements will occur. When ordinary steel–concrete composite beams are used to reduce displacement, cracks may develop in the concrete due to the high tensile stress. However, when a UHPC–steel structure composite girder is used, because UHPC has better tensile strength than ordinary concrete and can bear greater tensile stress, UHPC can reduce the risk of bridge deck cracking while reducing the lateral displacement by about 20% (comparing Figures 7 and 12), which has a great effect on improving the adaptability of the lateral displacement of the main bridge.

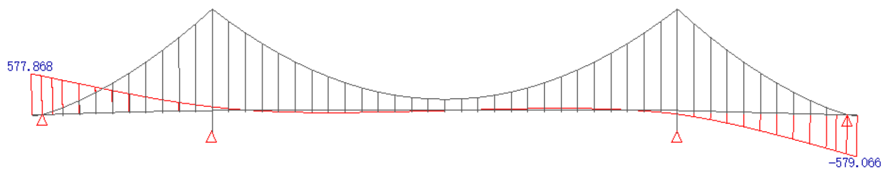

Figure 12 Lateral displacement of the steel–UHPC main girder under the influence of the maximum live load along the lateral direction (Unit: mm)

3.2 Effect of UHPC on Bridge Deck Pavement During the Construction of the Main Bridge With Partial Ground Anchors

The UHPC–steel structure composite girder and the ordinary steel–concrete composite girder deck has similar connection methods, and they are both connected by shear studs. However, the test by Huang et al. [11] showed that the stress bearing of the shear stud group in an ordinary steel–concrete composite structure was not uniform and was related to the load magnitude, shear stud length, and shear stud spacing. The force distribution in the shear stud group tends to become more uniform as the load increases. Because UHPC has a higher elastic modulus, the reduction factor when considering the load transfer of shear studs will be lesser, which can effectively reduce the cost of shear studs and increase safety.

For orthotropic steel bridge decks, Zhan et al. [12] proposed that during the operation period, bridge deck cracking or bridge deck pavement damage are prone to occur due to the excessive fatigue load on the steel structure. For ordinary steel–concrete composite girders, due to the large thickness of the concrete, it is difficult to achieve coordination between the deformation of the steel girder and the concrete bridge deck pavement. If the difference in deformation between the two piles is too large, the shear studs will be cut, and the bridge deck pavement will be damaged. On the other hand, UHPC–steel composite beams have a low thickness and similar elastic modulus, so they can achieve coordinated deformation and load bearing together, which can greatly improve the ability of steel girders to resist fatigue loading.

To ensure the effectiveness and force transfer requirements of UHPC for steel girders, it is necessary to analyze the ability of UHPC to improve the load-bearing ability of the main girder.

3.2.1 Effect of UHPC on Bridge Deck Pavement Under Various Loads

If the construction method of "cable first, girder later" is chosen for the main bridge construction process, it is necessary to build temporary anchorages on both sides of the main bridge. However, in soft-soil foundation areas like Shanghai, the cost of constructing and removing temporary anchorages is relatively high. If the anchorage is not removed, the self-anchored suspension bridge system will be directly converted; that is, the main girder and the cables will be anchored together with scatter saddles while there are ground anchors on both sides, and a relatively large tensile stress will be generated in the main girder. The self-adaptation ability of the main girder can be effectively improved by adding UHPC. The calculation results are as follows:

(1) Without removing the main cable anchorages, the stress distribution in the bridge deck pavement layer under constant load is shown in Figure 13.

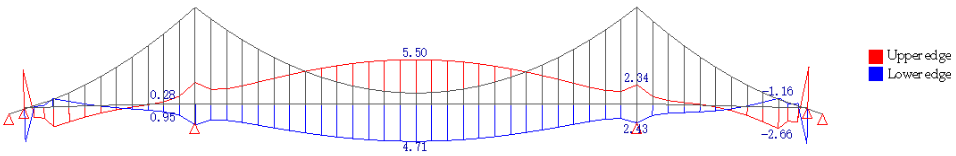

Figure 13 Normal stress in the bridge deck of the steel–UHPC main girder under a dead load (Unit: MPa)

If the main cable anchorage is retained, a large tensile stress will occur at the upper and lower edges of the main girder under a dead load. If ordinary C50 concrete is used as the bridge deck, the structural tensile strength is relatively low, and the upper side of the bridge deck may experience tensile cracking. When the UHPC structure is used, it can ultimately bear tensile stress, which can effectively improve the self-adaptation ability of the main girder under dead loading.

(2) Without removing the main cable anchorages, under vertical live loads, the stress in the bridge deck pavement layer is as shown in Figure 14.

