Reinforced concrete beams with console ribs along their side surfaces

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Abstract: The formulas for determining losses in pre-compressed high-strength reinforcement are given, as well as the condition for closing the initial technological cracks in bent elements with pre-compressed reinforcement necessary for calculating reinforced concrete beams with pre-compressed and stretched high-strength reinforcement

Introduction
The existing reinforced concrete beams have, as a rule, a rectangular, t-shaped or I-beam cross section. Stretched area is reinforced with a high strength pre-stretched reinforcement, and a condensed – normal non-stressed or pre-stretched S’ (with the aim of improving crack resistance upon the prestressed rebar transfer in concrete). Pre-stretching of S’ rebar is always sought to take the minimum from the crack resistance condition, since it can reduce the beam strength (at $\xi$ close to $\xi_R$). The shelves’ dimensions in the compressed area are received from the conditions of strength and ability of bearing plates cover the two adjacent spans, and the shelves stretched zone of the accommodation conditions and tensile reinforcement [1].

With these beams, the structural coating height is equal to the sum of the beam and the coating plates’ heights.

Unlike the traditionally specified solutions, the authors have developed a new solution truss of reinforced concrete beams with consoles for the slab support (Fig. 1). Consoles in the beam height are arranged so that the plate coating surface available on consoles, makes it flush with the top face of the beam, and the consoles’ departure is received from the plates’ support conditions.

With this solution, the structural height of the coating will decrease by the height of the slab, which will lead to a significant reduction in the volume of brickwork on the walls of the building [2].

The beam edge above the console is taken from the condition for placing the compressed rebar in it. As the latter, the use of high-strength pre-compressed rod fittings of large diameters is provided. The latter makes it easier to ensure its stability during pre-compression and reduces the labor intensity of reinforcement work.

Main part
The compressed zone high-strength reinforcement pre-compression use makes it possible to significantly increase the maximum stress in it before the compressed concrete destruction, which leads to a significant reduction in reinforcement consumption with constant load-bearing capacity of the beam. For example, if the valve class is A1000 and the pre-compression of the valve is $\sigma'_{sp} = -400$ MPa, the maximum compressive stress is $R_c + \sigma'_{sp}$, i.e. it is doubled. The use of pre-compressed
high-strength rebar in the compressed zone of the proposed beam compensates for the shelves’ lack in this zone and provides the possibility of accepting the minimum rib width necessary for the rebar placement [3].

The stability of rebar rods 1 subjected to pre-compression is provided by their binding with a knitted wire 2 to the transverse L-shaped rebar 3 at the inflection points (Figure 1, b). The rebar frame stability as a whole is achieved by placing the transverse rebar 3 in the walls 4 of the metal formwork in the horizontal direction and in the vertical direction by placing the rebar frame in the step plates 5, placed in increments of about 100 cm [4].

These principles were implemented in the design of a reinforced concrete truss beam with a span of 24 m. The beam height is 200 cm, the distance from the top of the consoles to the upper face of the beam is assumed to be equal to the standard ribbed plates’ height with the dimensions of 45.5 x 300 x 1200 cm. The beam has 6 hexagonal holes with the dimensions 90x150 cm to facilitate it and reduce
concrete consumption. Transverse and all structural fittings are accepted with a diameter 8 mm of A500 class. Longitudinal working fittings for stretched and compressed zones made of A1000 class steel. Concrete of class B30.

With the dimensions shown in Figure 1 the beam weight in the absence of holes is 13570 kg, and in their presence – 12010 kg. The arrangement of the holes shown in Fig. 1 reduces the beam weight by 11.5%. The consumption of heavy concrete is reduced by the same amount.

Note that the weight of the beam in question and concrete consumption is almost the same as the trusses with parallel belts at the same span and load.

The calculation of the developed beam (Figure 1) for both groups of limiting states is performed for the following real load:

- the design loads \( N/m^2 \): the weight of the roof - 1195; the same, reinforced concrete ribbed slabs 3x12 m - 2255; the same reinforced concrete beams - 465; snow (with a combination coefficient of \( \Psi_2=0.8 \)) - 1120, total - 5035 N/m².

