The Distortion Effect of Thin-walled Wide Hollow PC Beam Under Bridge Deck Pavement

Houxuan Wu[1], Juanyan Li[2] and Hanbin Yi[3]
[1]*Jiangxi Ganyue Expressway CO.,LTD,, Nanchang, Jiangxi, China*
[2]Jiangxi transportation vocational technical institute, *Nanchang,Jiangxi, China*
[3]Jiangxi transportation institute, *Nanchang, Jiangxi, China*

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Abstract: The distortion stress of thin wall hollow slab is solved by using elastic foundation beam analogy method and finite element method. The influence of the structure distortion effect on 10cm thick concrete pavement was considered. The results show that the numerical solution and the finite element method are consistent, and the finite element method is simpler and more efficient. The transverse tensile stress of calculation point 1 and 2 decreased by 13.2% and 13.6% respectively when considering the effect of deck pavement. The distortion effect causes a large transverse tensile stress on the bottom plate.

1 INTRODUCTION

Thin-walled PC wide open hollow plate has been widely used in highway Bridges in the 1990s due to its characteristics such as large hollowing-out rate, thick wall thickness, structural economy and light weight. Due to the thin wall thickness of hollow wall, the effect of transverse tensile stress caused by the distortion cannot be ignored. At present, the scholars all over the world have focused on the study of distortion effect mainly in the steel box girder. The theoretical calculation methods mainly include the method of substitute the beam, the Kupfer method and the generalized coordinate method. In this paper, an example of thin-walled PC wide slabs is given based on an expressway bridge, the elastic foundation beam analogy method and the finite element method were used respectively to calculate the distortion of the hollow slab stress, the torsional effect and the influence of Poisson effect on structure horizontal stress is analysed. In addition, the influence of concrete pavement on the stress of structural distortion is considered.

The superstructure of bridge is constructed of a 20-meter PC wide open hollow slab and a total length of 9.1 km. There are 8 hollow plates in each transverse section, with height of 0.9 m, width 1.55 m, bottom and top plate 10cm thick, and the web thickness is 11cm, as shown in Fig.1. Each board has 15 ASTMA416-90a270 (0.6 inch diameter) steel hinge lines.

The lateral layout of the deck is: 0.5m guardrail +11.5m carriageway +0.5m guardrail +2m central divider with +0.5m guardrail +11.5m carriageway +0.5m guardrail (total 27m). Design load of the bridge: car - super 20 level; Trailer - 120; the crowd - 3.5 KN/m^2.

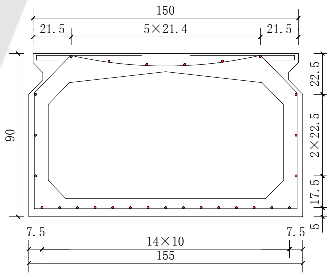

Figure 1: the transverse section of thin wall hollow slab (unit: cm)

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2 THE CALCULATION OF THE LATERAL FORCE OF DISTORTION

2.1 The calculation of torsional load of single hollow plate

The transverse distribution coefficient of the load of hollow slab is calculated using the hinged plate method, the influence line of torque's horizontal distribution of 1-4 beam is shown in Fig. 2.

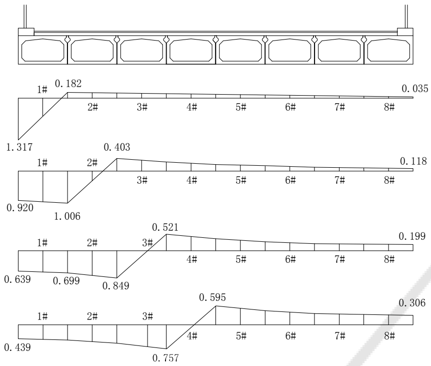


Figure 2: the influence line of torque's horizontal distribution

The influence line is loaded and calculated, and the results show that the horizontal distribution coefficients of the 4# hollow plates with the load of trailer-120 load and car-20 load are the largest, and the results are listed in table 1. According to the cross-medium torque influence line and load lateral distribution coefficient, the torque of 4# hollow slab is obtained. Then the torsion and distortion load are solved, as shown in Fig. 3.

