Design and analysis of full framing of arch ring in national highway reconstruction project

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Abstract: This paper takes the support system of a 25m span arch bridge in the reconstruction project of Yunnan National Highway 323 in China as the analysis object. Based on the Midas Civil bridge structure analysis software, the space discrete model of scaffold is set up to simulate analysis and calculation. Firstly, checking intensity and stiffness of the pole, I-steel and distribution beam of wooden keel, anti sliding checking the bearing capacity of foundation and abutment, the foundation bearing capacity and abutment slip resistance calculation; then the buckling analysis is carried out on the overall and local stability of the brackets. The results show that the strength and stiffness of each member of the support system meet the specification requirements and have a certain safety margin; the foundation pad shall be properly enlarged on the basis of the original design to meet the requirements of the counterforce of the support; the overall and local stability of the support can meet the construction requirements.

1. Background of Project

The bridge analyzed in this paper is located in Yunnan, China. It belongs to the part of the national highway 323 reconstruction project. This is a 3 hole 25m spandrel vierendeel reinforced concrete arch bridge, Cast-in-place construction with full frame is adopted. Full frame support adopts bowl-fastener scaffold as the support system of cast in place arch ring. The steel pipe support is mainly composed of vertical pole, cross bar, scissors support and diagonal brace. See fig.1-3.

Figure 1 Layout map of full scaffold
2. Computational model

Using the finite element analysis software of Midas Civil bridge structure, the space discrete model of scaffold is established (see fig.4), and the full frame is simulated. The main beam and support are simulated by beam element. The weight of beam by uniform load are arranged in the wooden keel, and the beam unit weight is 26 kN/m³. The design bracket adopts φ48.2mm×3.25mm bowl buckle scaffold, the material is Q235 steel; The wooden keel adopts 50mm×100mm pine; the flange beam adopts 100 flange beam type A.

According to the requirements of 《Technical Code for Safety of Steel Tubular Scaffold with Couplers in Construction》 (JGJ_130-2011) . The calculation of the scaffold shall be considered: the load and wind load generated by the constructor, the equipment load and the vibrating concrete.

(1) The following construction temporary load is obtained according to the site condition:
- Constructor, machinery: 2.5 kN/m²;
- Loading on wooden keel is uniform load: 2.5×28.5×15/101/15=0.71kN/m;
- Concrete vibrator: 2.0 kN/m²;
- Loading on wooden keel is uniform load: 2×28.5×15/101/15=0.56kN/m;
- Wind load: =0.7ω₀μ₀μ₁μ₂=0.7×0.3×1.14×1.2=0.287kN /m²;

ω₀—fundamental wind pressure; according to <load code for the design of building structures> is 0.3;
μ₀—exposure factor for Wind Pressure is 1.14;
μ₁—shape factor of Wind Load, full frame vertical pole (open) is 1.2.

(2) Combination of load

Consider the following main load calculation: ○ template, bracket and arch weight; ○ reinforced concrete structure gravity; ○ the constructor and construction materials, equipment and other load; ○ load caused by vibrating concrete; ○ wind load.
Table 1 Comparison Between Numerical and Experimental Results

| Load combinations | Calculation method | Description |
|--------------------|--------------------|-------------|
| Strength checking   | \(1.2 \times (1+2)+1.4 \times (3+4)\) | Without wind load |
| Stiffness check     | \(1 \times (1+2)+1 \times (3+4)\) | Including wind load |
| comb 1              | \(1 \times (1+2)+0.9 \times (3+4+5)\) | Combining wind load |
| Stiffness check     | \(1 \times 1+1 \times 2\) | Without wind load |
| Stability check     | \(1 \times 1+0.9 \times (2+5)\) | Including wind load |

3 The basic calculation

3.1 The strength calculation

(1) Vertical pole

The calculation results of the vertical pole are shown in fig.5, and the maximum combined stress is 90.8 Mpa (compressive stress), which is less than the allowable stress of 205 Mpa. The safety factor is 2.26.

Figure 5 Test results of vertical pole strength

(2) I-beam

The calculation results of the I-beam are shown in fig.6, and the maximum combined stress is 181.8 Mpa (compressive stress), which is less than the allowable stress of 205 Mpa. The safety factor is 1.13.
(3) square wood

The calculation results of the 50×100mm square wooden beam are shown in fig.7, and its maximum combined stress is 8.31MPa (compressive stress)<1.15×12MPa=13.8MPa, tensile stress is 7.77MPa>1.15×8.0=9.2MPa. Meet the requirements of the specification.

