# Discussion of 800m Composite Bridge with CFST Flying Swallow Arch and Self-anchored Suspension Cable

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**Abstract.** In view of the demand of 800 meters Super Long Span CFST arch bridge, the composite bridge of CFST flying swallow arch and self-anchored suspension cable is proposed. The thrust of flying-bird CFST arch bridge and the tension of self-anchored suspension bridge are balanced, forming a self-balanced structure system. The arch rib structure is mainly stressed, supplemented by the self-anchored suspension system, which works together and has complementary advantages. Using the single leaf hyperboloid variable section steel tube four limb space truss arch rib structure, the self-weight of the mid span arch rib section structure is reduced, the risk of construction and hoisting of the mid span section is reduced, the section size at the arch foot is increased, the mass center and stiffness center of the arch bridge structure are effectively reduced, and the stability of the super long span concrete-filled steel tube arch bridge is increased. Combined with the actual project, the parameters are designed, the Midas finite element model is established, the internal force analysis and calculation, modal analysis and buckling analysis are carried out, and the superiority of the structural technical measures is verified.

## 1 Introduction

Flying-swan arch bridge is a self-balanced structure system, which is deeply loved by people for its advantages such as beautiful shape, large span capacity, good economy, convenient construction, large structural stiffness and good durability [1-2].

With the increase of span swallow type of concrete-filled steel tube arch bridge, arch bridge weight increasing, structural internal force increase, segmental hoisting construction difficulties, a significant reduction in the arch bridge structure stability, can lead to the development of swallow type of concrete-filled steel tube arch bridge in technical bottleneck [3-4], build more long-span concrete-filled steel tube flitting models type arch bridge will have a greater risk of structural technology.

At present, under construction in span length of 507 meters mountain Yangtz river highway bridge is the world's largest span concrete filled steel tube swallow type arch bridge, for the sake of giving full play to the advantages of swallow type steel tube concrete arch bridge of the economy, to carry out the swallow type steel tube concrete arch bridge design and construction technical improvement of level to build 800 meters of large span concrete filled steel tube swallow type arch bridge will be a big challenge problem of the civil engineer [5-6].

It is impossible to build an 800-meter arch bridge only relying on a single structure of concrete filled steel tube Flying-Swallow arch bridge. The main problem lies in ： As the span of flying-Swallow arch bridge increases, the internal force of arch foot increases, and the section size of arch foot increases, which leads to the problem of economic rationality. With the increase of flying-bird arch span, the structural stability of the arch bridge decreases significantly, which leads to the problem of structural safety. With the increase of span of flying-bird arch bridge, the lifting weight of mid-span segment increases, which leads to the difficulty of lifting construction of mid-span segment. As swallow the arch span increases, the variable load will be large arch foot base imbalance caused by internal force (half through bridge swallow type arc bridge under dead load only can balance arch foot base internal force), will lead to the arch foot base to produce larger deformation displacement, will appear the arch foot based low reversed cyclic stress fatigue damage problem [7-8].

As a single bridge structure has its own advantages and disadvantages, it is often difficult to meet the carrying capacity demand of super-large span Bridges. Therefore, it is necessary to consider the combined use of multiple bridge structure forms at the same time, so as to form a composite bridge structure system, complement each other's advantages and work together, so as to give full play to the advantages of various bridge structures [9-10].

The main cable of self-anchored suspension bridge is anchored at the end of the beam, which transfers the horizontal force to the main beam, and the main beam is under compression. Self-anchored suspension bridge can avoid the construction of large volume anchoring, and its economic index is reasonable. The disadvantages of self-

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anchored suspension bridge are that the construction method of "first beam then arch" must be adopted, which is complicated in construction.

The thrust of concrete filled steel tube arch bridge exerts huge thrust on the foundation, while the self-anchored suspension bridge exerts huge pull on the foundation. Therefore, the two types of bridge types can be considered. The thrust of the Flying-type concrete filled steel tube arch bridge and the pull of the self-anchored suspension bridge balance each other, so as to improve the working performance of the flying-type concrete filled steel tube arch bridge and form a new bridge type structure of the super-large span concrete filled steel tube arch bridge and self-anchored suspension bridge.