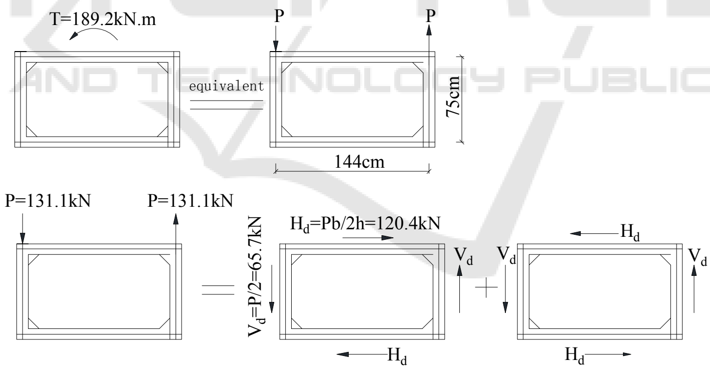


Figure 3: the distortion load of wide hollow plate

Table 1 The torque horizontal distribution coefficient of No 1-4 hollow plate

Load type	1# hollow slab	2# hollow slab	3# hollow slab	4# hollow slab
car-20	0.300	0.643	0.696	0.852
trailer-120	0.165	0.312	0.545	0.622

2.2 Analytical method

The lateral internal force generated under the deformation load is calculated based on the beam ratio method of elastic foundation. The calculation steps are as follows:

$$EI_b\omega^{IV} + K\omega = V_d \qquad (1)$$

There into:

$$EI_b = EJ_c \cdot \frac{3+2(\overline{a_0}+\overline{a_\mu})+\overline{a_0}\cdot\overline{a_\mu}}{6+\overline{a_0}+\overline{a_\mu}} \qquad (2)$$

$$K = \frac{96EI_c}{b^2h}\cdot\frac{1}{1+\dfrac{2\dfrac{b}{h}+3\dfrac{I_0+I_\mu}{I_c}}{\dfrac{I_0+I_\mu}{I_c}+6\dfrac{I_\mu\cdot I_0}{I_c^2}\cdot\dfrac{b}{h}}} \qquad (3)$$

According to the dimensions shown in Fig. 4, the symbols in the above formula are explained.

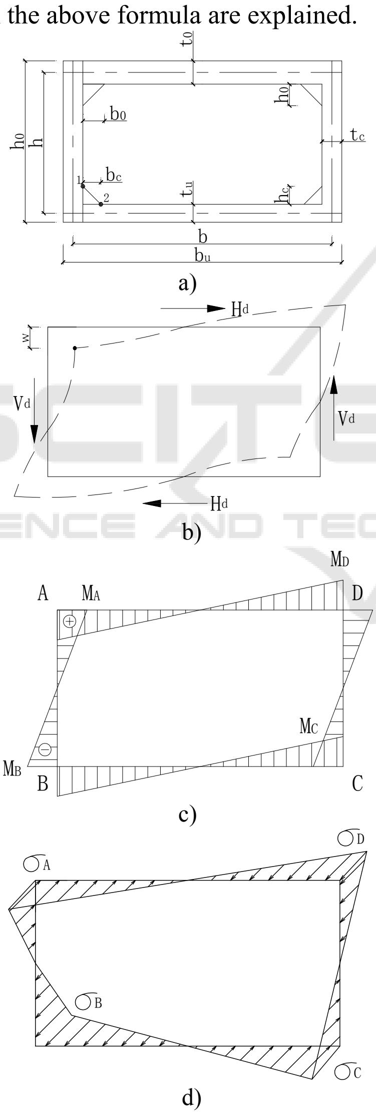


Figure 4: Distortion deformation, lateral bending moment and warping stress diagram

