Discussion on the installation checking method of precast composite floor slab with lattice girders

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Abstract. Based on the installation checking requirements of China's current standards and the international norms for prefabricated structural precast components, it proposed an installation checking method for precast composite floor slab with lattice girders. By taking an equivalent composite beam consisted of a single lattice girder and the precast concrete slab as the checking object, compression instability stress of upper chords and yield stress of slab distribution reinforcement at the maximum positive moment, tensile yield stress of upper chords, slab normal section normal compression stress and shear instability stress of diagonal bars at the maximum negative moment were checked. And the bending stress and deflection of support beams, strength and compression stability bearing capacity of the vertical support, shear bearing capacity of the bolt and compression bearing capacity of steel tube wall at the bolt were checked at the same time. Every different checking object was given a specific load value and load combination. Application of installation checking method was given and testified by example.

1. Introduction

As a horizontal composite component, composite floor slab with lattice girders (hereinafter referred to composite floor slab) do not participate in seismic calculation, and in the construction scene it can save a lot of floor form-work. So it is extensively used in the current application. In the *Code for design of concrete structure* GB50010-2010[1] of China (hereinafter referred to design codes), horizontal composite components are designed in two situations according to whether or not to set the vertical and reliable support, and it lists the relevant design calculation formulas. Precast concrete components should be checked by real in the production and construction process. Checking load should consider the dynamic coefficient, and the value of the dynamic coefficient should be adjusted appropriately in consideration of specific conditions; In *the Load code for the design of building structures* GB50009-2012[2] (hereinafter referred to as load codes), it lacks of load value in construction stage; In *the Technical specification for precast concrete structures* JGJ1-2014[3] (hereinafter referred to as precast specification), the value of load under different working conditions is stipulated. The specific checking method refers to *the Code for construction of concrete structures* GB50666-2011[4] (hereinafter referred to as construction codes)； Construction codes indicating the stress checking method only gives normal compression tensile stress index of concrete cross section and the tensile stress index of steel bars. Composite floor slab is composed of lattice girders and reinforced concrete slab. It is not only need to ensure the safety and reliability of the reinforced concrete slab in the construction and installation stage, but also to ensure that the lattice girders are within the enable loading capacity.

In this paper, based on the existing internal codes, combined with the requirements of foreign relevant standards, we proposed an installation checking method for precast composite floor slab: First, take an equivalent composite beam consisted of a single lattice girder and precast concrete slab as the checking object, and use stress checking method to check the horizontal spacing of support beams in floor slab. Second, when the horizontal spacing of support beams is determined, check the horizontal spacing of vertical supports. Ensure the strength, deflection of support beams and the strength, stability of vertical supports.

2. Checking calculation of bearing capacity of normal section of composite floor slab

2.1. Equivalent composite beam section and basic parameters

Composite floor slab is composed of lattice girders and reinforced concrete slab. We take an equivalent composite beam consisted of a single lattice girder and precast concrete slab as the checking unit (Fig. 1). It is stipulated in European standards EN 13747:2005[5] that the range of action of a single lattice girder is min{630， 0.75(15t+125)}*mm*. And in precast specification, the minimum thickness t of precast floor slab may be more than 60*mm*, so the range of action of a single lattice girder is 630*mm*; in precast specification, the maximum spacing of lattice girders is 600*mm*, so the maximum width B of composite beam is equal to the maximum spacing of lattice girders, 600*mm*.

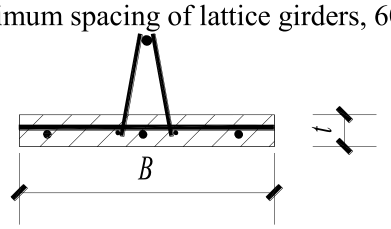

Fig.1 equivalent composite beam schematic diagram

2.1.1. Equivalent composite beam neutral wheelbase y_0

$$y_0 = h - \frac{B\cdot t\cdot(h-t/2)+(A_1h_1+A_sh_s)(\alpha_E-1)}{B\cdot t+(A_1+A_s)(\alpha_E-1)+A_c\cdot\alpha_E} \tag{1}$$

In the formula: h is the distance from the bottom of the precast floor slab to the centroid of upper chords;

h_1 is the distance from the centroid of slab distribution reinforcement parallel to lattice girders to the centroid of upper chords; h_s is the distance from the centroid of upper chords to the centroid of lower chords; t is the thickness of precast floor slab; B is the effective width of the composite beam; A_1 is the area of slab distribution reinforcement parallel to lattice girders in the effective width of the composite beam; A_s is the area of upper chords; A_c is the area of lower chords; α_E is the ratio of elastic modulus between steel bars and precast slab concrete.