With the development of transportation, it will be necessary to build a large number of Bridges with 800 meters span on large rivers. The traditional flying-type concrete filled steel tube arch bridge will be faced with great structural technical risks. If the suspension bridge and cable-stayed bridge are adopted, the price is expensive and the construction is difficult. The combination bridge with 800m steel tube flying-type arch and self-anchored suspension cable has the advantages of convenient construction, large span capacity, low cost, large stiffness, high bearing capacity and good durability, etc., and its structural technical advantages are very obvious.

Combining with the design requirements of Chongqing in the planning of the Yangtze river highway bridge, for 800 meters level of large span concrete filled steel tube swallow type arch combined with the anchor cable bridge geometric configuration research, engineering parameter design, and establish the Midas finite element model, internal force analysis, modal analysis and buckling analysis research, in order to verify the structural advantages of technical measures.

## 2 Configuration research

At present, the traditional technology of concrete filled steel tube flying-type arch bridge cannot be used to build the super-large span bridge with 800 meters of span, so technical improvement should be carried out. There are two aspects of technical improvement measures:

Firstly, steel tubes with single leaf hyperboloid shaped variable section form the arch ribs of basket arch limbs space truss, which can reduce the dead weight of middle span segment, improve the internal force of arch bridge structure, reduce the difficulty of hoisting construction of middle span segment, reduce the structure gravity center and improve the stability.

Second, a self-anchoring suspension cable system is added to strengthen the structural system of the flying-type arch bridge of concrete filled steel tube, forming a super-large span flying-type arch bridge of concrete filled steel tube and a self-anchoring suspension bridge. The two sets of structural systems work together.

Flying-arch and self-anchored suspension cable composite bridge is an organic combination of modern suspension bridge and classical arch bridge. It is a composite structure system composed of flying-arch ribs, double slings, bridge towers, self-anchored suspension cable and deck system. The arch structure is mainly stressed by the suspension cable.

Swallow arch combined with the anchor cable bridge shows the arch bridge and suspension bridge, the characteristics of both the advantages of two kinds of bridge is again complement each other, the existence of the main tower, is the body of the cable attachment, also in construction as the guy in the tower and cable hoisting tower, cable to assist the main arch stress, can rise to adjust pressure line, the improvement of arch rib structure stiffness, and reduce the role of the main arch thrust.

The 800 meters flying-type arch and self-anchored suspension cable composite bridge adopts four single-blade hyperboloid variable section steel tubes to form the space truss arch ribs of the base-shaped arch limbs. The variable section steel tube arch rib reduces the section size at the arch top, increases the section size at the arch foot, reduces the lifting construction weight of the mid-span segment, and increases the stability of the super-large span Flying-type concrete filled steel tube arch bridge.

**Figure 1.** Single - lobed Hyperboloid Variable Section Steel Tube

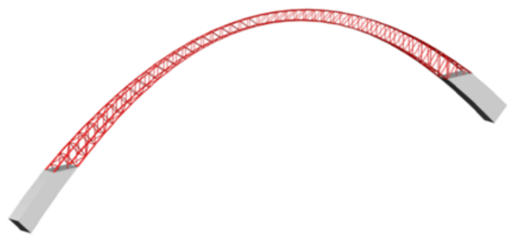


**Figure 2.** Four - limb Truss Arch Ribs with Hyperboloid Variable Section

Drawing on the concept of external prestressed concrete structure reinforcement, the two sets of suspender system work together with the flying-type concrete filled steel tube arch bridge as the main body and the self-anchored suspension bridge as the auxiliary, complementing each other's advantages. The diagonal back cable of the self-anchored suspension bridge is anchored in the rear beam of the Flying-type CFST arch bridge. The tension of the self-anchored suspension cable system on the foundation is balanced with the thrust of the flying-type CFST arch bridge on the foundation.

Swallow type of concrete-filled steel tube arch bridge self-anchored suspension bridge and share the same base, almost no increase infrastructure investment cost of the bridge, self-anchored suspension bridge pylon is both swallow type of concrete-filled steel tube arch bridge without stents cable hoisting temporary pillar structure, and permanent pillar structure of self-anchored suspension bridge structure, kill two birds with one stone, no increase bridge tower construction investment, only added a small amount of suspension cable, new models combined hybrid bridge has a good economic performance.

