Mechanical Performance Analysis of Prestressed Concrete Composite Box Girder Bridge with Corrugated Steel Webs under RW Cantilever Construction

Zhuchang Jiang, Hongliang Cao and Yongsheng Yin*
Shandong Expressway Gaoguang Highway Co., Ltd, Binzhou, China.

*Corresponding author e-mail: 1741567258@qq.com

Abstract. As a new type of steel-concrete composite bridge, PC composite box Girder Bridge with corrugated steel webs has been rapidly developed in China in recent years. With the deepening of research, a new type of construction technology - RW cantilever construction began to be applied to the construction of such bridges. This paper first introduces the general steps of RW cantilever construction and the advantages compared with traditional cantilever construction. Then, take a continuous rigid frame bridge with corrugated steel webs under RW cantilever construction as an example, and build its finite element model. The crack resistance and compressive stress of the concrete and the shear stress of the corrugated steel web were checked to meet the requirements of the specification, and the feasibility of the construction method was verified.

1. Introduction
In PC composite box girder bridge with corrugated steel webs, the top and bottom flanges are reinforced concrete, the web is corrugated steel plate, and prestressed system is a combination of internal prestressing and external prestressing [1]. The overall structure is shown in Fig. 1. Compared with the traditional PC box girder bridge, PC composite box girder bridge with corrugated steel webs has absolute advantages in reducing the structural weight, improving the prestressing efficiency and speeding up the construction progress [2].

Figure 1. Overall structure of PC composite box girder with corrugated steel webs

With the continuous research and application of PC composite box girder bridge with corrugated steel webs, the construction method is gradually enriched and matured. Combining with the bridges with
corrugated steel webs built and under construction in China, the construction methods are summarized and analyzed. It can be seen that in the construction of such bridges, in addition to the same construction methods as traditional concrete bridges, a new type of construction technology - RW cantilever construction has also begun to be gradually used [3].

During RW cantilever construction process, the corrugated steel web is the main load-bearing member and bears the construction load such as the hanging basket with the upper and lower steel plates. The top flange and bottom flange of concrete and corrugated steel web in the same segment are staggered, that is, the top flange of N-1 segment, the bottom flange of N segment and the corrugated steel web of N+1 segment are divided into three independent construction faces, as shown in Fig. 2 [4].

Figure 2. RW cantilever construction process

The general steps of the typical section of RW cantilever construction are as follows:
(1) Move the hanging basket to the N segment, and the bottom template is in place;
(2) Install regular reinforcement in the bottom flange of N segment and the top flange of N segment;
(3) Firstly, pour the bottom flange of N segment, and then pour the top flange of N-1 segment;
(4) Cure concrete, and lift corrugated steel web of N+1 segment;
(5) Tension the longitudinal prestressing of N-1 segment and the transverse prestressing of N-2 segment after the concrete strength meets the requirements;
(6) Move the hanging basket forward and pour the concrete of next section.

Compared with traditional cantilever construction, RW cantilever construction has many advantages, such as: the operation of the top and bottom flanges is carried out at the same time, the construction work surface is more open, and the construction period can be shortened effectively; the hanging basket used for RW cantilever construction is a simple support structure, the weight is 1/3~1/2 lighter than the traditional hanging basket, and the economic effect is remarkable; the hanging basket used for RW cantilever construction does not need the rear anchor, and the walking is safer and smoother than the traditional hanging basket [5].

In this paper, a continuous rigid frame bridge with corrugated steel webs under RW cantilever construction is used as the engineering background, and the finite element model of full bridge is established to simulate the process of RW cantilever construction, then the bridge structure is checked to verify the feasibility of the construction process.