$$\overline{a_0} = (\frac{b_0}{b})\frac{bt_0}{ht_c}\ ;\quad \overline{a_\mu} = (\frac{b_\mu}{b})\frac{bt_\mu}{ht_c} \qquad (4)$$

$$I_i = \frac{t_i^3}{12(1-\mu^2)} \quad i=(0,\ \mu,\ c) \qquad (5)$$

The above varieties: E , μ are the elastic modulus and Poisson ratio respectively, K is the rigidity of the anti-distortion frame, ω is the vertical deflection of the distortion load, V_d , H_d are the vertical and horizontal component of the distortion load respectively.

According to the similarity relation between bending of elastic foundation girder and box beam distortion (Xiang H.F. 2013), the above parameter values are calculated.

$M_A = 7.24\text{kN}\cdot m$, $M_B = 5.47\text{k}N\cdot m$.

After find the transverse bending moment of the bottom plate M_B , It is calculated by linear interpolation $M_{B,1}$ and $M_{B,2}$,The transverse tensile stress is calculated according to the material formula $\sigma_{B,1}$, $\sigma_{B,2}$.

$$\sigma_{B,1} = \frac{M_{B,1}}{\frac{1}{6}\cdot t_{B,1}^2\cdot B}\ ;\quad \sigma_{B,2} = \frac{M_{B,2}}{\frac{1}{6}\cdot t_{B,2}^2\cdot B}$$

Of which $t_{B,1}$ is thickness of the bottom plate at 1, $t_{B,2}$ is thickness of the bottom plate at 2, B is width per meter, B equal to1m.

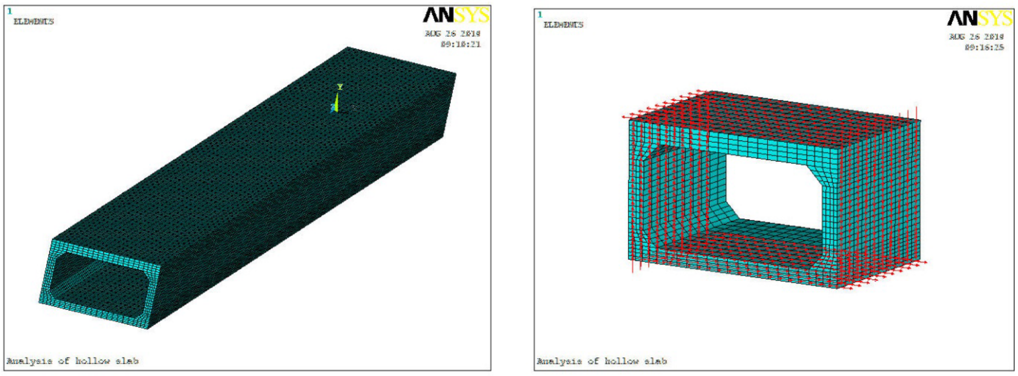
It can be solved that：

$\sigma_{B,1}$=0.76MPa $\sigma_{B,2}$=2.58MPa

Considering the distortion transverse tensile stress calculation of deck pavement, the calculation formula is still based on the above calculation formula. The deck pavement is regarded as the joint force of the PC wide hollow plate. Obtain $M_A = 8.17\text{k}N\cdot m$, $M_B = 4.74\text{k}N\cdot m$, The transverse tensile stress of calculation point 1 and 2 $\sigma_{B,1} = 0.66MPa$, $\sigma_{B,2} = 2.23MPa$.