2.1.2. Equivalent composite beam moment of inertia I_0

$$\begin{aligned} I_0 = A_c\cdot\alpha_E(h-y_0)^2 + [\{y_0-(h-h_1)\}^2A_1+\{y_0-(h-h_s)\}^2A_s] \\ (\alpha_E-1)+(y_0-t/2)^2B\cdot t+\frac{1}{12}B\cdot t^3 \end{aligned} \tag{2}$$

2.1.3. Equivalent composite beam concrete elastic resistance moment of pulling edge W_0

$$W_0 = I_0 / y_0 \tag{3}$$

2.1.4. Equivalent composite beam upper chord elastic resistance moment of pulling edge W_c

$$W_c = I_0 / (h - y_0) \tag{4}$$

2.2. *Internal force calculation model of equivalent composite beam*

The equivalent composite beam can be divided into single-span simple beam and multi-span continuous beam by the arrangement of support beams. The internal force and deformation coefficient of multi-span continuous beam can be found in *the Technical code for safety of forms in construction* JGJ 162-2008[6] (hereinafter referred to as forms safety technical codes) Appendix C.

2.3. *Load value and combination*

Taking construction codes, forms safety technical codes and the actual loading features of the equivalent composite beam into consideration, the constant concrete self-weight of the equivalent composite beam takes 24kN/m^3, reinforcement self-weight takes 1.1kN/m^3, the construction variable load takes 2.5kN/m^2, and the concentrated load takes 2.5kN for checking.

As the checking for the equivalent composite beam takes experience method, that is permissible stress method. Load combination takes characteristic combination, not considering the load partial factor.

2.4. *Checking indexes and methods*

For the single-span simple beam, reinforcement yield stress of plate bottom and compression instability stress of the upper chord at mid-span, shear instability stress of diagonal bars at the support should be checked. For the multi-span continuous beam, the reinforcement yield stress of plate bottom and compression instability stress of the upper chord at the maximum bending moment at mid-span, tensile yield stress of upper chord and concrete compression stress of plate bottom at the maximum negative moment at the support, shear instability stress of diagonal bars at the support should be checked.

2.4.1. *The tensile yield stress of the distribution reinforcement parallel to lattice girders*

$$\sigma_s = \frac{M_+}{A_1 \cdot h_1} \le 0.7 f_{yk} \tag{5}$$

In the formula: M_+ is the maximum positive bending moment at mid-span; f_{yk} is the standard value of tensile strength of reinforcement.

2.4.2. *The compression instability stress of the upper chord*

$$\sigma_{sc} = \frac{M_+}{A_c \cdot h_s} \le \varphi_c f_{yk} \tag{6}$$

In the formula: φ_c is the compression stability coefficient of the upper chord, valued according to *the Code for design of reinforcement structures* GB 50017-2003[7] (hereinafter referred to as reinforcement structures codes). And the upper chord slenderness ratio $\lambda = 0.9 l_c / i_c$ (l_c is the distance between welded joints of the upper chord, generally taking 200mm; i_c is the radius of gyration of cross-section of the upper chord).

2.4.3. *The tensile yield stress of the upper chord*

$$\sigma_s = \alpha_E \frac{M_-}{W_c} \le 0.7 f_{yk} \tag{7}$$

In the formula: M_- is the maximum negative bending moment at the support.

2.4.4. *Normal section normal compression stress of precast slab*

$$\sigma_{cc} = \frac{M_{-}}{W_0} \le 0.8 f_{ck}^1 \tag{8}$$

In the formula: f_{ck}^1 is the standard value of compression strength corresponding to concrete cube compression strength in each construction link.

