Calculation and Analysis of Through Concrete Filled Steel Tubular Tied Arch Bridge

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Abstract. In order to understand the stress of small through tied arch bridge. In this paper, the finite element simulation analysis of Lu Shanqu bridge is carried out in the completion stage by using MADIS / civil software, and the tie bars, arch ribs and suspenders of the superstructure are monitored. The results show that the axial force of the arch rib of this bridge is reduced by the balance of the tie rod, and the bending moment of the tie rod is greatly reduced by the action of the suspender. The stress characteristics of the bridge type are internal statically indeterminate and external statically indeterminate structure.

Keywords. Through concrete filled steel tube tied arch bridge; Tie Bar; Arch Rib; structure

1. Introduction
Through tied arch bridge is a kind of composite bridge combining arch and beam. The interior of the bridge is statically indeterminate and the exterior is statically indeterminate. Its remarkable feature is that the interaction between arch and beam through arch foot greatly reduces the bending moment borne by arch and the axial force borne by beam. The mechanical characteristics of arch compression and beam bending are brought into full play.

The bridge adopts the construction method of beam before arch. After the completion of the bridge, the focus of this paper is whether the alignment of the arch ring and the bending moment of the beam meet the design specifications. Taking lushanqu bridge as an example, this paper introduces the stress state of arch and beam in the completion stage.

2. Project Summary
The structural form of the bridge is a through concrete-filled steel tubular simply supported tied arch bridge with a calculated span of 80m. The rise span ratio is 1/5 and the calculated rise height is 16m. In order to improve the overall stiffness of the structure, the bridge deck adopts longitudinal and transverse beams and integral bridge deck system. The arch rib is fixedly connected with the stiffening longitudinal beam. The two arch ribs are provided with concrete-filled steel tubular wind bracing. The cross section of the wind bracing is circular, and the wind bracing steel pipe is not filled with concrete.

One suspender is set every 5m. The suspender adopts the form of single end tension, with a total of 14 suspenders. The tensioning end is set at the bottom of the longitudinal beam and the fixed end is set at the top of the arch rib.

The substructure of the bridge adopts a zigzag abutment, the thickness of the abutment body is 1m, the foundation is bored pile foundation, the thickness of the abutment cushion cap is preliminarily proposed to be 3M, and the pile foundation is designed with friction pile. Basin type rubber bearing
with high bearing capacity and good turning performance is adopted for the bridge bearing. The expansion joint adopts D80 expansion joint.

![Figure 1. Elevation.](image1)

![Figure 2. Cross section.](image2)

![Figure 3. Plan.](image3)

3. Finite Element Analysis Model

![Figure 4. Finite element analysis model.](image4)

4. Bridge Completion Status Detection Content

The bridge detects the stress of arch rib, tie rod and suspender in the completed state to ensure that the structure in the completed state is under absolute safety control. According to the actual state of the structure, the most unfavorable situation of bending moment and shear force of each member in the completion stage is obtained, and whether each member is in the stress state after the completion of the bridge is checked.

4.1. Internal Force Detection

When the bridge is completed, the bending moment and axial force of the arch rib, the bending moment and axial force of the tie rod and the axial force of the suspender are tested.
Figure 5. Arch bending moment diagram.

Figure 6. Arch axis diagram.

Figure 7. Tie bar bending moment diagram.

Figure 8. Tie bar axial force.

Figure 9. Hanger shaft diagram.
4.2. Deflection Detection

The deflection of arch rib and tie bar is detected, and whether it meets the requirements of design specifications is calculated through simulation analysis.

5. Test Results of Bridge Completion Status

5.1. Internal Force Test Results

The section of concrete-filled steel tubular arch rib is equivalent to beam column for checking calculation. The effective length of the equivalent beam column shall be 0.36s without hinged arch, and the force at both ends of the equivalent beam column shall be the bending moment and axial force at the L/4 (or 3L/4) section of the arch. Due to the symmetry of the structure, the most unfavorable internal force of L/4 section is equal to that of 3L/4 section. Therefore, only the most unfavorable internal force of L/4 section needs to be checked during the overall checking calculation of the structure.

Axial compression section resistance:

\[ N_D = \sum (N_0^i + N_1^i) = 2 \times 29301.91 + 2 \times 2462 = 63527.82kN \]

For maximum combination of axial forces:

\[ \phi \cdot \phi_e \cdot k_c \cdot k_p N_D = 0.831 \times 0.825 \times 0.8 \times 0.742 \times 63527.82 \]
\[ = 25853.11kN > \gamma_O N_s = 1.1 \times 18091.51 = 20791.66kN \]

Therefore, the stable bearing capacity meets the requirements.

