



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

# IJIRSET

International Journal of Innovative Research in  
**SCIENCE | ENGINEERING | TECHNOLOGY**

# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 12, Issue 4, April 2023

**ISSN** INTERNATIONAL  
STANDARD  
SERIAL  
NUMBER  
INDIA

Impact Factor: 8.423

9940 572 462

6381 907 438

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# Stiffness Analysis of Steel Truss Composite Slab during Construction

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**ABSTRACT:** Through the theoretical analysis and experimental research of the section flexural rigidity of steel truss composite slab in the construction stage, the contribution of the bottom profiled steel sheet to the flexural rigidity of the floor in the construction stage is discussed, and the calculation method of the flexural rigidity of reinforced truss composite slab in the construction stage is proposed, which provides a theoretical basis for the better play of the structural performance of the new floor and the expansion of the application range of reinforced truss floor.

**KEYWORDS:** Steel bar truss, Composite floor, Flexural stiffness.

## I. INTRODUCTION

In the traditional concrete floor structure, when the floor span is large, the construction stage of the floor needs to set a complex support structure, which has a great impact on the construction speed of the project. To overcome this adverse effect, engineers have put forward a variety of types of floor structure systems without support form, steel truss composite floor is a new type of floor structure without support form which has developed rapidly in recent years. It will be three steel bars arranged according to the triangle, the above steel bar as the upper string reinforcement, the following two steel bars as the lower string reinforcement, and the upper and lower string reinforcement through the abdominal bar reinforcement for fixing. At the end of the truss, the horizontal and vertical reinforcing bars of the support are welded together to form the end supports. The galvanized steel slab is then pressed into a molded steel slab with a 2mm rib height, and the spot welding process is used to weld the steel slab and the truss together to form a single unit (see Figure 1).

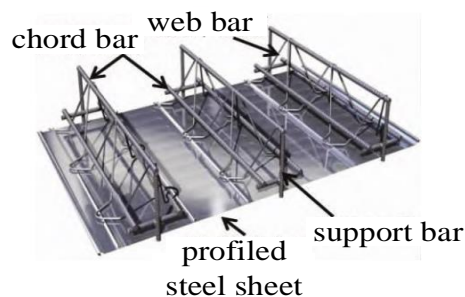


Fig. 1. Steel truss formwork

As a new type of floor structure, steel truss concrete floor has the characteristics of fast construction speed and superior structural mechanical performance. Once proposed, it has been widely concerned by the engineering field, and more achievements have been made in the relevant research on the bearing performance of the floor [1,6]. As a kind of floor structure without support, the floor stiffness during construction directly affects its engineering application range. At present, the relevant design code [7] does not consider the stiffness contribution of the bottom-pressed section steel sheet in the construction stage and is designed according to the ordinary cast-in-place concrete floor. This treatment tends to be conservative, and the design is not economical. Based on the actual process of steel truss floor construction and site construction, this paper discusses the stiffness calculation method of steel truss composite slab in the construction stage considering the influence of profiled steel sheet.

II. THEORETICAL ANALYSIS OF STIFFNESS OF STEEL TRUSS COMPOSITE SLAB IN THE CONSTRUCTION STAGE

For the steel bar truss composite slab in the construction stage, the concrete pouring has just been completed but has not yet been set and hardened, and all the load is borne by the steel bar truss and the truss temslab composed of galvanized steel slab at the bottom. According to the treatment method in literature [7], the stiffness of the floor in the construction stage only considers the stiffness of the steel bar truss itself, and the stress unit of the steel bar truss at this stage is shown in Figure 2.

