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IMPACTS OF PRE-STRESS LOSS ON THE LONG-TERM DEFLECTION FOR LONG-SPAN PC CONTINUOUS GIRDER BRIDGE

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In order to analyze the impacts of pre-stress loss on the long-term deflection for long-span PC continuous girder bridges, this paper presents a numerical analysis using the finite element analysis software MIDAS/Civil based on a long-span PC continuous box-section girder bridge in Shijiazhuang. Once the 3-D finite element model was established, the influences of different pre-stress loss levels and locations were analyzed in a numerical simulation. Pre-stress loss is often the key reason for long-term deflection in long-span PC continuous girder bridges, so we can estimate the development of deflection by considering these factors during the operation.

Keywords: Finite element model, Box-section girder bridge, Shrinkage, Creep, Deflection development.

1 INTRODUCTION

Consider an example of a PC continuous box-section girder bridge, the Balduinstein Bridge in Germany, with a main span of 62 m (Xie et al. 2007). While the bridge's deformation is stable, it is not perpetual, as the deflection increases by a uncertain rate with a lot of cracks (Wang 2008). The effects of pre-stress systems play a key role on the long-term deflection for girder bridges. The industry generally thinks this is due to excessive pre-stress loss, insufficient box-section girder bridge rigidity, the lack of standardization construction, concrete shrinkage and creep, and so on (Sui & Xie 2004). We consider a long-span pre-stressed concrete continuous box-section girder bridge as an example in this paper, establishing a finite element model, and then analyzing the relationship between the pre-stress loss and the long-term deflection of bridges.

2 FINITE ELEMENT MODEL SETTING

As a continuous box-section girder bridge whose span is 60 m + 90 m + 60 m, the long-term deflection variation law under the different pre-stress-loss states during the operation is analyzed.

2.1 Bridge Profile

The selected PC continuous box-section girder bridge is pre-stressed in a longitudinal direction, and has a single box and a single room section. Its roof is 11.5 m wide, the floor is 5.8 m wide, and it surface is set at a 2% one-way cross slope. The box-section girder above the pier is 5 m high, and the middle span and cast section beam is 2.2 m high. The girder height and floor thickness are both changed according to a 1.8 times parabola. The longitudinal pre-stressed system used a high-strength and low-relaxation steel strand, $f_{pk} = 1\,860\,\text{MPa}$, $E_p = 1.95 \times 10^5$ MPa . The pre-stressed duct used a plastic corrugated pore and strand-tapered anchorage. Longitudinal pre-stressed steel beams were formed with roof steel beams, floor steel beams, and bending beams. The width quota met the GB/T5224-2003 standard. The bending beams used $\phi^s 15.2\text{-}15$ steel, the roof steel beams used $\phi^s 15.2\text{-}5$ steel, and the floor steels beams used $\phi^s 15.2\text{-}9$ steel. Figure 1 and Figure 2 are the main span girder and pier girder section.

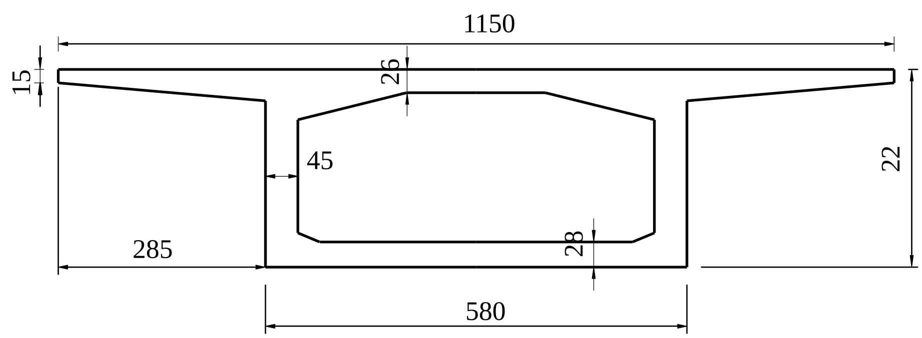

Figure 1. Cross section of the box-section girder bridge in the mid-span (Unit: cm).

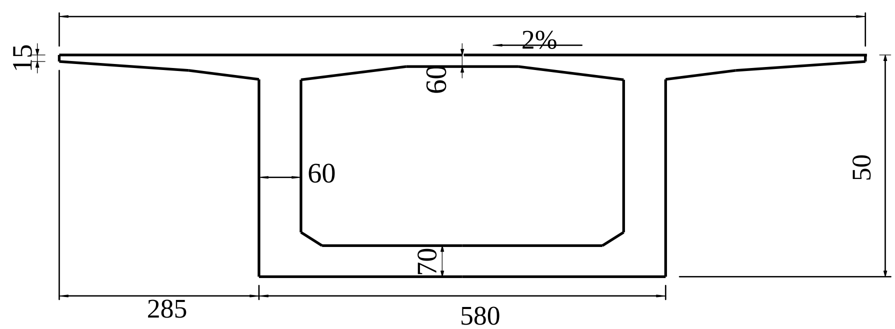

Figure 2. Cross section of the box-section girder bridge just above the pier (Unit: cm).