**Figure 3.** Effect Diagram of Combined Bridge with Swallow Arch and Self-anchoring Suspension Cable

Due to swallow type of concrete-filled steel tube arch bridge thrust to balance the tension of the self-anchored suspension bridge structure on the basis, therefore, self-anchored suspension bridge structure system can realize the construction scheme of "cable back rest is first", to avoid the self-anchored suspension bridge in the temporary pier, avoiding the complex system transformation from a mooring line cable structure construction process, save cost, greatly shortens the self-anchored suspension bridge in construction period.

Due to fly into a bridge type horizontal tie bar tensioning prestressed concrete filled steel tube arch bridge is constant, therefore, in the variable of vehicle under live load, swallow type of concrete-filled steel tube arch bridge foundation models will produce certain thrust, variable of vehicle of live load imbalance base internal force will affect the safety of the infrastructure. As the self-anchored suspension cable system participates in the stress, the self-anchored suspension cable system generates tension on the foundation, and the thrust and tension of the two cancel, which greatly reduces the unbalanced horizontal force of the bridge foundation under the action of variable vehicle live load, reduces the displacement of the foundation structure, and ensures the safety of pile foundation structure.

Traditional self-anchored suspension bridge's main cable can be replaced, the wind blows the rain has led to the damage of suspension bridge cable corrosion, self-anchored suspension bridge after using for a long time, the main cable of suspension bridge structure has certain security hidden danger, the swallow type of concrete-filled steel tube arch bridge self-anchored suspension bridge and two sets of bearing structural system, therefore, composite bridge models can easily replace the self-anchored suspension bridge cable.

In order to swallow type of concrete-filled steel tube arch bridge, the use of suspension bridge tower, draw lessons from in vitro pre-stressed reinforcement concept, using the as external prestressed strengthening cable anchor cable system, the integrated use of swallow type of concrete-filled steel tube arch bridge, and technical advantage of self-anchored suspension bridge, and work together, complementary advantages, one of the new hybrid bridge formed two bridge, concrete-filled steel tube arch bridge, seventy percent thirty percent of the self-anchored suspension bridge, spanning ability, good efficiency, structure rigidity, high bearing capacity, the advantages of beautiful appearance and good durability.

## 3 The establishment of finite element model

Chongqing Changjiang river highway bridge, in the planning of river width of 1400 meters, the need to build a 800 meters order to swallow type steel tube concrete arch bridge, with consideration of requirements, durability and economy to choose concrete-filled steel tube swallow arch and structure form of the combination of anchor cable bridge, expected to break through the existing structure of concrete filled steel tube arch bridge structure technology bottleneck.

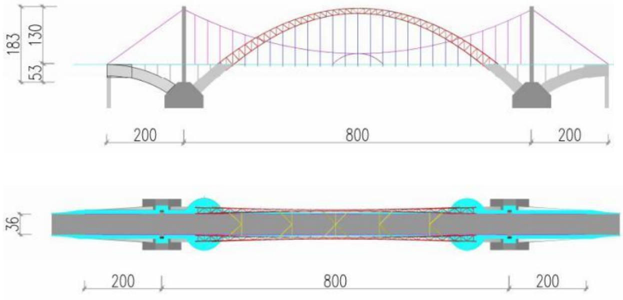



**Figure 4.** General Layout

Bridge span arrangement for (200 meters + 800 meters + 200 meters), the design load level for road, bridge deck width 32 meters (left the pavement + driveway 28 m + 2 m right sidewalk 2 meters), derrick spacing of 25 m, arch rib rise-span ratio of 1/5, the arch vector is 160 meters high, arch axis coefficient is 1.45, from the door of the anchor cable system bridge tower height is 173 meters, the distance from the top of the base to the bridge panel for 53 meters, bridge panel to the top of the tower height of 120 meters.

**Figure 5.** Elevation Drawing

Left and right side of the large span concrete filled steel tubular arch bridge hyperboloid of one sheet each set of variable cross-section tube limbs space truss arch rib, limbs space truss arch rib by two cross lean close to each other into a basket of arch truss arch, limbs space truss arch rib arch section 12 meters in height, the arch foot section height of 25 meters, limbs space truss arch rib in the vault after two upper chord close distance of 5 meters, two in two upper chord spacing is 20 meters.

Four limbs space truss arch rib using simple hyperboloid shape cross-section of steel tube arch arch limb, lower chord on the dome. Steel pipe diameter is 1500 mm, on the arch foot bottom chord steel pipe diameter is 3000 mm, the rest of the section, the lower chord variable cross-section steel pipe diameter determined by hyperboloid of one sheet equation, hyperboloid of one sheet of variable cross-section arch steel tube wall thickness 25 mm from the vault on the basis of hyperboloid of one sheet equation change to the arch foot 36 mm.