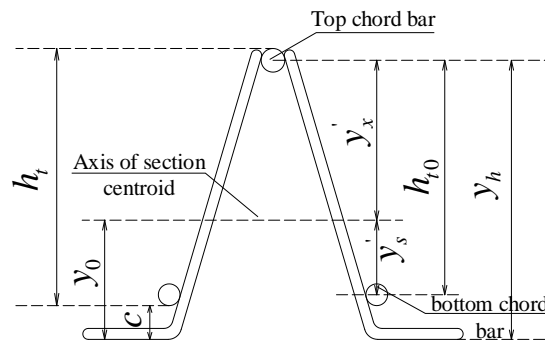


Fig. 2. Schematic diagram of the force element of the steel bar truss (not considering the profiled steel sheet)

In Figure 2,  $h_t$  is the height of the truss;  $h_{t0}$  is the distance between the upper and lower chord centers of the truss;  $c$  is the thickness of the steel protective layer of the lower chord truss;  $y_h$  is the distance between the core of the upper steel bar and the bottom of the truss;  $y_0$  is the distance between the axis of section centroid and the bottom of the steel bar truss;  $y'_x$  and  $y'_s$  is the distance from the upper and lower chord bar to the axis of section centroid respectively; When the diameter of the steel bar of the upper and lower chord rods is  $D_1, D_2$  respectively,  $y_0, y'_x, y'_s$  can be calculated according to equations (1-1) ~ (1-3) :

$$y_0 = \frac{A'_x \left( h_t + c - \frac{D_1}{2} \right) + A_s \times \left( \frac{D_2}{2} + c \right)}{A'_x + A_s} \tag{1-1}$$

$$y'_x = h_t + c - \frac{D_1}{2} - y_0 \tag{1-2}$$

$$y'_s = h_t - \frac{D_1 + D_2}{2} - y'_x \tag{1-3}$$

In Formula (1),  $A'_x, A_s$  are the section areas of the upper and lower chord bars respectively. When the upper and lower chord bars are reinforced with different elastic moduli, they need to be converted into a section of the same material. After determining the section centroid position of the truss reinforcement, the section moment of inertia  $I_s$  and section flexural stiffness  $B$  of the truss reinforcement can be obtained, as shown in Formula (2) and Formula (3).

$$I_s = \frac{\pi D_1^4}{64} + A'_x (y'_x)^2 + \frac{\pi D_2^4}{32} + A_s (y'_s)^2 \tag{2}$$

$$B = E_s I_s \tag{3}$$

In engineering, the abdominal bar reinforcement of composite slab, the upper string reinforcement, the lower string reinforcement, and the bottom profile steel slab are usually welded into a whole, which can ensure the collaborative deformation between the components. The actual force unit of a composite slab in the construction stage can use the section shown in Figure 3.

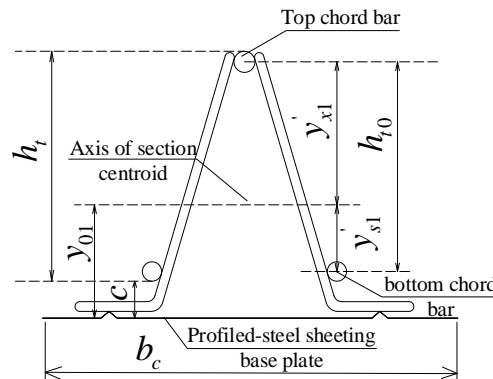


Fig. 3 Schematic diagram of force element section of steel bar truss (considering the profiled steel sheet)

In Figure 3,  $b_c$  is the load width of a single truss, and the section area of the bottom profiled steel sheet within this range is  $A_{sp}$ . When the elastic modulus of the upper steel bar, lower steel bar, and bottom profiled steel sheet is inconsistent, the three parts of steel can be uniformly converted into the section of steel properties of the lower chord.

The section area of the upper string steel bar:

$$A'_{s1} = \alpha_{s1} A'_s, \quad \alpha_{s1} = \frac{E_{s1}}{E_s} \quad (4-1)$$

Section area of molding steel slab:

$$A'_{sp} = \alpha_{s2} A_{sp}, \quad \alpha_{s2} = \frac{E_{s2}}{E_s} \quad (4-2)$$

In Formula (4),  $E_s$ ,  $E_{s1}$ ,  $E_{s2}$  are the elastic modulus of lower chord reinforcement, upper chord reinforcement, and profile steel slab respectively.

