Hydraulic and Civil Engineering Technology VII
M. Yang et al. (Eds.)

doi:10.3233/ATDE220928

Calculation of Short-Term Deflection of a Composite Slim Floor with Single Span

Chunxiu HAN [a,1], Peng WANG [b] and Huanlin HE [a]
[a] *Department of Physics and Civil Engineering, Yunnan Minzu University, Kunming, Yunnan, 650504, China*
[b] *Faculty of Civil Engineering and Mechanics, Kunming University of Science and Technology, Kunming, Yunnan, 650224, China*

Abstract. For the problem of stiffness calculation of a composite slim beam with reinforced concrete composite truss slab as floor slab, the short-term deflection of the slim beam is calculated and analyzed by theoretical and numerical methods. The result shows that the load-deflection curve is linear in the middle span of the composite slim beam, and the cross section of the composite slim beam is the ideal cross section. The stiffness of the composite flat beam can be calculated according to the linear elastic theory. The concrete area is converted into steel beam area by the method of conversion section, and then analyzed by the method of material mechanics. The elastic deflection obtained by the theoretical formula is in good agreement with the finite element analysis. The load - displacement curve of a single span composite slim beam is obtained by numerical simulation using finite element method. The curve is nonlinear. In front of the concrete cracking (the load reaches 25% of the failure load), the curve is accord with the theoretical calculation of the elastic curve, then the curve of the finite element calculation is along the horizontal deviation, especially when the load applied to 45% of the breaking load, then the offset value increase, this match the experimental analysis of the early stage of our research team is good.

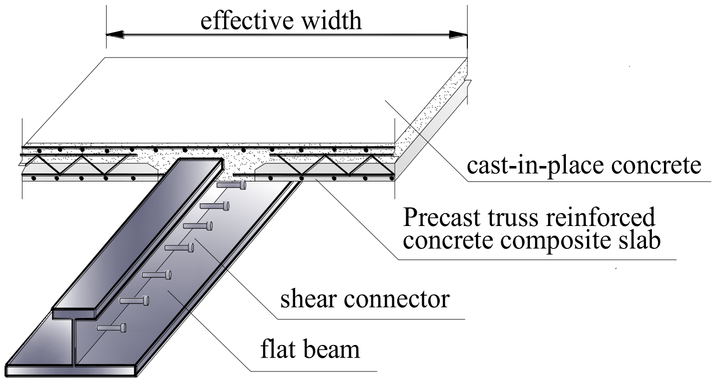
Keywords. Composite slim floor, short-term deflection, theoretical calculation, numerical calculation

1. Introduction

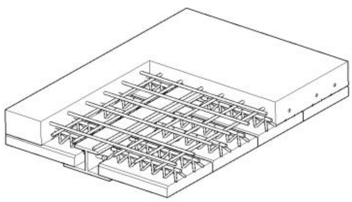
Based on the traditional composite beam, steel-concrete composite slim floor is a new type of a composite beam developed to reduce the structure height and fully consider the combination of floor and steel beams, as well as the prefabricated construction mode [1-5]. The flat beams are embedded in the concrete slabs to achieve the similar effect of "beamless floor", which reduces the height of the floor structure to the greatest extent and improves the space utilization. The prefabricated plate is usually in the form of SP hollow plate and deep rib compression steel plate [2,6]. We proposed a truss reinforced concrete composite slab as the composite slim beam of the floor [7,8] (as shown in figure 1). The floor system consists of flat beam, precast truss reinforced concrete composite slab and cast-in-place concrete, with transverse reinforcement and shear connectors to ensure that all components work together. The reduction of the

[1] Chunxiu Han, Corresponding author, Department of Physics and Civil Engineering, Yunnan Minzu University, Kunming, Yunnan, 650504, China; E-mail: 593416010@qq.com.