From the arch foot to the deck section, steel plates are wrapped around the outer ribs of the space truss limbs. The thickness of the steel plates changes from 14mm at the deck to 18mm at the foot of the arch.

The wall thickness of inclined ventral steel tube of space truss arch rib of four limbs changed from the wall thickness of 500mm in diameter at the arch top to the wall thickness of 800mm in diameter at the bridge deck.

The no brace cable lifting scheme was adopted. Starting from the arch foot foundation, the space truss rib segment of the steel tubular limbs with hyperboloid shape variable section was piecewise hoisted and splice until the arch bridge was closed.

During the cable hoisting of the arch rib segment of the space truss for four limbs, the wind-resistant K-type supports are installed synchronously. The K-type supports are made of steel tubes. The diameter of the K-type supports varies linearly from the wall thickness of 600mm at the arch top to the wall thickness of 1200mm at the arch foot to 16mm.

The vacuum assisted continuous filling tube concrete technology and the single blade hyperboloid variable section arch steel tube were filled with C60 high performance concrete by jacking method.

The semi-span auxiliary arch rib adopts the solid arch of steel concrete with variable section, and adopts the form of rectangular section, which changes from the linearization of 20×25 meters at the base of arch to 12×15 meters at the deck.

The sling spacing of flying-bird arch bridge is 25 meters, and the derrick is made of 1670MPa high-strength steel wire with a diameter of 0.16 meters.

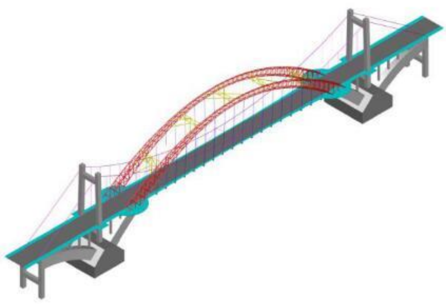


**Figure 6.** 3D Design Drawing of 800m Concrete Filled Steel Tube Arch Bridge

Each side arch rib offlying-bird arch bridge is provided with 8 finished arch bridge tie cable, which is arranged under the pavement plate. The single-strand tie cable is made of high-strength steel wire cable with a diameter of 0.4 meters, the strength of which is 1860MPa, and the high-strength steel wire cable is covered with PE protective sleeve.

The self-anchoring suspension cable system tower column is the structure of the rigid concrete hollow bridge tower, with the external dimension of 12×12 meters and the wall thickness of 1.2 meters. C70 high-performance concrete is used for pouring, and the steel framework is set inside.

The cable of self-anchoring suspension system adopts 1860MPa high-strength wire rope with diameter of 0.65 meters, the span ratio of self-anchoring suspension cable is 1/8, the spacing of self-anchoring suspension cable system is 25 meters, and the self-anchoring suspension system adopts 1670MPa high-strength wire rope with diameter of 0.1 meters.

The deck stiffened girder is made of concrete girder grid system. The stiffened girder is suspended under the sling of arch bridge and self-anchored suspension bridge, and the arch structure is mainly stressed, supplemented by the suspension.

The central arch buckle is installed in the middle span to adjust the tension of the suspender of the arch bridge and the suspension cable of the self-anchored suspension bridge, the internal forces of the flying-type concrete filled steel tube arch bridge system and the self-anchored suspension bridge system are adjusted, asphalt concrete pavement is installed, and balustrades are installed to form an 800-meter composite bridge of the flying-type concrete filled steel tube arch and the self-anchored suspension cable.

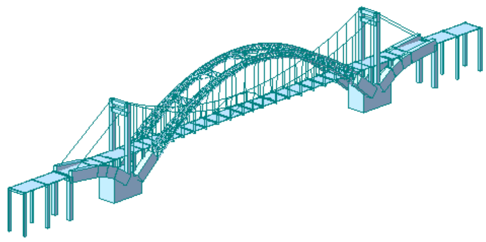


**Figure 7.** Midas Model

## 4 Calculation results under vertical load

Full load is applied to the main bridge deck, uniform load standard value is adopted for the additional constant load of the bridge deck, 5KN/m2 is adopted for the standard value of road first-grade load is adopted for the live load of the bridge deck, and the calculation results are as follows:

