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Analysis on the Structural Type of Large-span Steel Truss Bridge Specially Designed for Cables

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ABSTRACT

When the installation of cables and pipelines needs to go across rivers, bridges are usually adopted to support the cables and pipelines for crossing the rivers. The measure can make full use of the space resources and have no effect on the flow pattern of rivers. For this reason, analysis on the structural-type design of a large-span steel truss bridge specially used for cables has been performed. The numerical results indicate that the stayed-cable bridge with steel truss beam and concrete main tower has better performance and improved structural type compared with that of the beam and arch bridges, and the construction of the major beam can be without the temporary support.

1. Introduction

With the rapid growth of the national economy, the demand for power supply is further improved. However, due to the large-scale development of land and the construction of heavy industrial parks, it is often difficult to select the transmission line path, and high voltage power cables crossing rivers are frequently encountered. When crossing a wide river, more cable bridge structures are used, among which steel bridge structures are the most common.

There are many structural systems suitable for long-span structures. As for cable bridge structure across rivers, it can be selected from beam structure, truss structure, rigid frame structure and arch structure in plane bar system structure, or the combination of the above structure and prestressed technology^[1-3]. The research on me-

chanical properties and structural design of truss cable pipe bridge has made some achievements. Zhang Zhen^[4] discussed and analyzed the key points of structure design of 55 m steel truss bridge and believed that welded I-beam and H-beam could better adapt to the connection design of steel truss structural members. Wang Chuncai et al.^[5] used TDAP III nonlinear structural analysis software to analyze the nonlinear dynamic characteristics of a large-span steel truss rail-road dual purpose bridge, which consisted of three continuous steel truss Bridges with a main span of 168.85 m. The research shows that the safety reserve of the bearing capacity of the bridge is insufficient, and there are certain safety risks. Jiang Li-mei et al.^[6] based on ANSYS finite element analysis software, carry out static and dynamic analysis of a steel truss railway bridge. The maximum span of the bridge is

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126 m+196 m+126 m continuous steel truss bridge. The research shows that the static and overall modal analysis of steel truss bridges has a good guiding significance for the design of this kind of structure. Hassen et al. [7] take a steel truss bridge as the research object, using ANSYS modal analysis, get the natural vibration period and vibration mode diagram. It provides parameters and basis for further structural dynamic analysis. Hao Tian-tian [8] used finite element analysis software MIDAS / CIVIL 2010 to analyze the dynamic characteristics of a continuous steel truss bridge in Nanchang. The analysis of the structure shows that the torsional stiffness of the truss bridge is large, and the superstructure has a great influence on the transverse stiffness. Zhang Yuan-liang et al. [9] conducted a preliminary standardized design and construction technology research on 30 m, 40 m, 50 m three large span high voltage cable across the river bridge structure. Based on the reliability theory, Li [10] analyzed the optimal design of a 64 m simply supported steel truss bridge. It is considered that the contradiction between economy and safety can be solved to a certain extent by optimizing the design based on reliability and strengthening the bearing capacity of composite materials, and the unity of economy and safety can be realized. Tan Jinhua [11] analyzed the fine fracture mechanics of simply supported steel truss bridge by ANSYS software, which provided the premise for further analysis of crack propagation and fatigue life evaluation. Zhang Chenglong [12] carried out the numerical simulation of the three-component force coefficient of an assembled steel truss bridge, which provided direct data support for the analysis of the wind resistance of the bridge and provided reference for the optimization of the bridge structure.

More detailed studies on long-span continuous steel truss bridge have been carried out in the literature [13,14], but they are mainly the railway bridges or the highway-railway bridges in transportation. There are few reports on the mechanical characteristics analysis and structural design of cable pipe bridges with a span of more than 100 m. There are great differences between long-span steel truss cable pipe bridge and truss bridge with highway, railway and other traffic functions. And the current codes and regulations do not give clear calculation methods, design concepts and corresponding design standards. According to the requirements of structural functions, more stiff supporting skeletons are added inside the cable pipe bridge structure, and the load transfer path is also complex. If designed in accordance with the current specification, there will be a large deviation, making the structure have greater security risks.