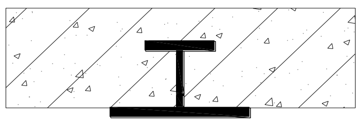
height of the flat beam brings advantages to the structure, but also makes the deformation performance of the structure face great challenges. The stiffness of the composite flat beam is the weak point of the structure and plays a controlling role in the structural stress. The short-term deflection of the flat beam is calculated and analyzed theoretically and numerically in order to provide some support for the deformation characteristics of the structure.



(a) Internal structure of the composite slim beam



(b) Composite slim beam floor system



(c) The calculated cross section

Figure 1. Structure of a composite slim beam.

2. Theoretical Calculation of Short-term Elastic Deflection of the Composite Slim Beam

According to the loading test of single-span composite flat beams [7] in the previous stage, the concrete did not crack before the load was added to 25% of the failure load, and the load-deflection curve in the middle span was linear with the composite slim beam section an ideal section. The stiffness of the composite slim beam could be calculated according to the linear elasticity theory. The concrete area is converted into steel beam area by the method of conversion section, and then analyzed by the method of material mechanics. The basic assumptions adopted are:

1) Steel beam is an ideal elastic-plastic material, so the contribution of slim beam to deformation is considered, and the contribution of steel bar to deformation is ignored.

2) According to the preliminary test [7], the slip between the steel beam and the concrete can be ignored when the web of the flat beam is equipped with appropriate bolts.

3) The concrete is not cracked, and the load-deflection curve of mid-span is linear.

4) The combined section meets the assumption of plane section in the process of force.

According to the section parameters of the composite flat beam (see figure 2), the inertia moment of the composite flat beam I_s and the inertia moment of the composite section I_{cs} are calculated [9]. Among them, the effective width is highly correlated with the span and spacing of the flat beam [10].

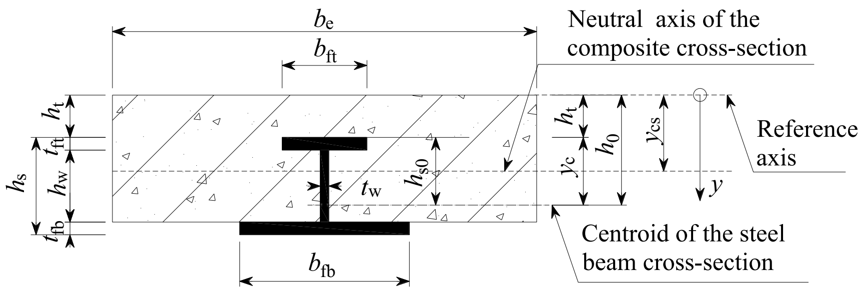


Figure 2. Parameters of the calculating cross-section.

I_s and I_{cs} are calculated as follows:

$$I_s = \frac{b_{fb}t_{fb}^3}{12} + b_{fb}t_{fb}(h_s - h_{s0} - t_{fb}/2)^2 + \frac{t_w h_w^3}{12} + t_w h_w (h_{s0} - t_{ft} - h_w/2)^2 + \frac{b_{ft}t_{ft}^3}{12} + b_{ft}t_{ft}(h_{s0} - t_{ft}/2)^2 \tag{1}$$

$$\begin{cases} A_1 = b_e h_t/\alpha_E,\ A_2 = (b_e - b_{ft})\cdot t_{ft}/\alpha_E,\ A_3 = (b_e - t_w)\cdot h_w/\alpha_E,\ A_4 = A_s \\ I_1 = b_e h_t^3/12, I_2 = (b_e - b_{ft})\cdot t_{ft}^3/12,\ I_3 = (b_e - t_w)\cdot h_w^3/12,\ I_4 = I_s \\ y_1 = h_t/2,\ y_2 = h_t + t_{ft}/2,\ y_3 = t_{ft} + h_t + h_w/2,\ y_4 = y_s = h_{s0} + h_t \\ \sum A_i = A_s + \left[b_e h_t + (b_e - b_{ft})\cdot t_{ft} + (b_e - t_w)\cdot h_w\right]/\alpha_E, \\ \sum I_i = I_s + \left[b_e h_t^3 + (b_e - b_{ft})\cdot t_{ft}^3 + (b_e - t_w)\cdot h_w^3\right]/12, \\ \sum A_i y_i^2 = A_s(h_{s0} + h_t)^2 + \left[b_e h_t (h_t/2)^2 + (b_e - b_{ft})\cdot t_{ft}(h_t + t_{ft}/2)^2 + (b_e - t_w)\cdot h_w (t_{ft} + h_t + h_w/2)^2\right]/\alpha_E \\ y_{cs} = \dfrac{\sum A_i y_i}{\sum A_i},\ y_{cs}^2 \sum A_i = (h_{s0} + h)^2 \sum A_i, \\ I_{sc} = \sum I_i + \sum A_i y_i^2 - y_s^2 \sum A_i \end{cases} \tag{2}$$