2.4.5. The shear instability stress of diagonal bars. In reinforcement structures codes, there is no calculation formula of shear instability. So in this article, the shear force is converted to the pressure of diagonal bars N .

$$N = 0.5V \sin\phi \sin\alpha \tag{9}$$

In the formula: V is the standard value of diagonal bars shear under load; ϕ , α is the inclined angle of diagonal bars, $\phi = \arctan(H/100)$ (H is the outsourcing height of lattice girders); $\alpha = \arctan(2H/b_0)$ (b_0 is the outsourcing distance of lower chords, generally taking 80*mm*).

$$\sigma_{sr} = \frac{N}{A_f} \le \varphi_d f_{yk} \tag{10}$$

In the formula: A_f is the sectional area of a single diagonal bar; φ_d is the compression stability coefficient of diagonal bars, valued according to reinforcement structures codes. And the diagonal bars slenderness ratio $\lambda = 0.7 l_d / i_d$ (l_d is the length of free segment of diagonal bars, calculated according to formula (11); i_d is the radius of gyration of cross-section of diagonal bars).

$$l_d = \sqrt{H^2 + (\frac{b_0}{2})^2 + (\frac{l_c}{2})^2} - t_c / \sin\phi / \sin\alpha \tag{11}$$

In the formula: t_c is the distance from the bottom surface of the lower chord to the internal surface of the precast floor slab.

3. Checking of the support beam and the vertical support

Checking of the support beam and the vertical support refers to forms safety technical codes, based on the limit states design method which is based on the probability theory and expressed by partial factors.

3.1. Checking of the support beam

The support beam is calculated by the simply supported beam. The concrete self-weight takes 24 kN/m^3. The reinforcement bar self-weight takes 1.1 kN/m^3. The construction variable load takes 1.5kN/m^2. The bending stress and deflection of the support beam are checked.

3.2. Checking of the vertical support

Taking the construction convenience into consideration, the vertical support usually takes tool-type steel pipe column and is very convenient to adjust. Its compression bearing capacity, compression stability, shear bearing capacity of bolt and compression bearing capacity of steel tube wall at the bolt should be checked.

4. Examples

There are three composite floor slabs in a bay (7800*mm* × 6000*mm*, story height 3200*mm*), the total thickness of the composite floor slab is 160*mm*. The length of each precast floor slab is 6000*mm*, and width 2600*mm*, thickness 60*mm*. The concrete strength grade is C30. The stress bars and the distributed bars are grade HRB400 reinforcing bars. The diameter of the stress bars is 10*mm*, and spacing 100*mm*. The diameter of the distributed bars is 8*mm*, and spacing 200*mm*. The thickness of the protective layer is 15*mm*. The lattice girder is model E11 (All lattice girders are grade HRB400 reinforcing bars. The diameter of upper chord is 10*mm*, and lower chord, diagonal is 6*mm*) (Fig. 2). Try to make a support scheme.

4.1. Checking of the spacing of support beams

Support beams should be arranged along the direction vertical to lattice girders, and the distance between the first support beam and the support edge should not be greater than 500*mm*. It is preliminarily assumed that the support beams are H20 wood I beams, and their spacing is 1700*mm* (Fig. 3).