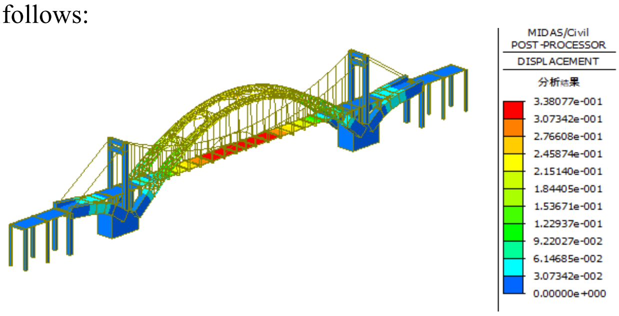
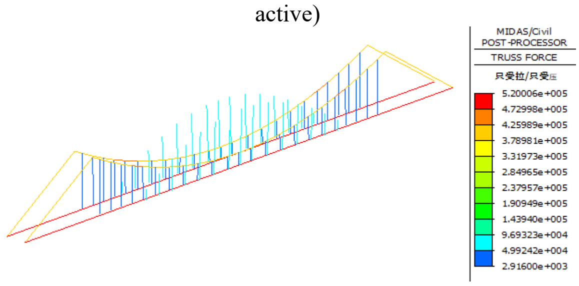
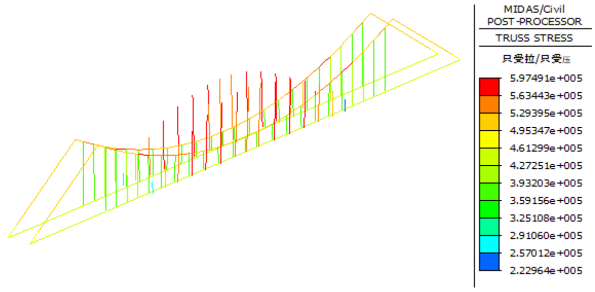


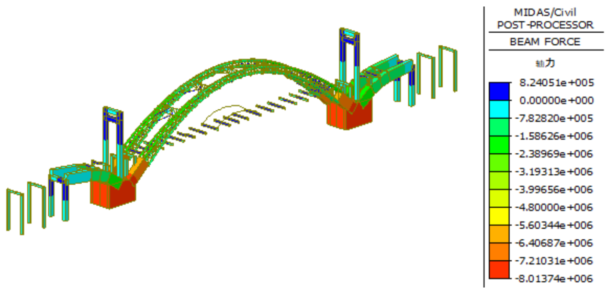

**Figure 8.** Displacement under Vertical Load (constant + active)



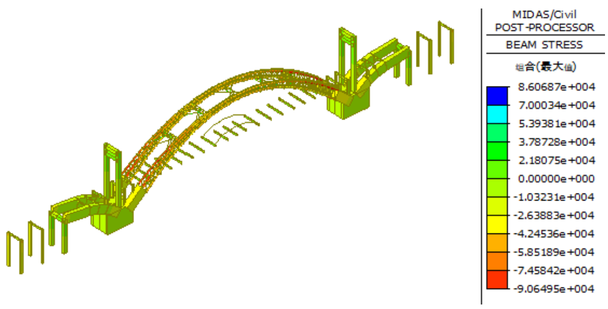

(a) Internal force of cable element




(b) Internal force of cable element




(c) Internal force of beam element




(d) Internal force of beam element

**Figure 9.** Calculation Results of Internal Forces and Stresses under Load

Under the action of vertical live load, the maximum vertical displacement occurs in the middle of the span, with the maximum displacement of 0.338m, which meets the requirement of 1/500 limit specified in the code. The combined structure of flying-arch and self-anchored suspension cable has large stiffness, which is conducive to reducing the resonance effect of vehicle and bridge and improving the driving comfort.

The maximum internal force of the suspension cable is 185,034.5 KN, and the maximum stress of the suspension cable is 557.6MPa, meeting the strength requirement.

The maximum internal force of arch bridge sling is 18767.8kN, and the maximum stress of arch bridge sling is 597.4mpa, which meets the strength requirement.

The maximum internal force of suspension system sling is 3206.8kN, and the maximum stress of suspension system sling is 408.3mpa, meeting the strength requirement.

The maximum internal force of the arch cable is 520006KN, and the maximum stress of the arch cable is 459.8mpa, which meets the strength requirement.