2.2 Calculation Model

According to the standards, we considered the main factors that cause the instant loss of pre-stress in the calculation, such as sliding anchoring device, the friction between the steel beam and channel, and the concrete elastic deformation.

The established FE model is as shown in Figure 3. The FE model has 77 nodes, and 72 units. It is divided into 17 stages of construction, and there are a total of 152 pre-stressed tendon elements. The details of pre-stressed tendon layout are shown in Figure 4 to Figure 6.

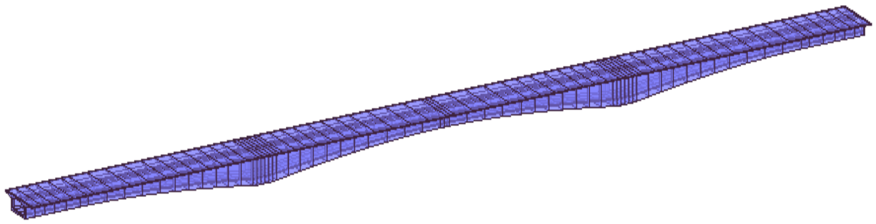

Figure 3. FE model of the continuous box-section girder bridge.

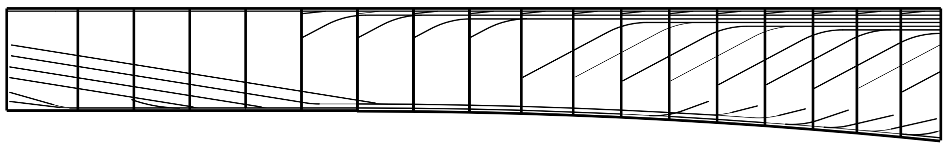

Figure 4. Details of stress tendons of the side span (unit 1-18).

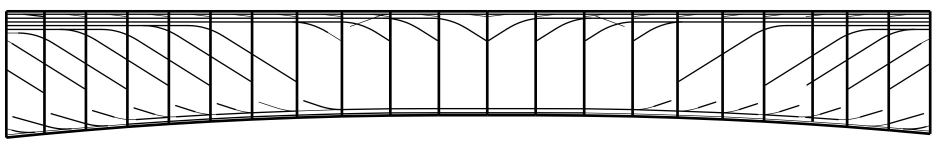

Figure 5. Details of stress tendons of the middle span (unit 25-48).

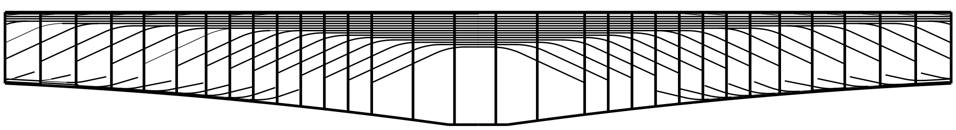

Figure 6. Details of statically determinate stress tendons (unit 7-35).

3 INFLUENCE OF PRE-STRESS LOSS ON LONG-TERM DEFLECTION

The main cause of the PC continuous girder bridge vertical deflection after bridge construction was that both dead and live load effects on the bridge cause downward displacement, while the effects of pre-stressed steel beam to girder bridge produces upward displacement, which is called inverted camber. From analyzing the bridge from total stress conditions, we can obtain the total deformation as shown:

$$\delta = \left(-\delta_p + \delta_d\right)\left[1+\Phi\left(t,t_0\right)\right] + \delta_L \tag{1}$$

Where δ is total deformation; δ_d is structural deformation caused by constant load, δ_L is structural deformation caused by live load, δ_p is structural deformation caused by pre-stress effect, and $\Phi\left(t,t_0\right)$ is loading age called t_0.

The total deflection increased continuously, which caused downward deflection deformation called $\delta_d\left[1+\Phi\left(t,t_0\right)\right]$ while upward deformation $\delta_p\left[1+\Phi\left(t,t_0\right)\right]$ decreased continuously. Because the effective pre-stress was normally more inadequate than the predicted value, it was affected by various factors during the operation process and would decrease further with time. Thus the major bridge deflection would inevitably increase in the post creep while pre-stress continued its loss. The lack of structural effective pre-stress became the key factor behind middle-span deflection (Yang et al 2010).

3.1 Effects of Pre-Stress Loss in Different Locations on Long-Term Deflection

The main factor that leads to middle-bridge span deflection is longitudinal pre-stress loss. In order to study the rule of how longitudinal pre-stress loss influences middle-span deflection, we simulated on the roof and floor an effective pre-stress at a design value of 90%, 80%, and 70% to analyze the biggest deflection in the pre-stress-loss case. The simulated results are shown in Figure 7 and Figure 8. From this we can get the following conclusions:

(1) The roof and floor pre-stress loss will affect the middle-span long-term deflection development. While the pre-stress loss increases, the rate of middle-span deflection growth increases.