The short-term elastic deflection of the composite flat beam is:

$$\begin{cases} f_s = S\dfrac{Ml_0^2}{E_s I_s} = S\phi_s l_0^2 \\ f_{cs} = S\dfrac{Ml_0^2}{E_s I_{cs}} = S\phi_{cs} l_0^2 \end{cases} \tag{3}$$

Where l_0 = calculation span of a slim beam; S =deflection coefficients related to load forms and supporting conditions can be calculated according to structural mechanics; M = bending moment of steel slim beam; E_s = elastic modulus of steel slim beam; I_s = moment of steel slim beam section; I_{cs} = moment of composite section; ϕ_s = curvature of steel slim beam; ϕ_{cs} = curvature of composite slim beam; f_s = short-term deflection of composite flat beam during construction; f_{cs} =short-term deflection of composite flat beam in service stage.

3. Numerical Calculation of Short-term Deflection of Composite Slim Beam

The concrete section height of common composite beam accounts for a small proportion of the total height, and most or all sections of concrete are compressed. The composite flat beam embedded in the floor slab, the concrete section height and the total height is almost equal, even if the simple beam, mid-span concrete bottom also prone to crack. According to the previous single span composite flat beams loaded test [7], load before failure load of 25%, concrete cracking, across the load deflection curve of the composite panels for linear distribution, when the load applied to 45% of the breaking load, the vertical cracks, concrete lower apparent across the load deflection curve of a non-linear relationship. The finite element numerical method is used to calculate the short-term stiffness of composite beams. Taking a section as an example, the section size is shown in figure 3, and the same model and constraint conditions are adopted as in reference [7]. In order to reduce the number of units, half of the model structure was established in a symmetric way (as shown in figure 4). The structural relationship between concrete and flat beam was shown in figure 5, the deformation before and after loading was shown in figure 6, and the mid-span deflection in figure 7.

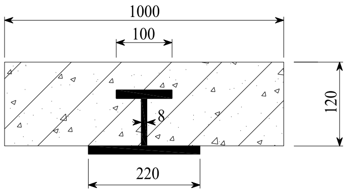


Figure 3. Calculation of cross section parameters.

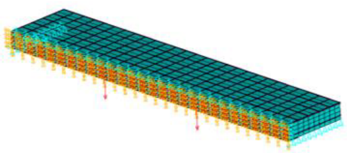


Figure 4. Symmetry constraint and load.

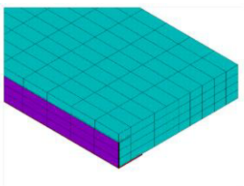


Figure 5. Symmetrical concrete and slim beam construction.

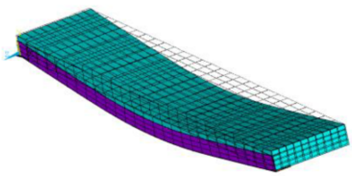


Figure 6. Deformation diagram of single span composite flat beam.

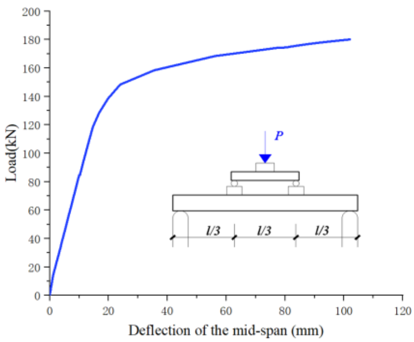


Figure 7. Load-deflection of the mid-span with finite element.

