

Mechanical Analysis of Prestressed Concrete Partially Cable-Stayed Bridge with Corrugated Steel Webs

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Abstract : The structure of C-bridge is prestressed concrete partially cable-stayed bridge with corrugated steel webs with a main span of 188m, and the span arrangement is 58m+118m+188m+108m, and the form of box-girder section is one-box four-rooms with inclined webs. In this paper, the finite element method is used to model C-bridge's structure and do analysis of construction stage and completed bridge stage, and the analysis is checked with the current corresponding regulatory of bridge design and construction. Checking results show that under the existing highway-I level loads, the main beam's carrying capacity, stress and crack resistance meet the regulatory requirements. Meanwhile, the adjustment process of cables for the partially cable-stayed bridge is narrated. The checking process also reflects the mechanical properties of corrugated steel webs.

Introduction

The prestressed concrete composite box-girder bridge with corrugated steel webs was a new type of bridge emerged in the 1980s. It was a new type of steel-concrete composite structure in which the traditional concrete webs were replaced by corrugated steel webs in the prestressed concrete box girder. Compared with the conventional structure, the advantages of it were as follows[1]. The dead load of corrugated steel webs was lighter, so the amount of substructure works could be reduced, thus to reduce the total project cost. The corrugated steel webs could't resist axial force, so the prestress could be applied to the concrete flange plate effectively, thus improving the efficiency of prestressing. Besides, since the concrete webs were not needed anymore, large number of templates, brackets and concreting works could be reduced, thus facilitating the construction and shortening the construction period. More importantly, the corrugated steel webs effectively solved the problem of diagonal cracks in the traditional prestressed concrete box-girder webs. As the research on the prestressed concrete composite box-girder with corrugated steel webs is deepening and the application of it becomes mature gradually, this structure will get a wide range of applications in the bridge engineering in our country.

Engineering Situation

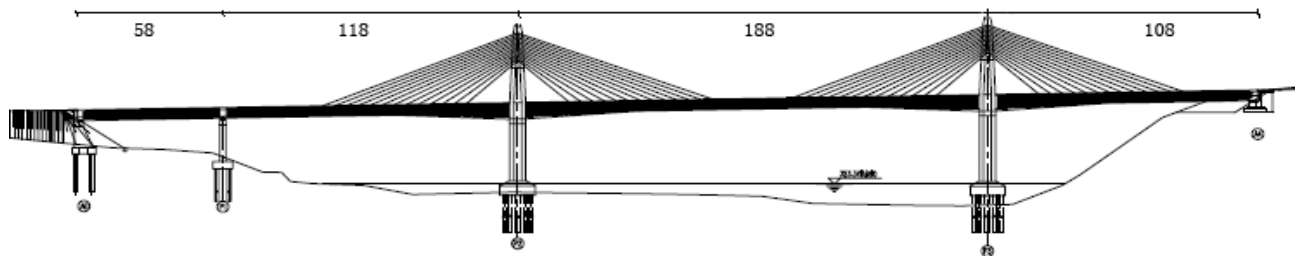


Fig. 1 The structure layout of C-bridge (Unit: m)

C-bridge is a prestressed concrete composite box-girder bridge with corrugated steel webs with a span arrangement of 58m+118m+188m+108m, as shown in Fig. 1. The main bridge box-girders use C55, main towers and pier bodies use C50, and bearing platforms use C40. The main beam uses full prestressing system in three-ways of longitudinal, transverse and vertical directions. The construction method of the main beam is cantilever erection using the hanging basket. This paper will do various aspects of checks to C-bridge based on China's current bridge design and construction regulatory.

Finite Element Simulation

Finite Element Analysis Model. The superstructure of C-bridge uses finite element calculation software for structural analysis, and the finite element model is shown in Fig. 2.

