Design of a kind of Steel Cable Bridge for Belt Conveyor

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Abstract. Steel cable bridge is a kind of flexible suspension bridge with steel wire rope as the main stress components. It has the advantages of low construction cost, short engineering period, reliable structure, simple construction, etc., and has been widely used in driving and walking passages. In this paper, a 110m steel cable bridge supporting the belt conveyor is as an example, the finite element software Midas/civil is used to establish a spatial calculation model, and the cable force and displacement are calculated and analyzed. The results and calculation process can provide theoretical basis and practical experience for the design of steel cable bridge for belt conveyor.

1. Introduction

As important continuous conveying equipment for bulk materials, belt conveyors have been widely used in the fields of coal mine, metallurgy, mines, ports, building materials and chemical industries. With the continuous improvement of production technology, belt conveyor is developing towards the trend of long distance and super long distance. Due to the influence of terrain and topography, the ultra-long-distance cross-country belt conveyor needs to cross various obstacles such as valleys, rivers, railways, highways, etc. Currently, the Steel truss structure trestle is mainly used to cross obstacles. The construction and installation of steel truss structure trestle is difficult, the investment is high, the degree of damage to the surface vegetation is high, and the restoration of the ecology requires a large amount of investment, even related to the feasibility of the project. In recent years, the calculation and analysis of steel cable structure has attracted the attention of mechanics workers from all over the world. It has been widely used in various structures such as mine cableway transportation, manned cableways in scenic area, suspension bridges and cableway bridges [1]. It has many advantages such as low cost, large span, can adapt to a variety of complex terrain, easy to set up and so on. Based on the engineering practice of a 110m span, this paper organically combines the belt conveyor and the steel cable bridge, studies the steel cable bridge suitable for belt conveyor, and provides a new theoretical basis and practical experience for the support structure of belt conveyor across obstacles such as rivers and gullies.

2. Project profile

A total of 34 suspension cables are installed on the whole Steel Cable Bridge. The suspension cables are composed of bridge deck cables and stability cables, including 22 deck cables and 2×6 stability cables. The specifications are 6 × 37W + IWR-54 -1870 steel wire rope, the nominal tensile strength of single steel wire rope is 1870 MPa, and the minimum breaking force is 1740kN. The bridge
is also equipped with two wind cables, whose specifications are $6 \times 37 + FC \cdot 24 \cdot 1770$, the nominal tensile strength of the single wire rope is 1770 MPa, and its linear shape is a space parabola. The bridge deck beams are made of 16Mn steel.

Design standards: (1) Design load: belt conveyor load, 1.5t/m; (2) Bridge type: single-span steel cable bridge; (3) Wind resistance rating: level 8, wind speed 20m/s; (4) Seismic fortification intensity: VII degree.

Main technical indicators: (1) Suspension cable span: 110m; (2) Bridge deck width (belt conveyor road width): 3.5m; (3) Suspension cable span ratio: 1/30 (working sag); (4) Working sag of suspension cable: 3.661 m; (5) Distribution width of suspension cable: 10.0m. The elevation, plan and section view of the cable bridge belt conveyor are shown in figure 1, figure 2 and figure 3 respectively.

3. Mechanics properties analysis

Because the steel cable bridge is a nonlinear system, the main load-bearing structure of the whole bridge is composed of inhaul cables, anchor cables and beams. In order to truly reflect the space stress state of the bridge, the related finite element program Midas / civil \([2, 3]\) is used to establish a spatial finite element model, and the cable force is calculated and analyzed.

3.1. Basic assumptions

In order to more accurately reflect the actual force of the structure, the following assumptions were made in the calculation model according to the specific structure and to accelerate the iteration speed: (1) Under various load conditions, only the effects of bridge deck cables, stability cables and beams of the mid-span bridge were considered; (2) When calculating the dynamic characteristics of the bridge deck structure, only the influence of mass is considered.
3.2. Shape calculation

Based on the finite displacement theory, the initial cable shape is assumed to be a parabola [4, 5], the line shape of the cable under load is obtained through analysis, compared with the design value, and then corrects the assumed parabola until it meets the requirements, thus determining the line shape and internal force of the steel cable bridge under the initial empty cable and the finished bridge. In view of the following theoretical calculation, the hypothesis of the initial mid-span sag f-value is expanded around the theoretical calculation value of 1.6m.

The theoretical f-value can be obtained according to the following formula:

\[
0) \quad H_2 - \left[ H_1 - \frac{EF}{2H_2^2(L + L_1)} \int Q_1^2 dx \right] H_1^2 - \frac{EF}{2(L + L_1)} \int Q_1^2 dx = 0
\]

In formula (1):
- \( H_1 \) - Tension of main cable, kN;
- \( H_2 \) - Horizontal tension of a steel cable under load at the middle span, kN;
- \( E \) - Elastic modulus of steel cable, 1.2x10^5 MPa;
- \( F \) - Cross-sectional area of a steel cable, m^2;
- \( L \) - Calculate span, 110m;
- \( L_1 \) - Total length of anchor cables on both sides, 45m;
- \( q_1 \) - Dead weight of a bridge Shared by a steel cable, kg;
- \( Q_1 \) - The self-weight of the bridge is distributed on a steel cable, which is equivalent to the shear force of the simply supported beam (kN);
- \( Q_2 \) - The fully load of the bridge is distributed on a steel cable, which is equivalent to the shear force of the simply supported beam (kN);

To solve equation (1), we can obtain:

\[
f_i = \frac{q_1 L_i^2}{8H_i} = 1.6(m)
\]

3.3. Calculation model

After the structure of the steel cable bridge is discretized, Midas/civil is adopted to establish the three-dimensional model of the whole bridge. The bridge deck cables and stability cables are both simulated by cable element, and beams are simulated by space beam element. There were 1381 units and 952 nodes in the calculation model. According to the force characteristics of the bridge, the mass of the bridge deck system is distributed to the beam according to the lever principle. Finally, the full bridge calculation model is established as shown in figure 4.