2.3 Finite element method

In order to verify the results of the theoretical solution, ANSYS was used to analyse the distortion effect of the finite element model. The key in numerical simulation is the imposition of the distortion load. In this paper, the surf154 surface unit is given on solid65 entity unit, and the uniform force is applied on the surface unit to achieve the distortion load. The calculation model and the distortion load are shown in Fig.5. The results of finite element numerical analysis are listed in table 2. The distortion tensile stress at the hollow corner of the hollow corner is 2.58MPa and 2.69 MPa respectively using analytical method and finite element method. The tensile strength of C40 concrete has been exceeded. Considering the effect of 12cm thick bridge deck pavement, the distortion tensile stress generated by the analytical method and finite element method is 2.23MPa and 2.35MPa less than C40 concrete. The numerical simulation method is more convenient to solve the distortion strain of the structure, and the calculation results of the two calculation methods are more consistent.



a) Calculation model b) The distortion load

Figure 5 Numerical calculation model

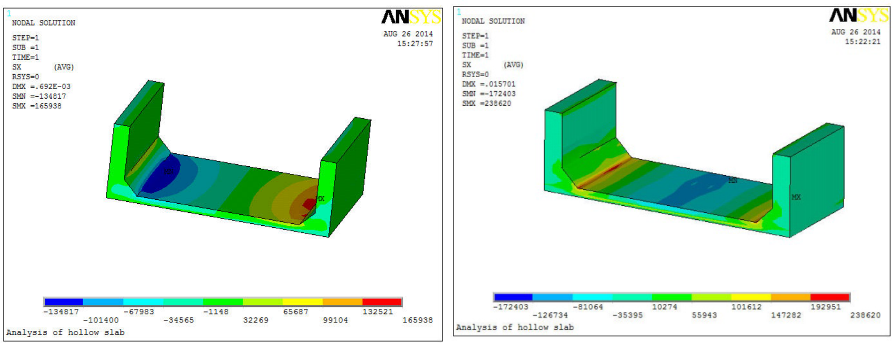
Table 2: The results of lateral stress calculation under the influence of car-20

Calculation method	Lateral stress at point 1 (MPa)	Lateral stress at point 1 that consider the deck pavement(MPa)	Lateral stress at point 2 (MPa)	Lateral stress at point 2 that consider the deck pavement(MPa)
Elastic foundation beam similarity method	0.76	0.66	2.58	2.23
FEM	0.83	0.73	2.69	2.35

According to the discussion in the previous section, torque is finally decomposed into distortion load and torsional load, and the distortion effect and torsion effect are common.

In the above analysis, the transverse tensile stress of 2# is obtained under the distortion load effect, while the thin wall hollow slab can produce transverse stress under the torsion effect and Poisson effect. Therefore, the lateral stress of the wide hollow plate under the torsion and Poisson effect is calculated by ANSYS.

The lateral stress of the corner under the torsion effect and Poisson effect is calculated, as shown in Fig. 6. The calculation results are shown in table 4. The results show that the distortion effect is the main factor causing the transverse tensile stress, accounting for 96% and 97% of the total stress respectively.



a) Lateral stress caused by torsional effect b) Lateral stress caused by poisson effect

Figure 6. The lateral stress of thin wall hollow is generated by torsion effect and Poisson effect

Table 3: Lateral stress caused by various effects

Type	Lateral stress at point 2(MPa)	Lateral stress at point 2 that consider the deck pavement(MPa)
Distortion effect（1）	2.69	2.35
Torsional effect（2）	-0.13	-0.17
Poisson effect（3）	0.24	0.24
TOTAL=（1）+（2）+（3）	2.80	2.42

3 CONCLUSIONS

Based on the thin wall hollow beam widely used in medium and small span Bridges, the distortion stress of the hollow slab is calculated by using the elastic foundation beam analogy method and the finite element method respectively, the following main conclusions:

(1) The numerical solution and the finite element method are consistent, however the finite element method is more simple and efficient. Considering the effect of deck pavement, the transverse tensile stress of calculation point 1 and 2 decreased by 13.2% and 13.6% respectively.

(2) The distortion effect is the main factor that causes the transverse tensile stress, which accounts for 96% and 97% of the total transverse tensile stress, and the tensile stress is larger.

Therefore, the design and use of this type of beam should pay attention to the influence of distortion effect in the future, the thin and thick of hollow slab inappropriate transition reduction.

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