The calculated bending moment in the middle of the span is \( M=4027.26 \) kN·m, the standard bending moment is \( M^d=3221.81 \) kN·m.

Let us assume that the prestress value is equal to:

\[ \sigma'_sp=800 \text{ MPa}; \sigma''_sp=-500 \text{ MPa}. \]

The indicated in Figure 1 cross sections of the working armature \( A_{sp}=6\varnothing 25 \text{ A}1000 (29.45 \text{ cm}^2) \) and \( a'_{sp}=2\varnothing 25 \text{ A}1000 (9.82 \text{ cm}^2) \) obtained the following results of the bearing capacity complete calculation

\[ M=4254.45 \text{ kN·m} > 4027.26 \text{ kN·m}; \]

the technological cracks’ width on the upper face is: \( a_{crc1}=0.266 \text{ mm} \);

the external load cracks formation moment is:

\[ M_{crc} = 2105.21 \text{ kN·m} = 0.5 M \text{ kN·m}; \]

the width of cracks opening at the rebar level is: \( S_p - a_{crc}=0.207 \text{ mm} \);

the beam bending is: \( f= 7.16 \text{ sm}; f/l=1/330 < 1/250. \)

Thus, the projected beam meets all the standard requirements. To determine the main technical and economic indicators’ impact of the considered beams on PC calculations 20 beams, which change only the values of the prestressed tensile reinforcement \( \sigma'_{sp} \) and prestressed compression \( \sigma''_{sp} \), were made. Each of the 5 values \( \sigma'_{sp} \) (from 0 to 800 MPa) corresponded to 4 values of \( \sigma''_{sp} \) (from 0 to -500 MPa).

\[ \text{Figure 2. Consumption of A1000 class valves in a 24m span truss beam for various combinations of } S'_{p} \text{ and } S_{p} \text{ valves’ pre-compression} \]
1, 2, 3 - flow rate of the compressed valves $A'_p$, stretched $A_p$ and total $A_p + A'_p$.

The results effects on working rate of the preliminary stretching reinforcement combinations of rebar $S_p$ and pre-compression valves $S'_p$ in the abbreviated form are shown in Figure 2 and in Table 1.

From the above shown data it is seen that the compressed zone reinforcement preliminary compression leads to a significant reduction in the working reinforcement total consumption (up to 24%). This is because with an increase in ultimate compressive stresses in the reinforcement $S'_p$ firstly, reinforcement consumption is reduced $S'_p$, and secondly, the compressive force proportion $S'_p$, coming to the reinforcement increases, which leads to a decrease in the compressed section zone height (see Table 1) and to an increase in the shoulder of the internal pair of forces and, as a consequence, to a decrease in the longitudinal forces in the reinforcement $S_p$ and the required reinforcement section $A_p$.

Table 1. Effect of pre-stresses on reducing rebar consumption and relative height of the beam span’s compressed area 24 m by $M = 4027.26$ kN·m Const.

| $\sigma_{sp}$ [MPa] | $\sigma'_{sp}$ [MPa] | $A_p + A'_p$ [%] | $\xi$ | $\xi/\xi_R$ |
|---------------------|----------------------|------------------|-------|------------|
| 0                   | 0                    | 49.29            | 100   | 0.436      | 1.26        |
| 0                   | -450                 | 37.7             | 76    | 0.331      | 0.96        |
| 640                 | 0                    | 40.71            | 82.6  | 0.469      | 0.83        |
| 640                 | -450                 | 35.47            | 72    | 0.346      | 0.61        |

When increasing preliminary stretching of $S_p$ rebar and the absence of a pre-stressed compression fittings $S'_p$ also a decrease in rebar consumption, but in a less degree than during pre-compression (to 17.4%). In this case, the reduction degree in the flow rate of the valve is related to the ratio $\xi/\xi_R$ - the less it is, the less the force in the valve Sp.

In the case of combined pre-stress adopted in the proposed solution, as it can be seen from Table 1, the ratio $\xi/\xi_R$ and the flow rate of the valve is the lowest.

If we assume constant reinforcement $A_p + A'_p = 26.95 + 8.89 = 35.84$ cm$^2 = $ Const and all other beam characteristics changing only the preliminary stress, we get the following results (Table 2).