2. Project overview
A bridge is a continuous rigid frame bridge with corrugated steel webs, and the span is arranged as (72+130+72) m (Fig. 3). The main beam adopts single box single room section, the top of the box girder is 11.75m wide, and the bottom is 7m wide; the height of the box girder at the mid-span is 3.5m, the height of the box girder at the top of pier is 7.5m, and the beam height is changed by a parabola of 1.8 times; the thickness of the bottom of the box girder is changed from 120cm in the root section to 30cm in the mid-span section, which varies by a parabola of 1.8 times; the thickness of the top of the box girder is 30cm, and that at the top of pier is thickened to 1.3m. The corrugated steel web adopts Q355NHC steel, the thickness of the steel plate is 14~24mm, the wavelength is 1.6m, the wave height
is 0.22m, the horizontal folding angle is 30.7°, and the bending inner diameter R is 15t (t is the thickness of the corrugated steel web).

Figure 3. Bridge span layout (unit: m)

3. Finite element analysis

3.1. Model establishment
In this paper, MIDAS/Civil is used for modeling calculation. The main beam is simulated by space beam unit and the whole bridge has 100 units and 107 nodes. The construction stage is divided according to the structural characteristics and the cantilever construction process. There are 69 construction stages. The definition of each construction stage is realized in the MIDAS/Civil by activating and deactivating the structural group, the boundary group and the load group. The finite element model is shown in Fig. 4.

Figure 4. The finite element model of main bridge

3.2. Calculation results
Normal section crack resistance checking of concrete under serviceability limit state. Under serviceability limit state, the normal section stress of top and bottom flanges of the box girder is shown in Fig. 5 and Fig. 6, when short-term effect combination is adopted. It can be seen from the figures that under short-term effect combination, except for the small tensile stress at the edge of the top flange near the top of the pier, the edges of the top and bottom flanges are all under pressure. Therefore, the normal section crack resistance meets the requirements.

Figure 5. Stress of top flange of box girder under short-term effect combination (unit: MPa)
3.2.1. Compressive stress checking of concrete under serviceability limit state. Under serviceability limit state, the normal section stress of top and bottom flanges of the box girder is shown in Fig. 7 and Fig. 8, when standard effect combination is adopted. It can be seen from the figures that under standard effect combination, the maximum compressive stress of concrete is 16.46 MPa, and the specification limit is $0.5f_{ck}=17.75$ MPa. Therefore, the compressive stress of concrete meets the requirements.

3.2.2. Shear stress checking of corrugated steel web under ultimate limit state. The shear stress of corrugated steel web mainly includes bending shear stress and free torsional shear stress, which should conform to the formula (1) [6]:

$$\gamma_0(\tau_{md} + \tau_{td}) \leq f_v$$  \hspace{1cm} (1)$$

Where: $\gamma_0$ - Structural importance coefficient;  
$\tau_{md}$ - Bending shear stress;  
$\tau_{td}$ - Free torsional shear stress;  
$f_v$ - Design value of shear strength.

It can be seen from the box girder theory that the torsional shear stress is negligible compared to the bending shear stress. Under ultimate limit state, the bending shear stress is calculated as formula (2) [6]:

$$\tau_{md} = \frac{V_d - V_p}{t_w h_w}$$  \hspace{1cm} (2)$$

Where: $V_d$ - Design value of vertical shear;  
$V_p$ - Design value of prestressed vertical component;  
$t_w$ - Thickness of corrugated steel web;
**$h_w$** - Height of corrugated steel web.

**Figure 9.** Shear stress of corrugated steel web under ultimate limit state

The bending shear stress of corrugated steel web is shown in Fig. 9. It can be seen from the figure that under ultimate limit state, the value of the bending shear stress at each node is smaller than the design value of the shear strength at the corresponding node, and the maximum value is 158.5 MPa. Therefore, shear stress of corrugated steel web meets the requirements.

4. **Conclusion**

(1) The PC composite box girder bridge with corrugated steel webs under RW cantilever construction was simulated and analyzed by finite element software. Then, normal section crack resistance checking and compressive stress checking of concrete under serviceability limit state and shear stress checking of corrugated steel web under ultimate limit state were carried out. And the results were all satisfactory, that is, the feasibility of the construction method was verified.

(2) Choosing RW cantilever construction to build PC composite box girder bridge with corrugated steel webs can effectively shorten the construction period and improve the construction efficiency. It is a new and efficient construction method, which is worthy of being promoted in the construction of the same type of bridge.

**References**

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