(4) template

According to the actual laying of the template, the bottom die is regarded as a continuous beam structure, and the concrete load directly on the bottom die. The bottom die is simplified as a three equal span continuous beam, which is equal to 25cm.

Load combination: $q = 1.2G + 1.4(Q1 + Q2) = 1.2 \times 22 + 1.4 \times (2.5 + 2) = 32.7kN/m$

1m elements of wide plywood

section: $W_{min} = 1000 \times 18^2/6 = 37500mm^3$; $I_{min} = 1000 \times 18 \times 18 \times 18/12 = 281250 \ mm^4$; $A_{min} = 1000 \times 15 = 15000mm^2$

From <Road bridge construction calculation manual>: The plywood allows for bending stress $[\sigma] = 25.0MPa$; Bending modulus $E = 6300MPa$; Allowable deflection $[f] = 250/400 = 0.625mm$

The maximum bending moment in the span:

$M = 0.08qL^2 = 0.08 \times 32.7 \times 250 \times 250 = 163500N.mm$

Intermediate pivot moment:

$M = 0.1qL^2 = 0.1 \times 32.7 \times 250 \times 250 = 204375N.mm$

$\sigma_{max} = M_{max} / W_{min} = 204375/37500 = 5.45MPa < [\sigma] = 25.0MPa$ Meet the requirement.

(5) Local force analysis
The axial force of the local diagonal and vertical bar is shown in fig. 8. The pressure of the left diagonal is 10.4 kN, and the right inclined bar is 4.2 kN, and the vertical bar is 8.4 kN. It can satisfy the maximum axial force requirement.

3.2 Stiffness checking

Maximum deflection of vertical pole 1.81 mm /1000 = 4.87 mm 1.81 mm /400 = 2.5 mm; steel I-beam 1.81 mm /400 = 2.5 mm; maximum deformation of wooden keel 1.80 mm /400 = 2.5 mm; maximum deformation of template f = 0.677 q l^4 /100 E I = 0.677 × 32.7 × 250^4 / (100 × 6300 × 281250) = 0.488 mm < 0.625 mm; all meet the requirements of design specifications.

(1) Checking computation of foundation bearing capacity

The calculation result of the maximum support reaction force is 41.8 kN at the height change of the vertical pole, the counterforce of the rest of the maximum support is 31 kN, and the foundation pad is 300 × 300 mm of C25 concrete block, the cushion is 100 mm. The contact area of concrete block and ground is 0.3 × 0.3 = 0.09 m^2

The foundation stress of vertical bar height changes is: 41800 / 90000 = 0.464 > 0.35 MPa, not meet the requirements. The area of padded block is 119429 mm^2, namely the contact area of the pad and ground is 350 × 350 mm to meet the requirements. Therefore, the advance in this area is 350 × 350 mm. The maximum value of foundation stress is: 31000 / 90000 = 0.34 > 0.35 MPa, meeting the requirements.

(2) Abutment anti sliding checking computations

friction coefficient f is 0.4. Through the following calculation to meet F_x < f × G, abutment slip will not occur.

S = 4 × 1 × 16.6 + 2.9 × 1.5 × 15 + (1.2 × 1 + 2 × 1/2 × 1.2 × (2.9 - 2 × 1)) × 15 = 132.8 + 65.25 + 34.2 = 232.25 m^2

G = 24 kN/m^3 × S = 24 kN/m^3 × 232.25 m^3 = 5574 kN

Figure 9 Support reaction
\[ F_x = 62.5 \times 16 = 1000 \text{kN} < f \times G = 0.4 \times 5574 = 2229.6 \text{kN} \]
\[ M = F_x \times h_1 - F_x \times h_2 = 1000 \times 3.5 - 52.5 \times 16 = 2660 \text{kN} \cdot \text{m} \]

(3) Against overturning checking

Horizontal thrust at arch feet of maximum bending moment:
\[ M = F_x \times h_1 - F_x \times h_2 = 1000 \times 3.5 - 52.5 \times 16 = 2660 \text{kN} \cdot \text{m} \]

Eccentricity:
\[ e_y = \frac{M}{P} = \frac{2660}{5774 + 840} = 0.403 \text{m} \]

\[ K = \frac{y}{e} = \frac{b/2}{0.403} = \frac{1.45}{0.403} = 3.59 > [K] = 1.5 \]

Resistive overturning stability coefficient calculation result is greater than 1.5, which meets the requirement.