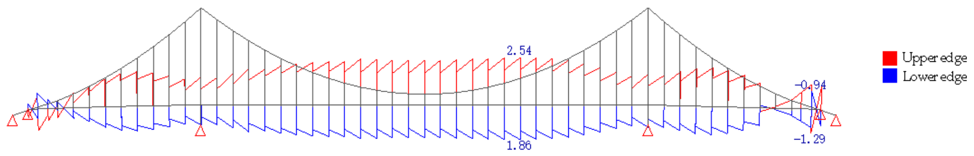

Figure 14 Normal stress in the bridge deck of steel–UHPC main girder under the maximum vertical live load (Unit: MPa)

Under the action of a live load in the vertical direction, tensile stress also occurred at the end, and the magnitude of the tensile stress was close to the tensile strength of ordinary concrete. To ensure safety, an ordinary concrete cross-section cannot be used to bear the load. Therefore, the UHPC cross-section is used to effectively improve the adaptive ability of the main girder under live load in the vertical direction.

(3) Without removing the main cable anchorages, under the maximum horizontal live load, the stress situation of the bridge deck pavement is shown in Figure 15

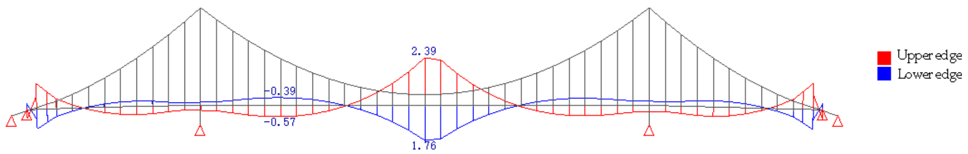

Figure 15 Normal stress in the bridge deck of the steel–UHPC main girder under the maximum horizontal live load (Unit: MPa)

Unlike in the case of a live load in the vertical direction, under the action of a live load in the horizontal direction, a longer section of the bridge deck pavement is subjected to tensile stress. Although this tensile stress is relatively small and falls within the tensile strength range of ordinary concrete, the difference is not significant. To ensure that the requirements are met under the most unfavorable load combination and to avoid the problems caused by the excessive tensile stress in the concrete in some sections during the construction process, UHPC is used as the bridge deck pavement structure. This can better withstand the tensile stress and improve the self-adaptation of the main girder under the action of a live load in the horizontal direction.

3.2.2 Effect of UHPC on the Self-adaptive Ability of the Main Girder Under Different Anchorage Tensions

Another advantage of using cables first and girders afterward is that they can ensure the navigation of the waterway and reduce the problem of cable adjustment during the construction of the cable-stayed bridge. However, during the construction of ground-anchored suspension bridges, the anchorages of side spans may experience relatively high tension, and soft-soil foundations in Shanghai cannot withstand such large tensions, preventing construction. If the tensile force carried by the ground anchor is reduced, the axial force of the main girder will increase significantly. The existence of axial tension will cause tensile stress on the deck of the side spans. Ordinary concrete is susceptible to tension cracking, while the use of UHPC is likely to cause it to bear tensile stress during the construction of ground-anchored suspension bridges. In this paper, based on the study of bridge deck stress in the ground-anchored suspension bridge stage and the modeling of Bridge Doctor software, the tensile stress in the bridge deck side span was-12.38MPa when the anchorage pull force in the side span was 71400 kN (Figure 16), which exceeds the tensile load-carrying capacity of UHPC. To obtain the anchorage tension values within the UHPC load-carrying range, the tensile stresses of the bridge deck and the minimum axial force of the main girder under the condition of different side-span anchorage tensions were selected, as shown in Table 1. Based on the stress state curve of the bridge deck between the anchorage force and the axial tension at the side spans (Figure 17), the relationship between the two is basically linear.

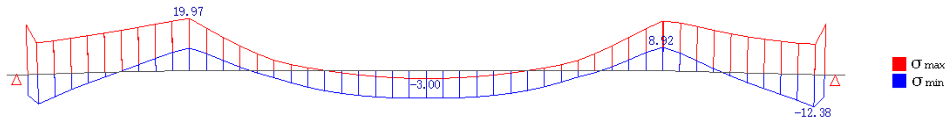

Figure 16 Normal stress of the bridge deck under the standard value combination when the anchorage tension at the side-span set the maximum value (Unit: MPa)

Table 1 Relationships between the anchorage tension at the side spans and the bridge deck stress and the minimum axial force of the main girder

Side-span anchorage force (kN)	Bridge deck Stress (MPa)	Minimum axial force of main girder (kN)
71400.0	-12.38	16456.1
68300.0	-11.76	21422.3
67000.0	-11.35	24728.2
64800.0	-10.93	28026.8
57000.0	-9.28	41102.2
49100.0	-7.60	54118.5
35585.0	-3.50	74943.3
22150.0	-0.50	94291.0
8640.0	10.50	114366.0
400.0	14.00	128500.0

