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To determine the optimal size of the elements of complex overlap

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Abstract. The article discusses the possibilities of optimizing the size of elements of reinforced concrete ceilings along. The optimization of the overlap consists in finding such parameters of the reinforced concrete slab, profiled flooring and steel beams, in which their strength is fully used. For ceilings with steel beams included, the dimensions of the sections of the elements and their strength characteristics are determined by the requirements of the limit states of the second group (deflections), and the calculation of the forces in the slab and beams and strength calculations are performed taking into account the geometric and strength characteristics established from the calculation of deformations. To clarify the features of the calculation and verification of the main provisions, a numerical experiment was carried out, where the center cell of the steel concrete slab along metal rolling beams was selected as the object of study. Formulas are obtained for determining the forces using predetermined dimensions of the components of the overlap based on satisfying the requirements of the 2 groups of limit states. These studies can serve as a basis for further research on the search for optimal parameters of complex floors.

1. Introduction

Complex monolithic reinforced concrete floors consist of steel beams, profiled flooring and reinforced concrete slabs (Figure1). In such ceilings, the profiled sheet is a formwork system that provides the structure with additional rigidity, which makes it possible to create a cost-effective and easily constructed structure, therefore the search for the optimal dimensions of such structures is always relevant [1-3].

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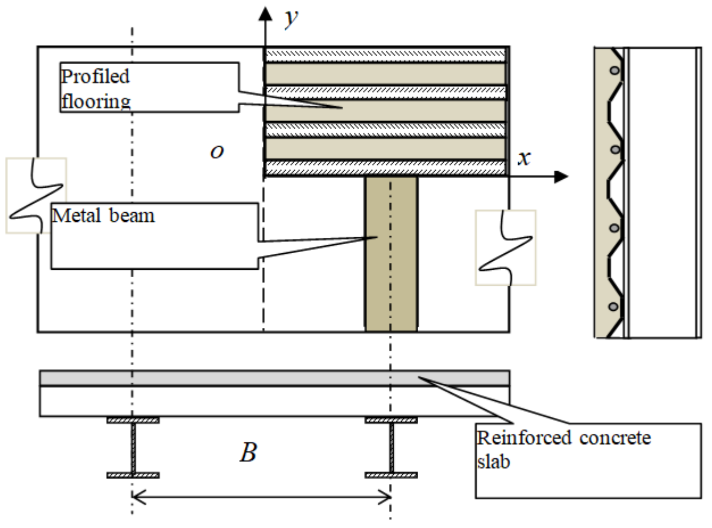

Fig. 1. Overlap scheme

Many Russian and foreign scientists were studying the work of complex monolithic ceilings, supported on metal beams. For example, in [1-3] the questions of the relevance of the use of such structures in buildings of various purposes have been studied. Features of calculations of such overlaps are presented in the studies [4-16].

Traditionally, the calculation of strength was carried out in accordance with the distribution of forces, in proportion to the rigidity of the components of the overlap [17]. Since 1984, the calculation of composite structures has been carried out in accordance with [18] and its subsequent versions [19], and in 2017 a normative document [20] has been introduced, which to some extent duplicates the provisions of previous standards. At present, in Russia it is recommended to calculate the steel-reinforced concrete structures in accordance with [20].

2. Methods

A feature of the calculation of these structures is to take into account the joint work of the profiled flooring with a reinforced concrete slab and steel beams. The connection of profiled flooring with a reinforced concrete slab, as a rule, is ensured by reliable adhesion of the decking and concrete slab, due to constructive measures and can be considered as a reinforced concrete slab with anisotropic stiffness. The retaining of a steel concrete slab on steel beams, as a rule, is a hinge and the distribution of forces from vertical loads is proportional to the flexural rigidity of the constituent elements.