In view of this, based on a cable transmission project,

this paper puts forward a special type of long-span steel truss cable pipe bridge. Through the mechanical characteristics analysis of long-span steel truss cable pipe bridge, the structural stress characteristics are understood, and the internal force distribution law of the structure is mastered, which has guiding significance for controlling the key stress parts of the structure and clarifying the structural optimization design idea.

2. Section Form of Cable Pipe Bridge

The cable pipe bridge needs to lay multiple cables with different voltage levels, and meets the needs of personnel in maintenance. The section form is generally single cabin or multi cabin rectangular section, as shown in Figure 1.

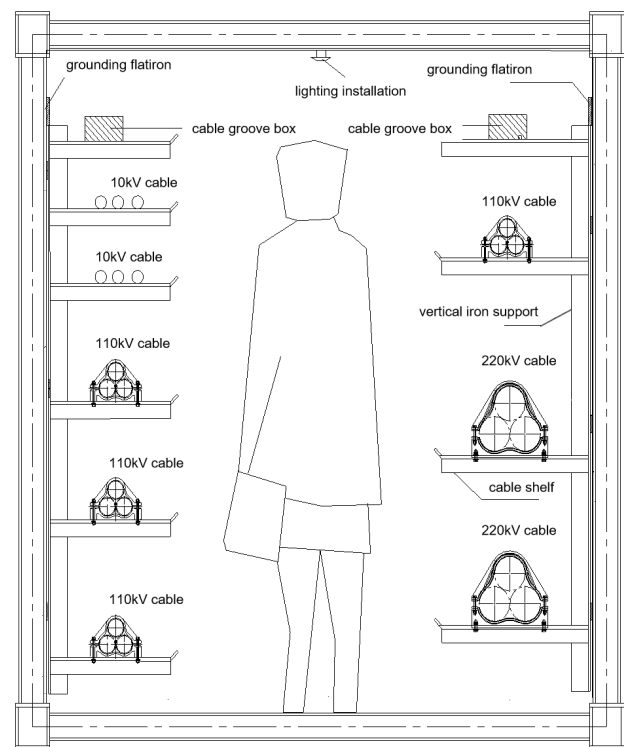


Figure 1. Section form of single cabin cable pipe bridge

3. Structural Type of Large-span Steel Truss Cable-stayed Bridge Designed for Cables and Pipelines

Large-span steel truss cable-stayed bridge designed for cables and pipelines adopts the bridge scheme of cable-stayed bridge without backstays. The main structure of the bridge is the Warren-type steel truss structure with double truss and vertical bar, and the bridge tower is the reinforced concrete structure without backstays and the H-type tower with variable width. The bridge pylon cap and abutment adopt reinforced concrete prism structure,

and the bridge pylon cap and abutment all adopt cast-in-place pile foundation. Schematic diagram of cable-stayed bridges designed for cables and pipelines is shown in Figure 2.

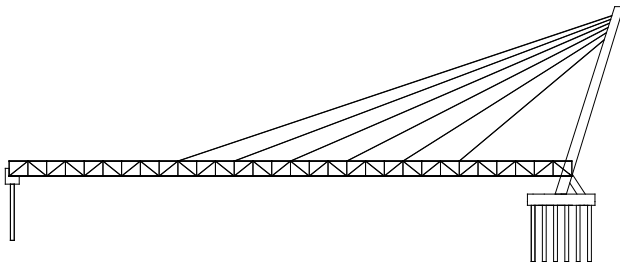


Figure 2. Schematic diagram of large-span steel truss bridge

4. Design Example of Large-span Steel Truss Cable-stayed Bridge Designed for Cables and Pipelines

4.1 Project Overview

A cable transmission project is a lifeline engineering for a large coastal super quality iron and steel products base. Due to the restrictions of terrain and local site conditions, a large-span bridge designed for cables with a length of 150 m needs to be built to cross a navigable river along the line. The whole project is located in a coastal city with good traffic conditions. After the completion of the pipe bridge, the bridge will be used for laying double circuit 220 KV cable, multiple circuit 220 KV cable and power line inspection personnel access.