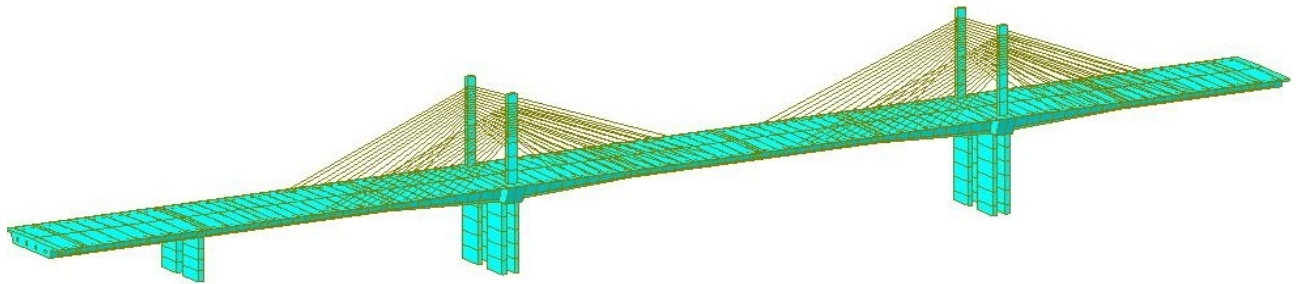


Fig. 2 Finite element model of C-bridge

Second Stage Dead Load. Deck: $g_1=52\text{kN/m}$, sidewalk board: $g_2=7.35\text{kN/m}$, anticollision railings: $g_3=0.65\text{kN/m}$, so $g=g_1+g_2+g_3=60\text{kN/m}$.

Impact Coefficient. The fundamental frequency of bridge reflects the structure's size, type, construction materials and other dynamic features, and it directly reflects the relationship between the impact coefficient and bridge structure. Regardless of whether the bridge materials, the structure type, size and span are different, as long as the fundamental frequency of the bridge structure is in the same, we can obtain substantially same impact coefficient under same vehicle load conditions.

After making dynamic characteristics analysis, we obtain the fundamental frequency of C-bridge is: $f=0.4748\text{Hz}$. According to the regulatory [2], the impact coefficient μ can be calculated as follows:

When $f < 1.5\text{Hz}$, $\mu=0.05$.

(1)

When $1.5\text{Hz} \leq f \leq 14\text{Hz}$, $\mu=0.1767\ln f-0.0157$.

(2)

When $f > 14\text{Hz}$, $\mu=0.45$.

(3)

In which f is the fundamental frequency (Hz). According to calculation, the vehicle load impact coefficient of C-bridge is 0.05.

Analysis Results

Flexural Bearing Capacity of Normal Section. Envelope of bending moment in ultimate limit state is shown in Fig. 3.

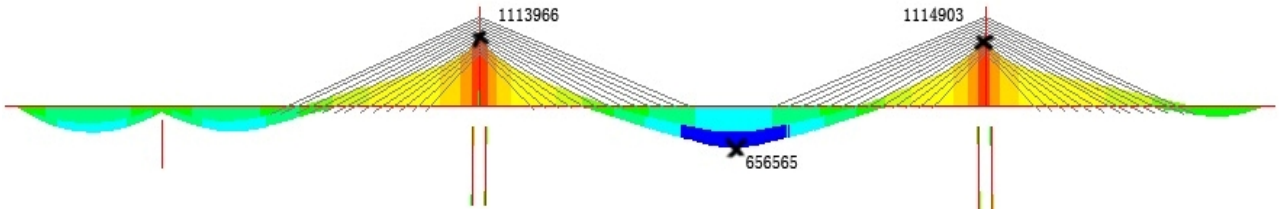


Fig. 3 Envelope of bending moment in ultimate limit state (Unit: kN·m)

Take the cross-section of the middle of the span, for example, and calculate its flexural capacity, and its value is $M_u = 1.00 \times 10^6$ kN·m. So, $\gamma_0 M_d = 6.57 \times 10^5$ kN·m $\square M_u = 1.00 \times 10^6$ kN·m, the cross-section of the middle of the span meets the requirement of bending in ultimate limit state. Using the same calculation method, it can be obtained that the fulcrum section also meets the requirement of bending in ultimate limit state.