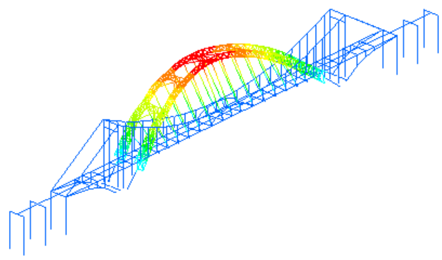
The maximum internal force of the truss arch rib (single limb) is 1057628KN, and the maximum stress of the truss arch rib is 90.6mpa, which meets the strength requirement.

The maximum internal force of half-span auxiliary arch rib is 4259536KN, and the maximum stress of half-span auxiliary arch rib is 29.1mpa, which meets the strength requirement.

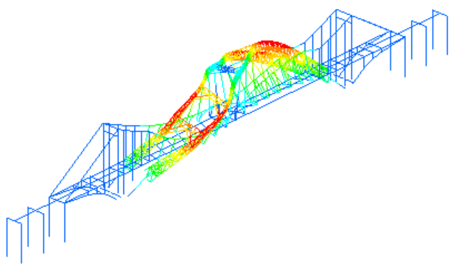
The analysis shows that the horizontal thrust on the left and right sides of the arch foot is basically balanced under the action of constant + live load, which is beneficial to improve the stress condition of the foundation of the flying-type arch and self-anchored suspension cable composite bridge. The self-balancing cable of the flying-arch realizes the horizontal thrust balance of the foundation under the action of constant load. Under the action of live load, the self-anchored suspension cable system exerts tension on the foundation, and the horizontal thrust of the arch bridge and the tension of the self-anchored suspension cable are basically balanced.

## 5 Modal Calculation Results

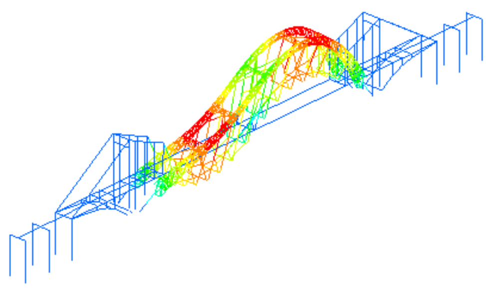
Midas structural analysis software is used for dynamic modal analysis. In order not to omit any vibration mode, the sub block method is used to solve the characteristic equation.



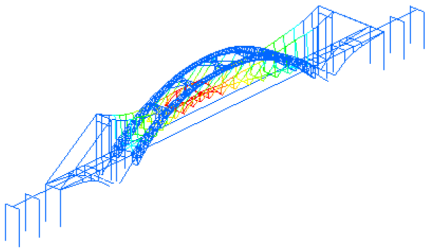
(a) First-order mode of vibration (positive symmetrical arch lateral bending) (0.236Hz)



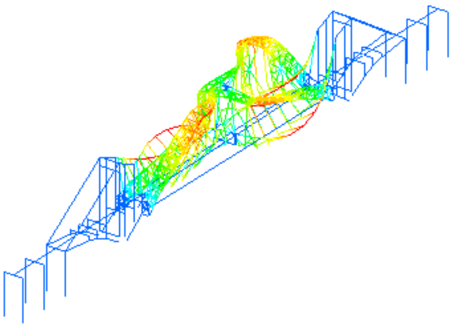
(b) Second-order mode (arch anti-symmetric lateral bending) (0.415Hz)



(c) Third-order mode (anti-Symmetric vertical bend) (0.438Hz)



(d) Mode of vibration (vertical bending with positive symmetry of bridge deck) (0.454Hz)



(e) 7 Mode of Vibration (torsion) (0.775Hz)

**Figure 10.** Typical Modes

From the calculation results in the figure above, it can be seen that the first-order mode of vibration is arch positive symmetric lateral bending, and the frequency is 0.236Hz. The second mode is the positive symmetrical lateral bending of the bridge deck, and the frequency is 0.415Hz. The 7th mode is a torsion mode with a frequency of 0.775 Hz.

On the whole, the vibration modes are dense and obvious grouping phenomenon appears. The first six modes are mainly side bending and vertical bending vibration, and the torsional vibration mode does not appear until the seventh order. The torsional frequency ratio is 1.87, which is high, and the structure has good wind-resistant stability.