4.2 Design Standards

The baseline period for structural design is 100 years and the security level is one. The peak ground motion acceleration is 0.1 g (basic intensity is 7 degrees), the bridge type is A, and the earthquake type is E2. The environmental category was Class II, and the design reference temperature was 20°C.

4.3 Main Bridge Design

4.3.1 Design Load

(1) Permanent load

The dead load includes the dead weight of the main truss structure, cable and accessory structure. The bulk density of the main truss structure steel is calculated according to 78.5 kN/m³. The 220 kV cable specification is 3 x 38.5 kg/m, and the 110 kV cable specification is 3 x 13.5 kg/m. The 10 kV specification can be approximately regarded as the same as 110 kV.

(2) Live load

The wind load is calculated according to the relevant provisions of *Wind-resistant design specification for highway bridges* and the snow load is calculated according to the relevant provisions of *Load code for the design of building structures* ^[15,16].

4.3.2 Main Design Materials

Concrete: C40 (Standard value of compressive strength of cube is 40 MPa); Reinforcement: HPB300, HRB400; Stay cable: low relaxation steel strand, HDPE sheath is arranged outside the cable; Steel: Q345qE (Steel for bridge and its' yield strength is 345 MPa); Bolts: 10.9s high strength bolts; Bearing: GPZ (II) uniaxial movable, fixed pot rubber bearing.

4.3.3 Main Truss Structure Design

In this design, the bridge span scheme of cable-stayed bridge without backstay is adopted. The total length of the whole bridge is 150 m and the height of the tower is 50 m. The main bridge structure adopts the Warren-type steel truss structure with flat chord double truss and vertical bar. The chord center spacing is 5 m, the truss height is 4 m, and the internode spacing is 5 m. The upper and lower chords of the truss adopt 200 mm x 266 mm welded box section, the web member and the flat coupling beam adopt 150 mm x 150 mm welded H-section, and the lower flat joint adopts 150 mm x 150 mm welded H-section and the lower flat joint at both ends of the beam adopts 250 mm x 208 mm box section for strengthening.

4.3.4 Design of Bridge Tower

The bridge tower adopts reinforced concrete structure, H-shaped tower with variable width without backstays. The thickness of the tower column in the transverse direction is 1.2 m, and the distance between the outer edge of the bottom of the tower column in the transverse direction is 8.525 m. The distance between the inner edge of the transverse girder tower column and the top of the tower is 5.852 m and 5.925 m. There are horizontal beams at vertical distances of 5 m, 42.5 m and 47.4 m from the bottom of the tower. Respectively for the erection of the main beam, improve the lateral stiffness and stability of the bridge tower. The Angle between the vertical column of the vertical bridge and the horizontal plane is 73°. The section of the vertical tower wall thickness of the vertical bridge is a variable section. The horizontal distance of the bottom wall thickness is 3 m, and the horizontal distance of the top wall thickness is 2.4 m.

4.3.5 Design Substructure of Bridge Pylon

The bridge pylon cap adopts reinforced concrete prism structure, and the size is 18 x 18 x 3 m. 36 cast-in-place piles with a diameter of 1.2 m and a length of 25 m for each pile are set under the cap.

4.3.6 Abutment Design

Because the abutment elevation is higher, the double-column reinforced concrete abutment is used, the pier column diameter is 1.2 m, and the pier height is 7.1 m.

4.4 Structure Calculation

4.4.1 Working Condition Combination

- (1) Dead load + cable force
- (2) Dead load + cable force + wind load + snow load + overall temperature drop
- (3) Dead load + cable force + wind load + overall temperature rise

4.4.2 Main Calculation Contents

Midas Civil /2015 was used for simulation calculation of the following contents:

- (1) Check the strength, stability and deformation of the main truss structure in the ultimate state of bearing capacity.
- (2) Check the strength and stability of local bar.
- (3) Check the bending and shear resistance of the concrete structure of the bridge tower under the state of bearing capacity.