Shear Carrying Capacity of Diagonal Section. Corrugated steel webs are generally made with coiled or sheet materials, and its longitudinal apparent elastic modulus is very small, so basically it can not bear the axial pressure from the longitudinal direction of the bridge. Besides, the vertical pressure on the corrugated steel plate from the roof and floor of the box-girder is also small, so the shear force is almost entirely beared by the corrugated steel plate, and the interaction between bending moment and shear force doesn't occur. So the bridge has no need to calculate the diagonal shear strength.

Calculation of Normal Section Crack Resistance. The maximum stress envelope of the sections in the serviceability limit state is shown in Fig. 4.

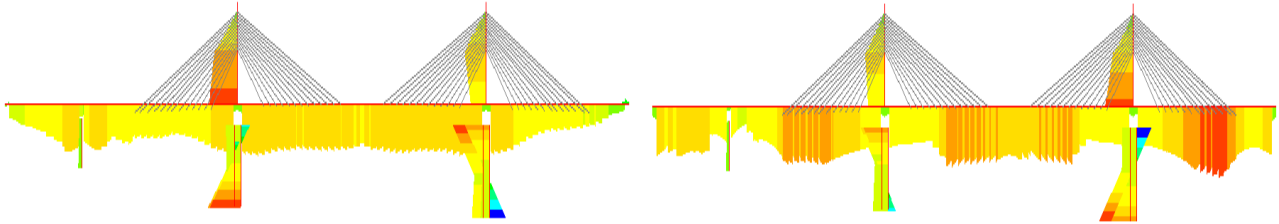


Fig. 4 The sections' maximum stress envelope in the serviceability limit state in the top and bottom flange (Unit: MPa)

The figure shows that the sections are all under compression and there is no tensile stress, so it can meets the requirement of crack resistance check.

Calculation of Diagonal Section Crack Resistance. The most unfavorable section to the diagonal section crack resistance is where both the bending moment and shear force are large. In concrete composite beam with corrugated steel webs, it is generally assumed that the top and bottom flange bear all the bending moment, and corrugated steel webs bear all the shear force, and the interaction between bending moment and shear force doesn't occur. So there is no need to do the calculation of diagonal section crack resistance.

Normal Stress of Normal Section in Using Stage. The normal stress of the normal section of the main beam is shown in Fig. 5.

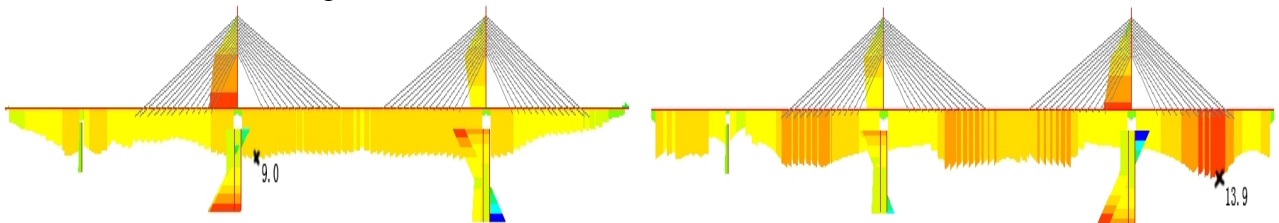


Fig. 5 The normal stress of section in using stage in the top and bottom flange (Unit: MPa)

As shown in Fig. 5, the maximum stress is 13.9MPa, and the limit value is $0.5f_{ck} = 17.75$ MPa. So it could satisfy the requirement of the regulatory [3].

Calculation of Stress in Construction Stage. The maximum compressive stress of section in construction stage is shown in Fig. 6.