While the tie bar longitudinal beam balances the horizontal thrust, it is also subject to the bending moment generated by the beam and suspender. Therefore, the tensile bearing capacity of the normal section, flexural bearing capacity of the normal section and shear bearing capacity of the inclined section of the tie bar are checked.

| Section position | Max / min | Bearing capacity limit state combination | Structural resistance | Checking results |
|------------------|-----------|-----------------------------------------|-----------------------|-----------------|
| End              | Max       | -8090.3295                              | 25516.0185            | Check calculation qualified |
|                  | min       | -11113.1848                             | 25516.0185            | Check calculation qualified |
| L/8              | Max       | 1623.7117                               | 15740.9467            | Check calculation qualified |
|                  | min       | -2032.4187                              | 20198.6573            | Check calculation qualified |
| L/4              | Max       | 736.3899                                | 15975.0600            | Check calculation qualified |
|                  | min       | -2494.1450                              | 20368.3365            | Check calculation qualified |
| 3L/8             | Max       | 3827.3776                               | 16573.1727            | Check calculation qualified |
|                  | min       | -2.3326                                 | 20819.8592            | Check calculation qualified |
| L/2              | Max       | 3691.5474                               | 16741.7523            | Check calculation qualified |
|                  | min       | -124.0382                               | 20953.1046            | Check calculation qualified |
Table 2. Calculation and checking results of flexural bearing capacity of normal section.

| Section position | Max / min | Bearing capacity limit state combination | Structural resistance | Checking results                      |
|------------------|-----------|---------------------------------------|----------------------|--------------------------------------|
| End              | Max       | -2365.5539                           | 149051.9011          | Check calculation qualified          |
|                  | min       | -3477.8345                           | 149051.9011          | Check calculation qualified          |
| L/8              | Max       | -782.7658                            | 89749.6430           | Check calculation qualified          |
|                  | min       | -1588.4749                           | 98349.4167           | Check calculation qualified          |
| L/4              | Max       | -5.3722                              | 89749.6430           | Check calculation qualified          |
|                  | min       | -708.3785                            | 89749.6430           | Check calculation qualified          |
| 3L/8             | Max       | 251.4853                             | 89749.6430           | Check calculation qualified          |
|                  | min       | -468.6064                            | 89749.6430           | Check calculation qualified          |
| L/2              | Max       | 459.0979                             | 89749.6430           | Check calculation qualified          |
|                  | min       | -279.5187                            | 89749.6430           | Check calculation qualified          |

The checking calculation of finished cable suspender of concrete-filled steel tubular tied arch bridge shall meet the following requirements: \( \sigma < [\sigma] = \frac{f_{pk}}{\alpha}, f_{pk} = \frac{1670}{3} = 556.67 MP \)

Table 3. Checking calculation of suspender bearing capacity.

| Boom No | Boom unit no | Stress calculation value | Stress limit |
|---------|--------------|---------------------------|--------------|
| 1(15)   | 79(125)      | 24.10                     | 556.67       |
| 2(16)   | 80(126)      | 30.24                     | 556.67       |
| 3(17)   | 81(127)      | 31.97                     | 556.67       |
| 4(18)   | 82(128)      | 32.41                     | 556.67       |
| 5(19)   | 83(129)      | 32.49                     | 556.67       |
| 6(20)   | 84(130)      | 32.47                     | 556.67       |
| 7(21)   | 85(131)      | 32.42                     | 556.67       |
| 8(22)   | 86(132)      | 32.42                     | 556.67       |
| 9(23)   | 87(133)      | 32.47                     | 556.67       |
| 10(24)  | 88(134)      | 32.49                     | 556.67       |
| 11(25)  | 89(135)      | 32.39                     | 556.67       |
| 12(26)  | 90(136)      | 31.92                     | 556.67       |
| 13(27)  | 91(137)      | 31.92                     | 556.67       |
| 14(28)  | 92(138)      | 24.01                     | 556.67       |

The stress under the most unfavorable combination of suspender endurance condition and bearing capacity limit state meets the requirements.
5.2. Deflection Calculation Results
Through calculation, the deflection of arch rib and tie bar of arch bridge meet the design requirements.

6. Conclusion
Taking Lushanqu Bridge as an example, this paper discusses the stress of the arch bridge in the completed state, and the conclusions are as follows:

(1) Through concrete tied arch bridge is a bridge with reasonable structure and giving full play to the mechanical characteristics of each component. Among them, it gives full play to the good compression characteristics of concrete and the bending characteristics of reinforcement. During the design, pay special attention to the rise span ratio of the bridge. If the span is too large, the dead weight load of the bridge will increase, so as to increase the stress of the arch rib and tie rod. If the span is too small, the mechanical characteristics of the combination of arch rib and tie rod will not be brought into full play In the construction process of the bridge, the stress of adjacent points of arch rib and beam tension is close to the theoretical value as a whole, and the average cross section of key points on the arch rib and beam is close to the theoretical value as a whole.

(2) In the completion stage, the arch rib mainly bears compressive stress. In the design, the reasonable arch axis of the arch ring should be obtained through simulation calculation, so as to reduce the bending moment borne by the arch ring as much as possible and give full play to the compressive characteristics of the arch bridge. The tie bar mainly bears the bending moment, and the joint action of suspender and arch rib reduces the bending moment of tie bar. In the completion stage, the suspender can be regarded as the support of the continuous beam bridge and act on the tie rod longitudinal beam, so as to reduce the bending moment of the tie rod.

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