On the Application of High-Strength Reinforcement in Beamless Slab

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Abstract. The paper considers the peculiarities of the stress-strain state in the zone of junction of the slab of slabs with the joint using conventional and high-strength reinforcement. The maximum stresses in the stretched concrete before cracking correspond to the tensile strength of the concrete, and the stresses in the reinforcement before cracking depend on the reduction factor and were calculated for various classes of concrete. After the formation of cracks, the increase in stresses in the tensioned reinforcement depends on the width of the crack opening and the deformation of the reinforcement between the cracks. The paper shows that with a sufficient width of crack opening and a certain distance between the cracks, high-strength reinforcement can be used to increase the bearing capacity of the support sections of the plate. The total stresses in the reinforcement were calculated for different crack opening widths and different distances between the cracks, the results of which were used to plot the graphs. The graphs of the dependence of the content of high-strength reinforcement on the strength of the normal section, as well as the graphs of the growth of strength with different ratios of the number of rods, are plotted. According to the results of the work, it can be seen that, depending on the class of high-strength reinforcement and its quantity, the strength of normal sections can be increased up to two times.

1. Introduction

The use of beam-free ceilings remains one of the most relevant areas of development in reinforced concrete construction. When designing monolithic flat girders, as a rule, special attention is paid to the calculation and design of the junction area of the glueless slab plate to the column, since this zone has a great influence on the overall structural safety of the slab. Therefore, the study of the stress-strain state of this site, as well as the possibility of increasing the carrying capacity of this zone is of great importance, which is especially important for large spans (over 6 m), and, accordingly, large loads on this site, the slab and column.

The main provisions and calculations of the junction of the plate and the column are usually made in accordance with the regulatory documents, such as [1-9].

The study of the stress-strain state of this site was carried out by many Russian and foreign scientists, as described in [10–17]. The problems arising from the calculations of the junction of a column and a slab in monolithic structures, including the calculation for pushing, are covered in a
wide range of works, for example [10-14]. The following works [15-22] are devoted to strengthening the interface zones of a plate and a column.

In the present work, the peculiarities of the stress-strain state in the zone of junction of the slab of slabs to the column are considered when conventional and high-strength reinforcement are used together (Figure 1).

2. Methods
Consider the bearing capacity of the zone of junction of the girderless ceiling to the column when using conventional and high-strength reinforcement together (Figure 1).

![Figure 1. Node adjoining the flat girder to the column.](image)

When reinforcing a slab with conventional reinforcement classes A400-A500 with a yield area and sufficient strength of concrete, ensuring failure along reinforcement (ξ ≤ ξₕ), the reference moments cannot exceed the values determined by the physical yield strength of the longitudinal reinforcement and its quantity in the design section.

The maximum stresses in stretched concrete before cracking correspond to the tensile strength of concrete \( R_{bt,n} \), and in conventional and high-strength reinforcement before formation of cracks are \( \sigma_{s,0} = 2\alpha R_{bt,n} \). Here \( \alpha \) is the coefficient of reduction, equal to the ratio of elastic moduli of reinforcement and concrete \( \alpha = E_s / E_b \).

The stresses in the reinforcement \( \sigma_{s,0} \) before cracking, calculated for various classes of concrete, are presented in Table 1.

| Concrete class | \( \sigma_{s,0} \) (MPa) |
|---------------|------------------|
| B20           | 19.64            |
| B25           | 20.67            |
| B30           | 21.54            |
| B35           | 22.61            |
| B40           | 23.33            |

After the formation of cracks, the relative deformations of the reinforcement are determined by the width of the crack opening \( a_{cr} \) and the distance between the cracks \( l_{cr} \) (excluding deformations of concrete and reinforcement in the block between the cracks).

The width of crack opening from the condition of retention of reinforcement with a short crack opening is assumed: for core reinforcement classes A240 ÷ A600 - 0.4 mm, for reinforcement A800 ÷ A1000 - 0.3 mm [1-3], the basic calculated distance between the cracks \( l_{cr} \), in accordance with [1-3], is determined by the formula (1).

\[
l_{cr} = 0.5A_{bt} \cdot d_s / A_s = 2A_{bt} / \pi d_s
\]  

(1)

In formula (1), the area of stretched concrete \( A_{bt} \) is calculated with the height of the stretched zone no more than half the section height of the element (0.5h) and at least twice the protective layer “2a”
[1-5]. Here \(d_i\) is the diameter of the reinforcement, \(n\) is the number of rods in the design section. Structurally, in accordance with [1-3] the distance between the cracks \(l_{crc}\) is taken not less than 100 mm and not more than 400 mm.

After the formation of cracks, the increase in stresses in the tensioned reinforcement depends on the width of the opening of the \(a_{crc}\) cracks and the deformations of the reinforcement between the cracks. The stresses in the reinforcement were in accordance with Hooke's law: for ordinary reinforcement to calculate the strength.

The stresses in the reinforcement were in accordance with Hooke's law: for ordinary reinforcement to calculate the values of relative deformations and normal stresses in the longitudinal reinforcement. It should be borne in mind that for conventional reinforcement the stresses cannot exceed the yield strength, and for high-strength reinforcement temporary resistance. However, fulfilling the requirements of the first group of limit states, the design characteristics of reinforcement \(R_s\) are used to calculate the strength. They correspond to the yield strength for ordinary steel and the conditional yield strength for high-strength reinforcement. The total stresses in the reinforcement due to crack opening at the modulus of elasticity of reinforcement \(E_s = 200000 \text{ MPa}\) are shown in Table 2 [18-20].