The best performance has a beam with combined prestressing - its load-bearing capacity is maximum (4027.3 kN·m), it is 17.5% more than a beam without pre-stressing.

Table 2. Changes in the parameters of the proposed truss beam with a span of 24 m at different combinations of compressive and tensile pre-stresses in the compressed and stretched zones’ reinforcement.

| $\sigma_{sp}$ [MPa] | $\sigma'_{sp}$ [MPa] | $M_c$ [k·Nm] | $a_{crc,1}$ [mm] | $M_{crc}$ [k·Nm] | $M_{crc}/M$ | $a_{crc}$ [mm] | $f_i$ [mm] | $ll_f$ |
|---------------------|----------------------|---------------|------------------|------------------|-------------|----------------|------------|--------|
| 0                   | 0                    | 3428.3        | 0                | 404.1            | 0.12        | 0.438          | 14.18      | /167   |
| 0                   | -500                 | 3838.3        | 0.01             | 661.9            | 0.17        | 0.79           | 14.65      | /161   |
| 800                 | 0                    | 3674.2        | 0                | 1957.8           | 0.53        | 0.142          | 5.13       | /461   |
| 800                 | -500                 | 4027.3        | 0.257            | 2081.1           | 0.52        | 0.206          | 6.64       | /356   |

Pre-compression of the compressed zone rebar increases the load-bearing capacity of the beam to a greater extent than pre-stretching of the stretched zone rebar. Pre-compression valves and the absence of pre-stretching the carrying capacity is increased by 12%, while pre-tension reinforcement and the absence of pre-compression is 7.2%.

In the beams’ manufacturing, pre-stress forces cause the technological cracks formation on the upper face, the width of which is within the acceptable limits. When an external load is applied to the
beam, these cracks often close, but reduce the stiffness and crack resistance of the sections. The beams with pre-stretched rebar have the highest crack resistance of cross sections and the lowest deflection. These indicators are also very favorable in beams with combined prestressing. The latter, if we also consider their greatest load-bearing capacity, are undoubtedly preferable to all the others.

![Diagram of reinforced concrete truss beam with console ledges]

Figure 3. Reinforced Concrete truss beam with console ledges
a)- General view of the beam with the installed coating plates (dotted line); b)- plan of the coating; c)- cross-sections of the beam; d)- solution with steel consoles

As it was mentioned above, when using the proposed beams with consoles, the coating plates are placed on the consoles, and that allows reducing the structural height of the coating by the height of the plate edge - in this particular solution - by 45.5 cm. This will significantly reduce the building masonry walls’ volume. If we take the building size in terms of 24x72 m (Fig. 1, d), and the wall thickness as 0.51 m, the masonry volume will decrease by 0.4550,512(24+72) = 44. m³.
Summary
In the development of the solution discussed above, instead of the solid longitudinal cantilever ribs on the side faces, it is proposed to provide for the cantilever protrusions’ device with a step equal to the width of the ribbed coating plates (Fig. 3). In this case, the longitudinal edges of the coating plates are laid on the cantilever protrusions 2 of the truss beam 3.

The reinforcement and pre-tension of the considered truss beam is maintained the same as in the previously proposed one (Fig. 1), except for the reinforcement of the consoles. In the previous solution about 79 kg of class A500 rebar was required to reinforce the cantilever ribs of a single beam with a span of 24 m, while in this case only about 9 kg.

The beam weight is also significantly reduced. If the beam weight with cantilever ribs in the presence of holes is 12010 kg respectively, then the device cantilever protrusions is 10140 kg, i.e. 1870 kg less. The heavy concrete consumption in the building is reduced by the same amount.

Note that the beam weight and concrete consumption from the holes’ device in the beam wall is reduced by 11.5 %, and from the device of cantilever protrusions instead of cantilever ribs by the additional 16 %.

As cantilever projections can also serve as shaped steel profiles-channels or L-shape (Fig. 3, d), the latter are bolted 5 to the thickened wall of the beam. In this case the cross-section profile of the reinforced concrete beam is simplified.

References
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