4.4.3 Finite Element Module Method

The overall calculation of the main bridge adopts the plane bar element model, the truss beam, tower and pillar adopt the beam element, and all the beam elements of the truss girder structure adopt the rigid connection form. cable adopts two-force bar unit; bridge pier adopts perfect rigidity restraint, and restraint between master and slave nodes is used between the truss beam and pillar and the tower. The vertical and horizontal master-slave rigid restraints between tower and beam. The calculation model is shown in the following figure.

In order to reflect actual stress state of the main bridge, in addition to the finite element model analysis of the bridge state, the finite element analysis of the construction stage of the main bridge is also needed, this ensures that the main bridge from construction to completion to the operation stage of the force situation is within the design requirements.

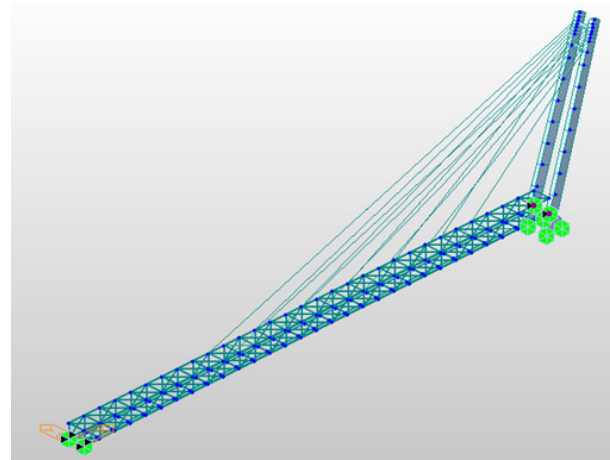


Figure 3. overall calculation model

4.4.4 Calculation

- (1) Vertical displacement of main bridge

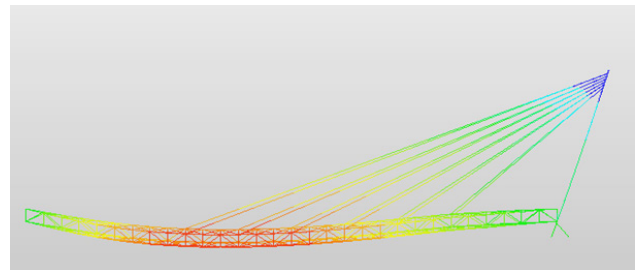


Figure 4. dead load+cable force+wind load+snow load vertical maximum displacement (cm)

Calculation by working condition, the maximum displacement of the main bridge under ‘ dead load + cable force + wind load + snow load ‘ is 24. 82 cm, which is less than the vertical deflection limit $L / 400 = 37. 5 \text{ cm}$ [17].

- (2) Tower top displacement

According to the above four load combinations, longitudinal and transverse bridge direction of the tower top are obtained in the following table: (Unit: cm)

Load	dead load+cable force	dead load+cable force+wind load+snow load	dead load+cable force+wind load+snow load+temperature drop	dead load+cable force+wind load+temperature rise
transverse direction	0	8.92	9	8.18
longitudinal direction	26.09	29.12	29.28	28.55

- (3) Bearing reaction force of main bridge

By calculation, the maximum vertical reaction force

at tower bottom is 11621.9 kN, the maximum vertical reaction force of the tower and the support is 514.6 kN, and the maximum vertical reaction force of the abutment support is 370.4 kN. The maximum reaction force at the bottom of the tower in the transverse direction is 603.1 KN, the maximum reaction force at tower and bracket in the transverse direction is 1086.7 KN, and the maximum reaction force at bridge abutment bracket in the transverse direction is 1005.4 KN;The maximum reaction force of tower bottom in longitudinal direction is 4598.1 KN, and the maximum reaction force of tower and bracket in longitudinal direction is 2263.3 KN.

4.4.5 Structure Checking Calculation

Structure checking shall cover all the following contents:

After checking calculation, the above checking calculation contents meet the requirements.

5. Conclusions

In this paper, based on a cable transmission engineering, a large-span steel truss bridge specially used for cables is firstly proposed, and analysis on mechanical characteristics of large-span steel truss cable pipe bridge. In this process, the following conclusions are drawn:

(1)Adopt a steel truss girder cable-stayed bridge with

isolated inclined tower. Compared with the beam and arch style of the same span, the major beam steel quantity is small, the major beam erection construction does not need temporary auxiliary measures (auxiliary pillar, temporary steel tower);The inclined main tower resists the horizontal action torque of the stay cable through the weight of the main tower relative to the bending moment of the tower root; The major beam is made of light and high strength steel, which not only satisfies the vertical stiffness of the major beam, but also reduces the force of stay cable.