Based on the section arrangement shown in Figure3, the section centroid position  $y_{01}$  and the distance between the upper and lower chord steel bars and the section centroid  $y'_{x1}$ ,  $y'_{s1}$  can be obtained when considering the participation of the bottom slab.

$$y_{01} = \frac{A'_{s1} (h_t + c) + A_s \times \left( \frac{D_2}{2} + c \right)}{A'_{s1} + A_s + A'_{sp}} \quad (5-1)$$

$$y'_{x1} = h_t + c - \frac{D_1}{2} - y_{01} \quad (5-2)$$

$$y'_{s1} = h_t - \frac{D_1 + D_2}{2} - y'_{x1} \quad (5-3)$$

After determining the section centroid position of the truss reinforcement shown in Figure 3, the section moment of inertia  $I_{s1}$  and section flexural stiffness  $B_1$  of the truss reinforcement can be obtained, as shown in equations (6) and (7).

$$I_{s1} = \frac{\pi D_1^4}{64} + A'_s (y'_{x1})^2 + \frac{\pi D_2^4}{32} + A_s (y'_{s1})^2 + A'_{sp} (y_{01})^2 \quad (6)$$

$$B_1 = E_s I_{s1} \quad (7)$$

### III. TEST VERIFICATION OF STIFFNESS ANALYSIS METHOD

Given the above theoretical analysis scheme of the stiffness of the steel truss composite slab in the construction stage, the design and production of three specifications of steel truss slab, the simulation of the composite slab under load during the construction stage of the composite slab stiffness test, based on the test results of the construction stage of the composite slab stiffness analysis method was evaluated.

The basic specifications of the selected steel truss slabs are shown in Table 1. The calculation span of the TD2-700 slab is 2.0m, and that of the TD3-700 and TD3-900 slabs is 3.0m. The section geometric parameters with and without profiled steel slabs are given respectively in the table. Figure 4 shows the basic situation of the loading element of the test truss slab.

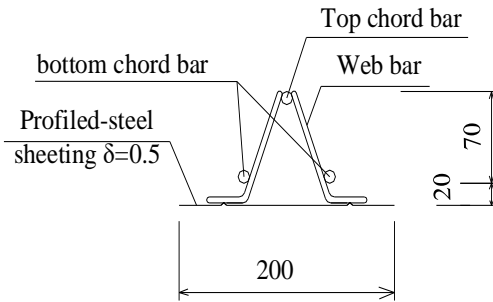
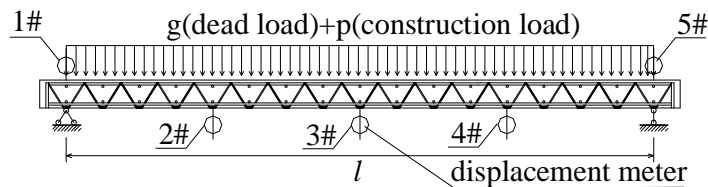


Fig. 4 Section of a load-bearing unit of the test truss slab

Table 1 Section characteristics of test steel truss floor slab

Type of steel truss slab	Truss height /mm	Diameter of top chord bar, web bar, and bottom chord bar /mm	Die steel slab analysis method is not considered		Consider the profiled steel slab analysis method		Floor section height /mm
			Height of neutralization axis $y_0$ /mm	The moment of inertia $I_0 / (x 10^5 \text{mm}^4)$	The height of the neutralizing axis is $y_0$ /mm	Moment of inertia $I_0 / (x 10^5 \text{mm}^4)$	
TD2-70-600	70	8,4.5, 8	39.7	1.294	25.2	2.179	100
TD3-70-600	70	12,5,12	40.3	2.567	32.2	3.913	100
TD3-90-600	90	12,5,12	47	4.618	37.1	5.101	120

Floor loads in the construction phase include dead weight (steel truss formwork dead weight, wet concrete weight) as well as construction loads. The simulation load test adopts the loading method of uniform load. The construction load is applied according to the uniform load of  $1.5 \text{kN/m}^2$ , and the weight is used to load the stage. The two ends of the floor are simply supported on the support, and the floor deflection is tested respectively at the support, four points, and mid-span positions. The test loading and testing methods are shown in Figure 5.