(2) The roof longitudinal pre-stress loss is more effective than the floor pre-stress loss on the bridge's middle-span deflection.

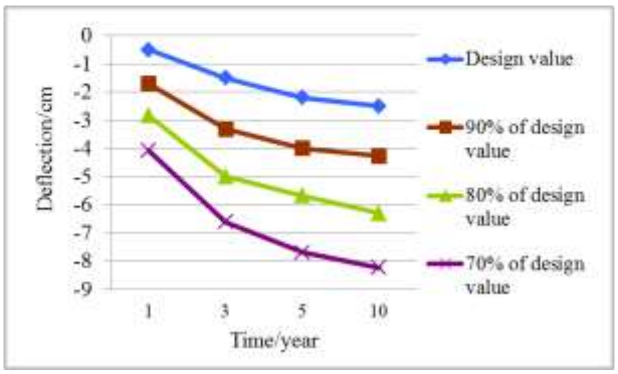

Figure 7. Effects on the mid-span deflection from the pre-stress loss of the roof slab.

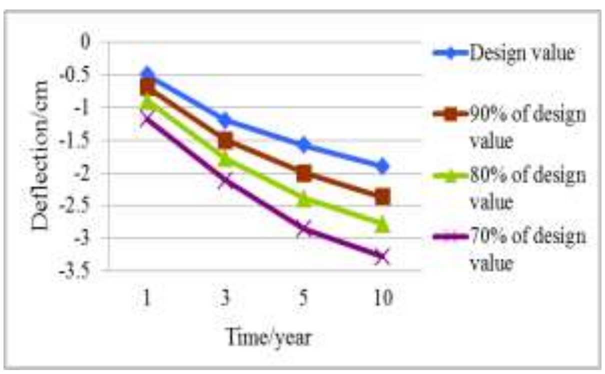

Figure 8. Effects on the mid-span deflection from the pre-stress loss of the bottom slab.

3.2 Effects of Different Pre-Stress Loss Models on the Long-Term Deflection

In order to further study the influence of pre-stress loss on bridge under creep after 10 years, we analyzed the following three cases: Case 1: Without pre-stress loss. Case 2: Including the shrinkage and creep of concrete without pre-stress loss. Case 3: Including the shrinkage and creep of concrete and pre-stress loss. Figure 9 plots the calculated results. According to Figure 9, the third case has the biggest influence on the long-term deflection. While without the shrinkage and creep of concrete and pre-stress loss, the deflection of the mid-span is 2.2 cm. When including the shrinkage and creep of concrete but not the pre-stress loss, the deflection is 3.9 cm. When taking into account all the shrinkage and creep of concrete and pre-stress loss, the deflection is 8.29 cm after 10 years.

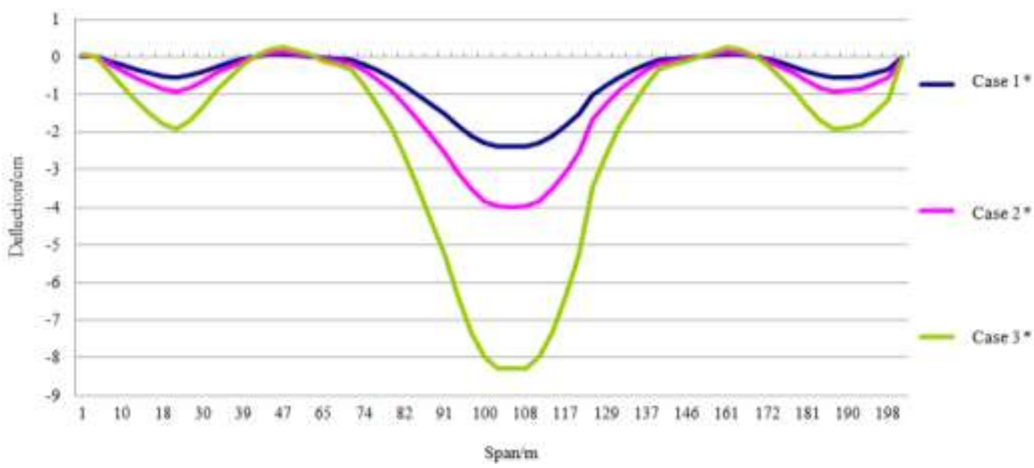

Figure 9. Deflection of 3-span continuous girder bridge for different condition combinations.

4 CONCLUSIONS

The following conclusions are drawn from the simulation studies:

(1) The main span deflection of long-span PC continuous girder bridge is long-term growth, and its growth rate is uncertain.

(2) The roof longitudinal pre-stress loss has more effection on the main span deflection than the floor longitudinal pre-stress loss.

(3) The shrinkage and creep of concrete and the pre-stress-loss cause long-term deflection for long-span PC continuous girder bridge, so we can estimate the developed deflection by considering these factors in the opration.

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