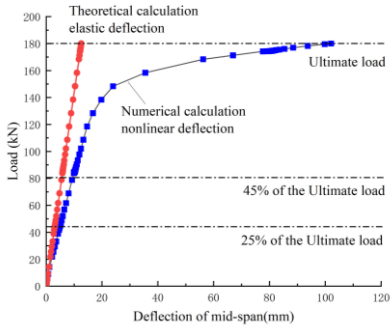


Figure 8. Contrast of Load-deflection of the mid-span with the two methods.

According to formula (3), the finite element calculation of the mid-span deflection as shown in figure 8, before the concrete cracking (25% damage load), the curve of two experimental data very well, then the curve of the finite element calculation along the horizontal deviation, especially when the load applied to 45% of the breaking load, the offset value increase, the numerical experimental data from literature [7] is very good.

4. Conclusion

In order to obtain the short-term stiffness of the composite flat beam, the short-term deflection of the flat beam is calculated and analyzed theoretically and numerically, and the following conclusions are obtained:

1) For the single-span composite flat beam, in the concrete uncracked stage, the load-deflection curve in the span is linear, the composite flat beam section is the ideal section, the stiffness of the composite flat beam can be calculated according to the linear elastic theory. The concrete area is converted into steel beam area by the method of conversion section, and then analyzed by the method of material mechanics. The elastic deflection obtained by the modified formula is in good agreement with the finite element analysis.

2) The finite element method is used to simulate the single-span composite flat beam numerically, and the load-displacement curve in mid-span is obtained. Nonlinear curve, the curve is in front of the concrete cracking (25% damage load), the curve is accord with the theoretical calculation of the elastic curve, then the curve of the finite element calculation along the horizontal deviation, especially when the load applied to 45% of the breaking load, the offset value increase, this agreement with the experimental analysis of the early stage of our research team is good.

Acknowledgments

The financial supports from the National Natural Science Foundation of China (Grant No. 52068068, 51708486) are gratefully acknowledged.

References

[1] Aristidis Iliopoulos. Zur Verformungsberechnung von Slim-Floor-Trägern. Stahlbau. 2019; 88, Heft 8.

[2] Gerhard Hanswille, Markus Schäfer. Zur praktischen Ermittlung der Verformungen von Verbundträgern und Flachdeckensystemen unter Berücksichtigung der Nachgiebigkeit der Verbundfuge. Stahlbau. 2007; 76, Heft 11.

[3] Gunter Hauf. Trag-und Verformungsverhalten von Slim-Floor Trägern unter Biegebeanspruchung. Institut für Konstruktion und Entwurf der Universität Stuttgart, 2010.

[4] Gunter Hauf, Ulrike Kuhlmann. Deformation calculation methods for slim floors. Steel Construction. 2015; 8(2).

[5] Inas Mahmood Ahmed, Konstantinos Daniel Tsavdaridis. The evolution of composite flooring systems: applications, testing, modelling and eurocode design approaches. Journal of Constructional Steel Research. 2019; 155: 286-300.

[6] Wang YQ, Shi YJ, Chen Q, et a1. An experimental study on the structural behavior of steel-concrete composite slim beams. China Civil Engineering Journal. 2005; 38(4):12-17, 31.

[7] Xia YX, Han CX, Zhou DH, et a1. Ultimate flexural strength analysis of composite slim floor beam Advances in Structural Engineering. 2021; 24(10): 2214-2226.

[8] Luo QJ, Han CX, He H, et al. The invention relates to a fabricated steel frame - composite flat beam floor: CN209397804U]. 2019.

[9] Liu J. Design principle of steel and concrete composite structure. Beijing: Science Press, 2005.

[10] Yang L, Wang YQ, Shi YJ. Factors analysis on effective width of simply supported composite slim beam. Journal of Hebei Institute of Architectural Science and Technology. 2006; 23(3): 3-6.