(a) Simplified loading diagram



(b) Field loading situation

Fig. 5 Test truss slab loading mode

Based on the section characteristics of the steel truss slab in Table 1 and the load value in the construction stage, the theoretical calculation results of the deflection of the steel truss slab in the construction stage can be obtained.  $\delta = Ml_0^2 / B$  Table 2 compares the theoretical analysis value of the mid-span deflection of the steel bar truss slab with the test results. It can be seen from the results of the table that the theoretical analysis results of deflection are significantly greater than the actual deflection value of the floor without considering the contribution of the stiffness of the molded steel slab, and the analysis method underestimates the actual stiffness of the steel bar truss slab. However, when considering the contribution of steel slab stiffness, the theoretical analysis results of deflection are all smaller than the actual deflection of the floor, indicating that the analysis method overestimates the actual stiffness of the steel truss slab. When considering the contribution of steel slab stiffness, the welding between steel slab and belly bar reinforcement is regarded as the ideal binding connection in the analysis model. At the same time, the calculated width of the steel slab is considered according to the load area of the truss reinforcement. There is a certain deviation from the actual performance of the floor, resulting in the overestimation of the real bending stiffness of the section in the analysis results of the model.

From the deviation values caused by the two analysis methods in Table 2, the deviation caused by not considering the contribution of steel slab stiffness is far greater than that caused by considering the contribution of stiffness. The maximum deviation of deflection of the former exceeds 50%, while the maximum deviation of the latter does not exceed 10%. At the same time, the greater the height of the steel truss, the smaller the influence of the molded steel slab on the section stiffness. Based on the above analysis, when the height of the steel truss exceeds 90mm in the project, the analysis model in literature [7] can be used to analyze the flexural stiffness of the steel truss slab in the construction stage, which can be calculated according to Formula (3). When the height of the steel truss does not exceed 90mm, the flexural stiffness of the steel bar truss slab in the construction stage can be calculated according to Formula (8), which is 0.9 times the flexural stiffness under the condition of the contribution of the molded steel slab.  $B_1'$

$$B_1' = 0.9 \times B_1 = E_s I_{s1} \quad (8)$$

**Table 2 Comparison of theoretical analysis and measured results of mid-span deflection of truss slab**

Type of floor-bearing slab	Theoretical calculation value of deflection		The measured value of deflection	Deviation	
	Do not consider the impact of molded steel slab	Consider the impact of molded steel slab		Do not consider the effects of molding steel	Consider the impact of molded steel slab
TD2-70-600	6.37	3.783	4.14	+ 53.9%	- 8.6%
TD3-70-600	16.26	10.667	11.84	+ 37.3	- 9.9%
TD3-90-600	10.17	9.207	9.51	+ 6.9%	3.2

#### IV. CONCLUSION

Based on theoretical analysis and experimental research, this paper discusses the contribution of molded steel slab bottom die to the flexural rigidity of reinforced truss composite slab in the construction stage, and draws the following conclusions:

- 1) When the height of the truss steel bar is more than 90mm, ignoring the bottom die of the molded steel slab has little effect on the bending stiffness of the steel bar truss composite slab. But when the height of the steel bar truss is less than 90mm, ignoring the bottom die of the molded steel slab will seriously underestimate the bending stiffness of the steel bar truss composite slab, which is not conducive to the play of the structural performance of the new floor.
- 2) When the height of the truss steel bar is more than 90mm, the flexural stiffness of the steel bar truss composite slab in the construction stage is suggested to be determined according to Formula (3), and when the height of the steel bar truss is less than 90mm, the flexural stiffness of the composite slab is suggested to be calculated according to Formula (8).

#### ACKNOWLEDGEMENTS

This work was supported by the University Students Innovation and Entrepreneurship Training program of China (202111527020)

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