**Table 2.** Total stresses in the reinforcement \(\sigma_s\) with \(a_{crc} = 0.4 \text{ mm}\) and different distances between the cracks \(l_{crc}\).

| Concrete class | \(\sigma_s\) | 50  | 100 | 150 | 200 | 250 | 300 | 350 | 400 |
|---------------|------------|-----|-----|-----|-----|-----|-----|-----|-----|
| B20           | 19.6       | 1619.6 | 819.6 | 553.0 | 419.6 | 339.6 | 286.3 | 248.2 | 219.6 |
| B25           | 20.7       | 1620.7 | 820.7 | 554.0 | 420.7 | 340.7 | 287.3 | 249.2 | 220.7 |
| B30           | 21.5       | 1621.5 | 821.5 | 554.9 | 421.5 | 341.5 | 288.2 | 250.1 | 221.5 |
| B35           | 22.6       | 1622.6 | 822.6 | 555.9 | 422.6 | 342.6 | 289.3 | 251.2 | 222.6 |
| B40           | 23.3       | 1623.3 | 823.3 | 556.7 | 423.3 | 343.3 | 290.0 | 251.9 | 223.3 |

The table shows that with a crack opening width of \(a_{crc} = 0.4 \text{ mm}\) and the distance between the cracks from 100 to 200 mm, the stresses in high-strength reinforcement reach \(\sigma_s \approx 550 \div 820 \text{ MPa}\), which indicates the possibility of using high-strength reinforcement for increasing the bearing capacity of the support sections of the plate.

To establish the share of high-strength reinforcement in increasing the load-bearing capacity of the slab in the support zone on the columns, a beam-less overlap was considered, with a thickness of \(h=200 \text{ mm}\), a column with \(b_h \times t_h = 400 \times 400 \text{ mm}\) section made of concrete of class B25 [21]. The upper reinforcement crossing the column are rods with a diameter of \(d_i = 14 \text{ mm}\), the number of rods is \(n = 5\), the pitch of rods is 70 mm, \(A_s = 7.69 \text{ cm}^2\) [18-20]. The width of the design section was equal to the width of the column \(b = b_h = 400 \text{ mm}\). In accordance with the standards, in all cases, the protective layer \(a_z \geq 20 \text{ mm}\) [1-3]. Take \(a_z = 20 \text{ mm}\)

\[a = a_z + d_i / 2 = 20 + 14 / 2 = 27 \text{ (mm)}.
\]

Maximum area of stretched concrete

\[A_{ht,max} = 0.5hb = 0.5 \cdot 20 \cdot 40 = 400 \text{ (cm}^2)\].

The minimum area of stretched concrete

\[A_{ht,min} = 2ab = 2 \cdot 2.7 \cdot 40 = 216 \text{ (cm}^2)\].

Estimated maximum crack spacing

\[l_{crc,min} = 0.5A_{ht,min} \cdot d_i / A_s = 2A_{ht,min} / (n\pi d_i) = 2 \cdot 400 / (5 \cdot 3.14 \cdot 1.4) = 36.4 \text{ (cm)}\].

It follows from the table that when reinforcing a plate with the most common reinforcement of class A400, \(R_s = 350 \text{ MPa}\), with a crack width of \(a_{crc} = 0.4 \text{ mm}\) and a distance between the cracks \(l_{crc} = 100 \div 200 \text{ mm}\), plastic deformations develop in the reinforcement, and the stresses stabilize on conditional yield strength (for calculating the strength of \(R_s\)) [18-21].

So the bearing moment on the face of the column with 5 rods of class A400 with a diameter of 14 mm and concrete B25 \((z_l = 0.6h = 0.6 \cdot 0.173 = 0.1038 \text{ m})\) is equal to

\[M_S = R_sA_z z_l = 350 \cdot 103 \cdot 7.69 \cdot 10^{-4} \cdot 0.6 \cdot 0.173 = 27.94 \text{ (kNm)}.
\]
When replacing 3 rods Ø14 mm class A400 with A600 reinforcement of the same diameter

\[ M_s = (R_s A_s + \sigma_s A_s) z_0 = (350 \cdot 10^3 \cdot 3.08 \cdot 10^{-4} + 520 \cdot 10^3 \cdot 4.62 \cdot 10^{-4}) \cdot 0.1038 = 36.13 \text{ (kNm)}. \]  

(7)

3. Results and discussion

The graphs in Figure 2 show the dependences of the stresses in the reinforcement with a crack width of 0.4 mm for different distances between the cracks and concrete classes.

**Figure 2.** Stresses in reinforcement with \( a_{crc} = 0.4 \text{ mm} \)

The graphs in Figure 3 show the dependences of the stresses in the reinforcement for different widths of cracks and the distances between the cracks for the concrete class B25.

**Figure 3.** Stresses in reinforcement with concrete B25, various crack widths and distances between the cracks.

The graphs in Figure 4 and Figure 5 show the bearing capacity of the section when reinforcing the section with fully A400 reinforcement and an increase in section strength by replacing the A400 reinforcement with the A800. It can be seen that, depending on the class of high-strength reinforcement and its quantity, the strength of normal sections can be increased up to two times.
4. Conclusions
The paper shows that with a sufficient width of crack opening and a certain distance between the cracks, high-strength reinforcement can be used to increase the bearing capacity of the support sections of the plate.

The strength of a section reinforced with A400 fully reinforcement can be increased by replacing A400 with an A800 reinforcement: depending on the grade of high-strength reinforcement and its amount, the strength of normal sections can be increased up to two times.

The results of the work can be used in the design of beam and flat floors in practical activities, if it is necessary to increase the bearing capacity of the section.

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