In general, the bearing capacity of the slab (external bending moment M_{pl}) depends on the thickness of the concrete slab h_{pl}, the concrete strength of the slab R_b, the strength of the reinforcement of the slab $R_{s,}$ the amount of reinforcement of the slab A_s, the cross-sectional dimensions A and the strength of the sheeting $R_{s,pf}$

$$M_{pl}=M\,(h_{pl};\,R_b;\,R_s;\,A_s;\,A;\,R_{s,\,pf}) \tag{1}$$

The bearing capacity of the steel beam (M_b) is a function of the geometrical parameters of the section and, in particular, the moment of resistance W_b and strength of the material R_{sb}.

$$M_b=M\,(W_b;\,R_{sb}) \tag{2}$$

Thus, the overlap strength in general (M) is determined by eight variable parameters, reflecting the geometric characteristics of the cross sections and the strength properties of materials.

$$M=M\,(h_{pl};\,R_b;\,R_s;\,A_s;\,A;\,R_{s,\,pf};\,R_{sb};\,W_b) \tag{3}$$

The optimization of the overlap consists in finding such parameters of the reinforced concrete slab, profiled flooring and steel beams for which their strength is used completely (the utilization rate of materials is close to unity).

However, in most cases, for ceilings with steel beams included, the dimensions of the sections of elements and their strength characteristics are determined by the requirements of the limiting states of the second group (deflections), and the calculation of forces in the slab and beams and strength calculations are performed taking into account the geometric and strength characteristics, established from the calculation of deformations.

To clarify the features of the calculation and verification of the main provisions, a numerical experiment was conducted, where the central cell of the steel concrete slab along metal rolling beams was selected as the object of study (Fig. 1).

In case of articulated support of the slab along the corrugated wave and uniform load, the maximum deflection in the middle of the span, in the slab stage of operation without cracks and without regard to the rigidity of the flooring, is equal to

$$f_{pl}=\frac{5q_{pl}l_{pl}^{\ 4}}{384E_{pl}I_{pl}} \tag{4}$$

q_{pl} - linear load on the slab, including dead weight,

l_{pl} - the calculated span of the slab was taken to be equal to the distance between the extreme supports, and the influence of the local deflection between the beams was not taken into account due to their smallness.

When $n_{pl}=l_{pl}/f_{pl}$ the moment of inertia of the plate is equal to

$$I_{pl}=\frac{5n_{pl}q_{pl}l_{pl}^{\ 3}}{384E_{pl}} \tag{5}$$

At the moment of inertia $I_{pl}=b_{pl}\,h_{pl}^{\ 3}/12$, b=1 the height of the plate section is equal to

$$h_{pl}=\frac{l_{pl}}{4}\sqrt[3]{\frac{q_{pl}n}{E_{pl}}} \tag{6}$$

Here, the coefficient of relative deflection $n=l_{pl}/f_{pl}$.

3. Results and discussion

In Figure 2 graphs of slab height under short-term load action (l_{pl} = 600 cm, n = 200, concrete class B20) are presented. The graphs show that the requirement of the plate rigidity, has a greater influence on the choice of height, than load growth.

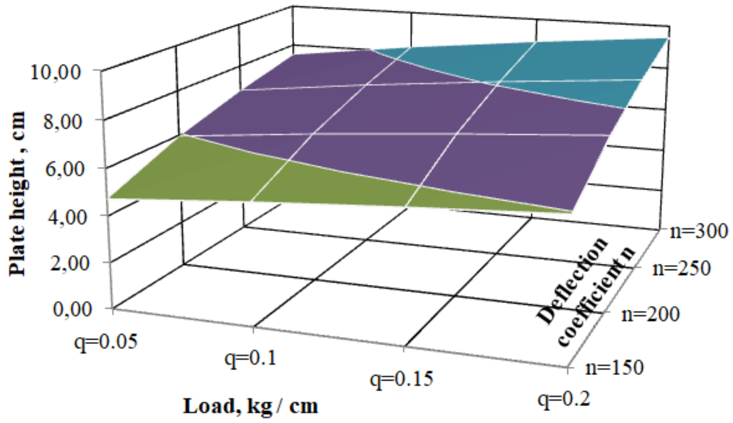

Fig. 2. The dependence of the height of the plate from the load q and n

Similarly, the moment of inertia of the beam is

$$I_b = \frac{5n_b q_b l_b^{\ 3}}{384E_b} \tag{7}$$

q_b - full regulatory load on the beam, including its own weight,
l_b - the estimated span of the beam,
coefficient of relative deflection $n_b = l_b / f_b$.