Vibration shape in order is the first level of lateral vibration shape vertical vibration form before they occur, the analysis shows that the increase in the auxiliary system of the mooring line cable obviously improves the vertical frequency of vertical stiffness has a larger increase, but its level of lateral frequency is low, the future remains to be further order to swallow the level of the arch combined with the anchor cable bridge to the research of structure stiffness of technical improvement measures.

## 6 Stability Analysis

Arch bridge is bridge is a kind of compression member, when the structure is unstable, there is no obvious sign, it is very sudden and destructive. Therefore, it is very necessary to analyze the stability of the structure based on the static and dynamic analysis, so as to avoid the failure of the structure.

Midas software was used to analyze the buckling of the designed bridge, and the structural stability coefficient was obtained. In general, the structure with the minimum stability coefficient has the greatest possibility of instability. The first 10 stability coefficients are listed in the table below.

| The modal | The eigenvalue | Allowable error |
|---|---|---|
| 1 | 10.010 | 1.4846e-018 |
| 2 | 10.657 | 8.6848e-013 |
| 3 | 11.484 | 3.1153e-010 |
| 4 | 12.410 | 1.3817e-010 |
| 5 | 14.003 | 6.6927e-009 |
| 6 | 14.401 | 5.8696e-009 |
| 7 | 16.103 | 1.2716e-009 |
| 8 | 16.234 | 4.2738e-009 |
| 9 | 16.318 | 2.5674e-009 |
| 10 | 17.238 | 1.1442e-009 |

It can be seen from the above table that the stability and safety coefficient of the tied arch bridge is 10.010, which meets the requirement of GB 50923-2013 technical Specification for Concrete-filled Steel Tube Arch Bridge greater than 4.0.

Analysis shows that the level of 800 meters swallows of concrete filled steel tubular arch bridge adopts hyperboloid of one sheet shape cross-section of concrete filled steel tube space truss arch rib limbs and swallow arch combined with suspension cable bridge two new technology, greatly improved the swallow type of concrete-filled steel tube arch bridge structural stability models, successfully solved the level of 800 meters of concrete filled steel tubular arch bridge, the stability of the key problems to break the swallow type of concrete-filled steel tube arch bridge structure of the development of the technology bottleneck.

## 7 Conclusion

Based on the engineering background of a concrete filled steel tube arch bridge of 800 meters, this paper studies the configuration of concrete filled steel tube flying-type arch bridge and self-anchored suspension cable composite bridge, establishes Midas finite element model, conducts internal force analysis under vertical load, conducts modal analysis and buckling analysis, and draws the following conclusions:

(1) The thrust of concrete filled steel tubular arch bridge and the tension of the self-anchored suspension bridge with both balance, form self-balancing structure of the system models, dropped sharply in variable based imbalance internal force under live load, concrete filled steel tube arch rib structure is given priority to, complementary with the force of anchor cable system, two sets of structural system work together, complementary advantages.

(2) Reform the traditional section steel tube arch arch body structure, adopts the hyperboloid of one sheet of variable cross-section tube limbs space truss arch rib structure, reduce the cross section in the weight of lifting, lowering the risk of construction hoisting difficulty,

increased the arch foot section dimension, the arch structure of mass center and stiffness center effectively reduce, increase the stability of the large span concrete filled steel tube arch bridge.

(3) The combination of flying-type arch and self-anchored suspension cable of concrete filled steel tube greatly improves the vertical stiffness of the structure. Under the action of vertical variable live load, the maximum displacement of mid-span position is 0.338m, which meets the requirement of 1/500 limit limit of the specification.

(4) The whole, modal density, apparent modal group phenomenon, the first six order vibration mode are mainly composed of lateral and vertical bending vibration, until the seventh order torsional vibration mode, vibration shape in order is the first level of lateral vibration shape vertical vibration form before they occur, analysis shows that the technical measures to increase the frequency of the vertical bridge, but the horizontal lateral frequency is low, the future remains to be further developed on the level of the combination arch bridge models to the structural stiffness of technical improvement measures.

(5) Buckling analysis calculation, the bridge is 800 meters swallow the arch models of minimum stability safety coefficient is 10.01, the analysis shows that the hyperboloid of one sheet shape cross-section of concrete filled steel tube space truss arch rib limbs and swallow arch combined with suspension cable bridge two new technology, successfully solved the level of 800 meters of concrete-filled steel tube arch bridge stability is the key problem.

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