4. Stability checking calculation

4.1 Integral stability checking calculation

In the design analysis, the overall stability of the support is studied with the load combination 3 and the load combination 4 as the basic load. 10 order buckling modes are taken.

| Modal | Load comb 3 | Load comb 4 | Modal | Load comb 3 | Load comb 4 |
|-------|-------------|-------------|-------|-------------|-------------|
| 1     | 8.255       | 9.194       | 6     | 10.755      | 11.955      |
| 2     | 8.752       | 9.736       | 7     | 11.152      | 12.394      |
| 3     | 9.183       | 10.218      | 8     | 11.191      | 12.439      |
| 4     | 9.482       | 10.535      | 9     | 11.398      | 12.665      |
| 5     | 10.329      | 11.495      | 10    | 11.537      | 12.816      |

The minimum eigenvalue of load combination 3 is 8.25. According to the stability specification, the first step instability is shown in the figure below: the minimum eigenvalue of load combination 4 is 9.19. It is concluded that the stability coefficient of the stents is 8.25, and according to the engineering practice, the elastic stability coefficient is greater than 4 to satisfy the requirements.

![Figure 10 The first step instability](image)
4.2 Local stability checking calculation

According to the Technical Code for Safety of Steel Tubular Scaffold with Couplers in Construction (JGJ_130-2011), the stability of the support bracket is checked. The design value of steel resistance, compression and bending strength is 205 MPa, elastic modulus 2.06 \times 10^5 \text{ MPa}, and other sections are shown in Table 3.

| Outside diameter/mm | Wall thickness/mm | Cross-sectional area (cm²) | Moment of inertia (cm⁴) | Section modulus (cm³) | Radius of gyration (cm) | Per meter long quality (kg/m) |
|---------------------|-------------------|-----------------------------|------------------------|-----------------------|------------------------|-----------------------------|
| 48.3                | 3.6               | 5.06                        | 12.71                  | 5.26                  | 1.59                   | 3.97                        |

The maximum member bar spacing of the bracket is 100cm, and the slenderness ratio of the member bar is \( \lambda = \frac{l_0}{i} = \frac{100}{1.59} = 62.9 \). Look up table: \( \phi = 0.806 \).

According to the maximum axial pressure \( N=41.7\text{kN} \) calculated by the model and the maximum axial force taking into account the comprehensive influence coefficient of 1.7, the maximum axial pressure after considering the influence coefficient is \( N=41.7 \times 1.7 = 70.89\text{kN} \). According to the stability calculation formula of the composite axial compression member, there are:

\[
\sigma = \frac{N}{A} = \frac{70.89 \times 10^3}{4.89 \times 10^2} = 145\text{MPa} \leq 0.806 \times 205 = 165.23\text{MPa}
\]

Therefore, the stability of the member bar meets the requirements.
And its radius-thickness ratio is less than 100, so the local stability of the rod meets the requirements.

\[
\frac{D}{t} = \frac{48.3}{3.25} = 14.86 < 100 \times \frac{235}{f_y} = 100
\]

5. Conclusion

Through the design of the 25m span arch ring support system of the national highway 323 reconstruction project, combined with Midas Civil for overall modeling analysis, the following conclusions are obtained:

1) The stress of the vertical rod, the horizontal bar, the scissors support, the I-beam and the wooden keel of the support system all meet the requirements of the specification and have a certain safety reserve.

2) The deflection of each member and element and the compression deformation of the vertical rod meet the requirements of the relevant codes, and the stiffness meets the requirements.

3) The foundation cushion block is changed at the height of the column. The size of the cushion block adopts 350mm×350mm, and the rest of the block blocks maintain the original design 300mm×300mm, and the bearing capacity of the foundation can meet the requirement.

4) The stability coefficient of the bracket is 8.25, which is greater than 4 of the engineering practice. The overall and local stability of the support can meet the construction requirements.

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