In Figure 3 graphs of inertia moments change under short-term load action are presented (beam span l_b = 600 cm, n = 200, distance between beams B = 1 m).

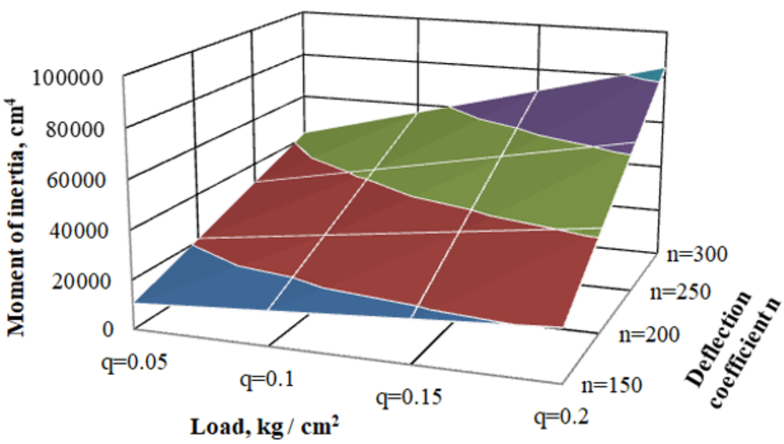

Fig. 3. Dependence of the moment of inertia $I = I\ (n;\ q)$

To derive general patterns of calculations, we consider a profiled sheet and a reinforced concrete slab as working together, that is, a single, seamless structure, where the distribution of forces should be proportional to the stiffness of the beam and floor, calculated from the calculation of equality based on the limiting deflections.

$$\frac{M_{pl}}{M_b}=\frac{I_{pl}}{I_b}=\frac{384E_b}{5n_bq_bl_b^3}\cdot\frac{5n_{pl}q_{pl}l_{pl}^3}{384E_{pl}}=\frac{E_b}{E_{pl}}\cdot\frac{n_{pl}q_{pl}l_{pl}^3}{n_bq_bl_b^3} \tag{8}$$

When replacing the ratio of the modulus of elasticity of concrete slabs to the modulus of elasticity of steel beams by the coefficient of reduction α

$$\frac{M_{pl}}{M_b}=\alpha\cdot\frac{n_{pl}q_{pl}l_{pl}^3}{n_bq_bl_b^3} \tag{9}$$

Taking into account that the load on the beam can be expressed through the load on the slab and the step of the beams qb = V · qpl

$$\frac{M_{pl}}{M_b}=\alpha\cdot\frac{n_{pl}l_{pl}^3}{n_bBl_b^3} \tag{10}$$

In the special case when the beam span equal span of end support plates $l_b = l_{pl}$, formulas (9) and (10) take the form respectively

$$\frac{M_{pl}}{M_b}=\alpha\cdot\frac{q_{pl}}{q_b} \quad \text{и} \quad \frac{M_{pl}}{M_b}=\frac{\alpha}{B} \tag{11}$$

Since 2017, the design of such ceilings, in the Russian Federation used the joint venture 266.1325800. 2016 «Structures of steel reinforced concrete. Design rules» [20].

4. Conclusions

1. These formulas can be used to define forces using predetermined dimensions of the components of the overlap based on satisfying the requirements of the 2 groups of limit states.

2. The presented article can serve as a basis for further research on the search for optimal parameters of complex floors.

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