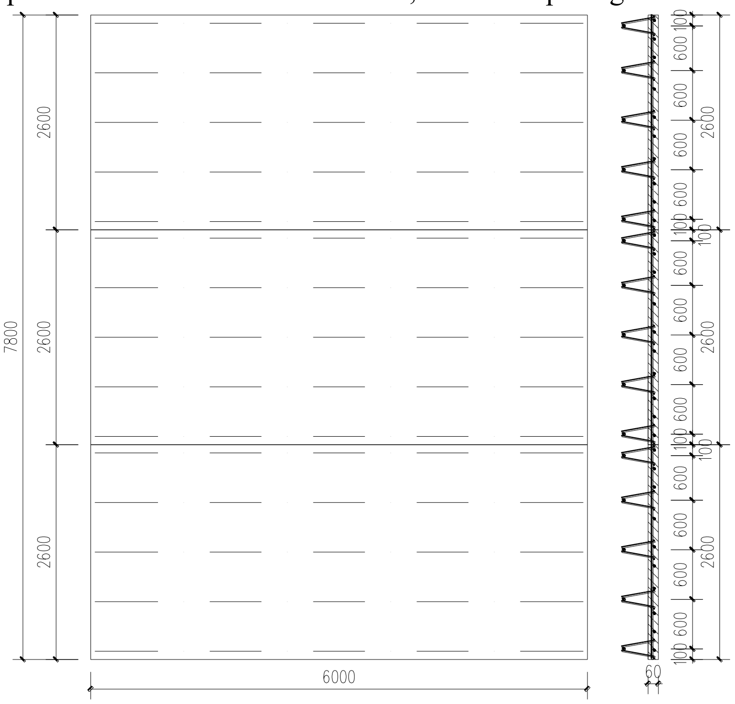

Fig.2 plan layout

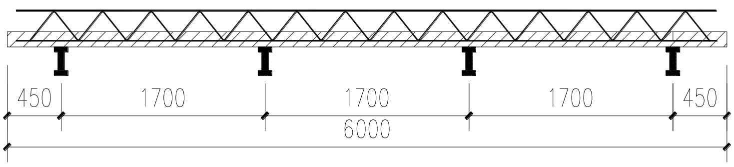

Fig.3 timber formwork beam layout

(1). The equivalent composite beam section calculation parameters of the precast floor slab are showed in Table 1.

Table 1 calculation parameters

parameters	value	unit	parameters	value	unit
y_0	30.62	*mm*	I_0	15779374	mm^4
W_0	515329	mm^3	W_c	168980	mm^3
ϕ	47.73	°	α	70.02	°
φ_c	0.684	—	φ_d	0.890	—

(2). Load calculation:

$$q_p = 0.16\times0.6\times(24+1.1) = 2.41kN/m \tag{12}$$

$$q_v = 2.5\times0.6 = 1.5kN/m \tag{13}$$

$$F_v=2.5kN \tag{14}$$

According to Figure 3, the equivalent composite beam is calculated by three-span continuous beam.

$$M_+ = 1.46kN \cdot m \tag{15}$$

$$M_- = 1.44kN \cdot m \tag{16}$$

$$V = 4.15kN \tag{17}$$

(3). The checking results are shown in Table 2.

Table 2 checking calculation results（units: *N/mm²*）

No	Checking index	Calculation index	Permission index	Checking results
1	pressure instability of upper reinforcement	σ_{sc} =251.0	$\varphi_c f_{yk}$ =273.6	OK
2	pressure instability of upper reinforcement	σ_s = 56.8	$0.7 f_{yk}$ =280.0	OK
3	tensile yield stress of distribution reinforcement parallel with lattice girders	σ_s =35.7	$0.7 f_{yk}$ =280.0	OK
4	normal section direct compressive stress of precast concrete	σ_{cc} = 2.79	$0.8 f_{ck}^1$ =16.08	OK
5	shear instability of oblique reinforcement	σ_{sr} =51.0	$\varphi_d f_{yk}$ =356.0	OK

4.2. Checking of the vertical support spacing

H20 wood I beam is made of Picea Koraiensis Nakai (TC13B). Its cross section is symmetrical I-shaped section. The sectional dimension is 89*mm* × 200*mm* × 38*mm* (width × height × thickness). Vertical supports are model CH steel pipe struts, spacing 1450*mm* (Fig. 4). Reinforcing bars take Q235B material. The cannula outside diameter is 48.6*mm*, internal diameter is 43.8*mm*. The bushing outside diameter is 60.5*mm*, internal diameter is 55.7*mm*. Both wall thickness is 2.4*mm*. The bolt diameter is 12*mm*, and the bolt aperture dimension is 15*mm*.