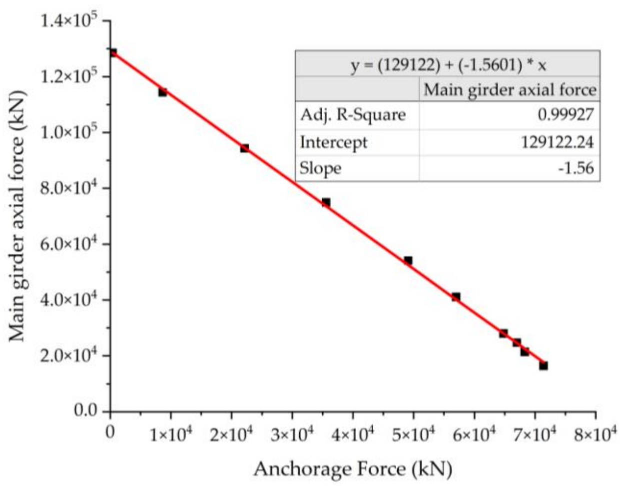

Figure 17 Relationship between the anchorage force at the side spans and the main girder force

Based on the distribution of the maximum tensile stress at different locations on the cross section, the relationship curve between the anchoring force and the stress value was drawn, and a good quadratic correlation was found between the two parameters (Figure 18).

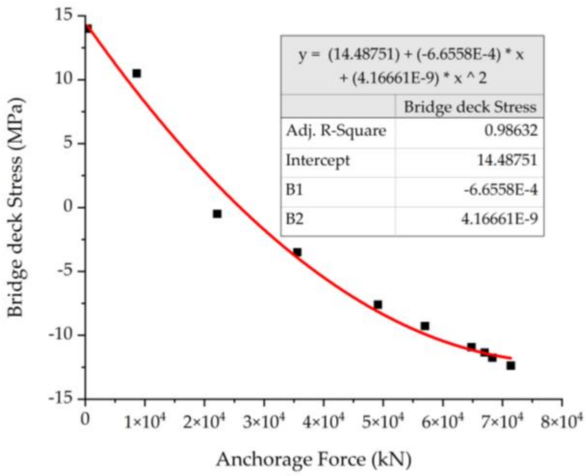

Figure 18 Relationship between the anchorage force at the side spans and maximum tensile stress of the bridge deck

The tensile strength of UHPC bridge deck is about 10 MPa, and 80% of the tensile strength is used as the allowable strength to fit the formula. The corresponding tension force of the edge span anchor is calculated to be 48,491 kN. During the construction of the ground anchor suspension bridge, under the tension of 48,491 kN of the anchor force, the UHPC main beam bridge deck meets the safety requirements. In the actual construction process, the anchor should bear more tension within the bearing capacity of the soft soil foundation, reduce the axial force of the main beam, and change the construction plan from "beam first, cable later" to "cable first, beam later" when constructing the suspension bridge with the main cable being installed first. This approach allows for segmental hoisting of the main beam and reduces the adjustment of cable forces during the cable-stayed method installation, avoiding the blockage of the navigation channel and affecting the water transportation of the Huangpu River.

4 Conclusions

This study compares the self-anchored and partially constrained approaches of UHPC bridge deck and determines the improvement effect of UHPC material on the stress state of the main girder. Based on the allowable stress of the main girder bridge deck, the corresponding anchor force is determined. The main conclusions are as follows:

(1) UHPC bridge deck can effectively enhance the adaptability and deformation capacity of the upper edge of the main girder under various load combinations, providing a possibility for the adaptive self-anchored suspension bridge scheme.
(2) During the construction of the self-anchored suspension bridge, if the non-removal of ground anchors or partial anchor forces are allowed, the main beam will be constrained and subjected to tensile stress, which needs to be adapted with the tensile strength of UHPC.
(3) In the construction process of the ground-anchor suspension bridge structure, the side span anchor force is linearly related to the axial tension of the main girder, while it is a quadratic curve relationship with the maximum tensile stress of the bridge deck.
(4) Based on the design tensile strength of UHPC at 8 MPa, for the bridge design scheme in this study, UHPC can bear the tensile stress exerted on the bridge deck when the anchor force is less than 48,491 N. Based on this, the required

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main cable force and the retained anchor force can be determined for construction needs.

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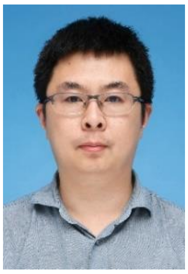

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