(2)Under the most unfavorable load combination, the vertical maximum deflection of the major beam is $24.8 < L/400 = 37.5$ cm. Vertical displacement meets the requirements of the specification. The horizontal offset displacement at top of main tower is $29.28 \text{ cm} < L/300 = 50$ cm, meeting the specification requirements. The maximum axial tension of main truss member is 938.2 kN, the maximum axial tensile stress is 151.3 MPa, the maximum axial pressure is 1459.2 kN, and the maximum axial compressive stress is -139.7 MPa, all of which meet the requirements of the design code.

(3)Because it is a cable-stayed bridge with one side stay cable floating system across single tower, the horizontal component force of the support at the tower beam under the action of stay cable reaches 2263.69 kN, then the tower crossbeam adopts the “L” shaped reinforced concrete beam, and the bracket resist the horizontal com-

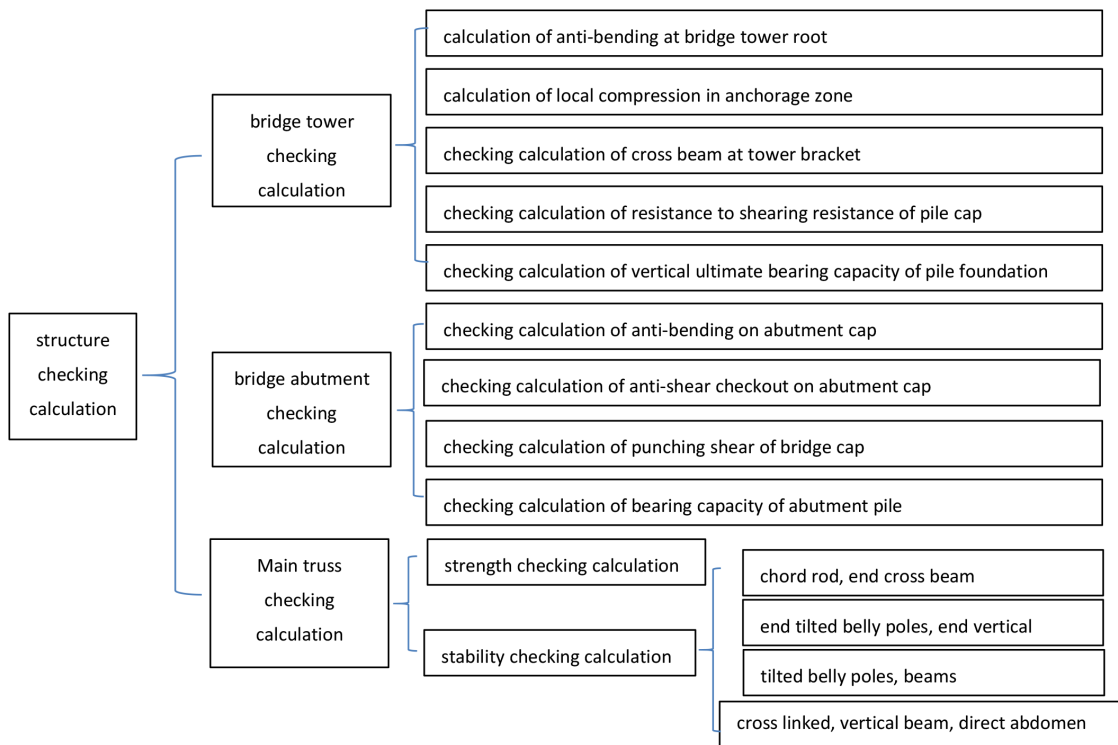


Figure 5. Flow chart of pipe bridge checking

ponent force here.

(4) The abutment, tower and foundation are all made of reinforced concrete structure, and the bearing capacity of each part meets the requirements of the design code.

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