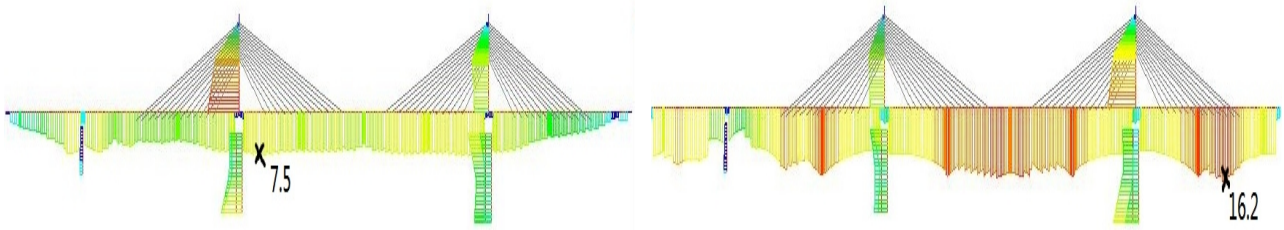


Fig. 6 The compressive stress of section in construction stage in top and bottom flange (Unit: MPa)

As shown in Fig. 6, the maximum compressive stress is $\sigma_{cc}^t = 16.2 \text{ MPa} < 0.7f_{ck}' = 24.85 \text{ MPa}$. So it could satisfy the requirement of the regulatory [3].

The maximum tensile stress of section in construction stage is shown in Fig. 7.

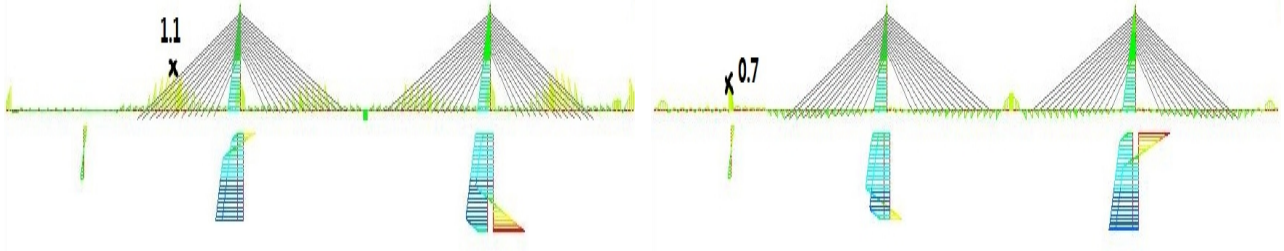


Fig. 7 The tensile stress of section in construction stage in top and bottom flange (Unit: MPa)

As shown in Fig. 7, the maximum tensile stress is $\sigma_{ct}^t = 1.1 \text{ MPa} < 0.7f_{tk}' = 1.918 \text{ MPa}$. It is enough to configure some longitudinal reinforcement with the reinforcement ratio not less than 0.2%.

Cables adjustment process for partially cable-stayed bridge. During the construction process of partially cable-stayed bridge, initial tensile force is firstly inflicted on the cables to a certain extent to balance the dead load of the structure. In order to improve the strained condition of girders, towers, cables and bearings of cable-stayed bridge after construction, after tensioning the box-girder prestressing tendons in vitro of the bridge, the cable forces are adjusted successively to the design values in orders from the tower to the middle span. The initial tensioning forces and adjusted values of C-bridge cables are shown in Table 1.

Table 1 Values of C-bridge cables

No.	Section component	Matched anchorage	Initial tensioning forces	Adjusted values
			(kN)	(kN)
1	37 – $f^s 15.2$	OVMAT-37	2400	4000
2			2500	4000
3			2600	4000
4			2700	4000
5			2800	4000
6	43 – $f^s 15.2$	OVMAT-43	3500	4300
7			3600	4300
8			3700	4300
9			3800	4300
10			4550	4700
11			4600	4700
12			4650	4700
13			4700	4700

NOTE: A total of eight rows of 104 cables are in C-bridge, and cable number increases with its distance from the tower. Table 1 shows the cable tensioning forces of a single row, and the change rule of cable values for the remaining seven rows is just the same as it is in Table 1.

Conclusions

Checking conclusions of the superstructure of C-bridge are as follows:

In the ultimate limit state, the flexural bearing capacity could satisfy requirements of regulatory.

In the serviceability limit state, all the sections are under compression.

In using stage, the maximum stress is 13.9MPa, which is less than the limit value 17.75MPa.

In construction stage, the maximum compressive stress is 16.2MPa, which is less than the limit value 24.85MPa, and the maximum tensile stress is 1.1MPa, which is less than the limit value 1.918MPa.

Acknowledgements

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