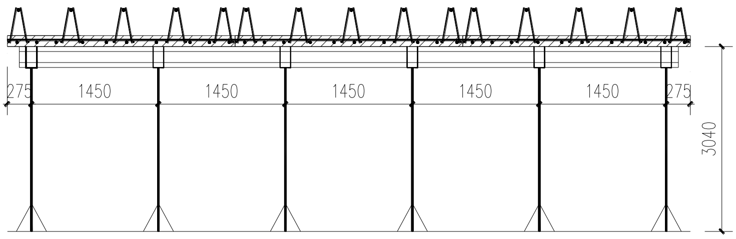

Fig.4 vertical floor props layout

4.2.1. Checking of wood I beams. Wood I beams are calculated by simply supported beams. The construction uniform variable load takes 1.5 kN/m^2. Reinforced concrete self-weight takes 25.1 kN/m^3. Wood I beams self-weight takes $5kN/m^3$. The load range of a single wooden I beam takes 1700*mm*.

1) Load calculation

Permanent load:

$$q_p=25.1\times0.16\times1.7+0.011476\times5=6.9kN/m \tag{18}$$

Variable load:

$$q_v{=}1.5\times1.7{=}2.55kN/m \tag{19}$$

2) Checking of bending strength

$$M = 2.8kN\cdot m \tag{20}$$

$$I = 5.12\times10^7 mm^4 \tag{21}$$

$$\sigma = \frac{My}{I} = 5.47N/mm^2 < 13N/mm^2 \tag{22}$$

3) Checking of deflection

$$\upsilon = \frac{5ql^4}{384EI} = 0.86mm < \frac{l}{400} = 3.6mm \tag{23}$$

4.2.2. Checking of the vertical support

1) Load calculation

Permanent load:

$$G_k = 6.9\times1.45 = 10kN \tag{24}$$

Variable load:

$$Q_k = 1.0\times1.7\times1.45 = 2.5kN \tag{25}$$

$$N = 0.9\max(1.35\times10 + 2.5\times1.4\times0.7, 1.2\times10 + 2.5\times1.4) = 14.36kN \tag{26}$$

2) Checking of strength

$$\frac{N}{A_n} = \frac{14.36\times10^3}{348-2\times15\times2.4} = 52N/mm^2 < f \tag{27}$$

3) Checking of compression bearing capacity

The looseness between the cannula and the bushing makes supports into the shape of a polyline, and forms the initial eccentricity. In this example, the eccentricity is $25mm$.

$$n = \frac{I_{x2}}{I_{x1}} = \frac{18.51\times10^4}{9.93\times10^4} = 1.99 \tag{28}$$

$$\mu = \sqrt{\frac{1+n}{2}} = \sqrt{\frac{1+1.99}{2}} = 1.223 \tag{29}$$

$$\lambda_x = \mu\frac{L}{i_2} = 1.223\times\frac{2840}{20.6} = 169 \tag{30}$$

$$\varphi_x = 0.251 \tag{31}$$

$$N_{EX} = \frac{\pi^2 EA}{\lambda_x^2} = 31kN \tag{32}$$

$$\frac{N}{\varphi_x A} + \frac{\beta_{mx}M_x}{W_{1x}(1-0.8\frac{N}{N_{EX}})} = 223.8N/mm^2 \tag{33}$$

Because of $223.8N/mm^2 < 215\times1.05 = 225.75N/mm^3$, so the checking also meets the requirements.

4) Checking of shear strength of bolt

$$\frac{N}{2A_0} = 63.5kN/mm^2 < 125kN/mm^2 \tag{34}$$

5) Checking of compression strength of steel tube wall at the bolt

$$\frac{N}{A_{ce}} = 249N/mm^2 < 320N/mm^2 \tag{35}$$

The layout of wood I beams and vertical supports meet the requirements of the calculation. In the construction site, we can construct according to the Figure (3) and Figure

5. Conclusion and Outlook

5.1. Conclusion

The installation checking is an important content of the construction checking of the bottom plate of the composite floor slab. It is a powerful guarantee to ensure the safety of site construction. This article proposes a computational method of the installation checking of the composite floor slab, and defines the load value and the combination. Then the computing method is used in a project case. It can be seen that the simple computational method and sufficient checking indexes can be used as the checking method of precast floor slab installation in the future.

5.2. Outlook

In actual projects, there are too many types of slab, and manual calculation workload is so heavy. In the future, we should focus on the research to develop the corresponding computer program, and use optimization analysis to provide the most reasonable layout of support beams and vertical supports. Try to achieve the lowest cost and the fastest construction layout under the premise of ensuring the safety of construction.

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