![Figure 4. Full bridge calculation model diagram](image)

4. Structural calculation

4.1. Structural internal force calculation

The suspension cables of the steel cable bridge are subjected to distributed loads and a series of concentrated loads. Its horizontal tension is \( H \), and the vertical reaction force of the support is \( V_1 \) and \( V_2 \). Since the suspension cable is flexible and cannot resist the bending moment, the bending moment at any point (its vector \( y \)) of the suspension cable is zero, that is:
\[ V_x = \sum P_i (x-x_i) - \int_0^1 q(x) (x-x^2) dx - H \cdot y = 0 \]

The first three terms in the formula are the bending moments of simply supported beams under different loads, so they are expressed by \( M_x \), so the above formula can be written as: \( M(x) - H \cdot y = 0 \). This is the relation between the suspension cable sag and the horizontal tension, which is derived from the static equilibrium condition, so it is called the equilibrium equation of the suspension cable.

If the maximum vector \( f \)-value of the suspension cable is given, then the horizontal tension \( H \) of the suspension cable can be calculated from the balance equation: \( H = \frac{M_{\text{max}}}{f} \), \( M_{\text{max}} \) is the maximum bending moment of the simply supported beam.

When the horizontal tension of the suspension cable under one load state is known, the horizontal tension under other load states can be calculated. The first load state is called empty cable state, and the second state is called completion state. Although the two states are different, since they are the same cable, their vector is the same, and the cable force can be obtained through this relation. The cable force and maximum deflection under different load conditions are shown in Table 1.

| No. | Load name                        | Maximum cable force /kN | Maximum displacement /m |
|-----|----------------------------------|-------------------------|-------------------------|
| 1   | Dead load                        | 291                     | -0.0230                 |
| 2   | Belt conveyor load               | 362                     | -0.7438                 |
| 3   | Wind load                        | 289                     | -0.0190                 |
| 4   | Dead load + Belt conveyor load   | 522                     | -1.1067                 |
| 5   | Dead load + Wind load            | 481                     | -1.0455                 |
| 6   | Dead load + Belt conveyor load + Wind load | 677 | -1.3180 |

4.2. Cable force checking

Load combination: according to the People's Republic of China industry standard Specifications for Design of Steel Structure and Timber Structure Highway Bridges and Culverts (JTJ025-86) [6], article 1.2.10, this bridge adopts load combination II: one or more of basic variable load (except flatbed trailers and tracked vehicles) in combination with one or more of the permanent loads and one or more of other variable load. The load combination calculated for this bridge is: bridge dead weight + belt conveyor load + wind load, and the combined coefficient is 1.25. The maximum cable force is \( F_{\text{max}} = 676.927 \text{kN} \) when the belt conveyor is running at full load.

According to the national standard of the People's Republic of China Steel Wire Rope for General Purpose (GB/T 20118-2006) [7]: the strength level is 1870MPa, the minimum breaking tension of 6x37 steel wire rope is 1740kn, and the minimum breaking tension sum of the steel wire rope is equal to the breaking tension of the steel wire rope \( x1.336 \) (steel core conversion coefficient).

Therefore, the minimum steel wire breaking tensions sum of the suspension cables of this cable bridge is: \( [H] = 1740 \times 1.336 = 2324.64 \text{(kN)} \), \( k = \frac{[H]}{H_i} = \frac{2324.64 \text{kN}}{676.927 \text{kN}} = 3.43 > 2.5 \).

According to the People's Republic of China's industry standard of Specifications for Design of Highway Suspension Bridge, the safety factor of the main cable shall not be less than 2.5 when the stress of the main cable is checked. Through calculation, it can be known that: \( k = 3.43 > 2.5 \), that is, the strength of the suspension cable (steel wire rope) of this steel cable bridge meets national standard requirements.

4.3. Structural displacement checking

As can be seen from the static displacement analysis results in Table 1, when the belt conveyor runs stably at full load, the maximum vertical displacement of the steel cable bridge is 1.318m, which is less than the value \( L/30 = 110/30 = 3.661 \text{m} \) (working sag) stipulated in the design, meeting the design requirements.
5. Conclusion
This steel cable bridge is a modern steel cable bridge suitable for erecting belt conveyor. It has the advantages of low construction cost, short engineering cycle, reliable structure and simple construction. Based on the nonlinear finite element analysis, the spatial calculation model of the cable bridge is established, and the main cable force and displacement of the steel cable bridge are checked. The obtained results and calculation process can provide theoretical basis and practical experience for the design of steel cable bridge for belt conveyor.

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