The design parameters’ analysis of typical support parts for the ferro-concrete roof beams reinforced with unweighted frame

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Abstract. It is necessary to use ferro-concrete roof beams of considerable length, which, together with operational loads, often leads to an abnormal state of the latter, especially their support parts, in industrial buildings, especially in the presence of large spans, when they overlap. The option of strengthening the beam with an unweighted frame, in comparison with a typical solution is considered.

Introduction
The supporting part of ferro-concrete roof beams is the most vulnerable structural link of an industrial building, especially when it comes to large-span structures [1, 2, 3]. At the same time, the repair of ferro-concrete roof beams, today, basically boils down to their replacement. Such actions are associated, first of all, with large material and labor costs, but even more negative is the need, in some cases, to stop the main production process in the workshop for the period of the reconstruction and repair of load-bearing structures, namely the ferro-concrete roof beams. It is proposed to solve this issue by means of local strengthening the most vulnerable places of the ferro-concrete roof beams, that is, their support parts [4, 5]. At the same time, it was necessary to take into account the fact that if the spans are large, then the additional requirements arise for the reinforcing structures, namely, for their weight, when in fact they should be unweighted.

Today, the most widespread method is the strengthening the support parts of ferro-concrete roof beams by installing unloading brackets on both sides of the beam in the form of a pair of rod elements forming an acute angle [6, 7]. In turn, each end of a bar element running horizontally is connected to the bottom of the beam, and each end of a bar element running at an acute angle is connected to the top of the beam [8]. The opposite ends of the bar elements are united by the support plates located on both sides of the beam, which, in turn, are joined by strips [9, 10, 11]. Between the rod elements, mirrored on both sides, the additional tensioning devices, connected to the rod elements, rigidly, by welding, with the upper element and flexibly, through a threaded connection, with the lower element, are installed. At the same time, the bar elements themselves are rigidly connected to the upper and lower parts of the ferro-concrete roof beams by means of local concreting of special nodes for a gable roof beam, which is shown in Figure 1. Due to the creation of adjustable forces, in additional tensioning devices, an increase in the reliability of the supporting parts of ferro-concrete roof beams is achieved, as a result of an increase in the bearing capacity, since it is possible to redistribute the loads not only between the rods of the unloading brackets, but also between the ferro-concrete roof beams and the reinforcing structure [12, 13]. At the same time, pairs of rod elements forming an acute angle are currently supposed to be
made of such rolled products as a channel, but this is a relatively heavy material, in comparison, for example, with angle beam. In our work, it is proposed to study the issue of the angle beam device made of an unweighted unloading frame through numerical modeling, which is shown in Figure 1. Otherwise, the technical solution for strengthening the supporting parts of reinforced concrete beams of the coating is similar to that when using a channel as a rod element.

Materials and technique

The technical solution for strengthening the support parts of ferro-concrete roof beams with an unweighted frame for a gable beam is shown in Figure 1.

In order to analyze the effect of unloading brackets with an unweighted frame, in the form of a pair of rod elements made of steel angles, installed on a beam with parallel chords of a square section, on the operation of its supporting parts, numerical modeling was carried out in the Etabs 2019 software package. Figure 2 shows the sections accepted for the ferro-concrete roof beam calculation with the length L=6 m. and Figure 3 shows the dimensions of elements and parts.

As a result of numerical modeling, implemented with a stepwise increase in concentrated loads F1 and F2, acting at a distance of a quarter of the span from each support. In this case, in the numerical experiment, the concentrated loads F1 and F2 with odd attempts (1, 3, 5, etc.) were taken to be the same. For example, at the attempt 1 we have that F1 is equal to F2 and is equal to 6 tons, and at the attempt 3 - F1 is equal to F2 and is equal to 7 tons, and so on. Whereas for the even attempts (2, 4, 6, etc.), in the numerical experiment, the concentrated loads F1 and F2 were taken different, which is reflected in Table 1.
C- cross section at the support  
D- section at a distance from the support

**Figure 2.** The sections taken into account for a ferro-concrete beam

![Dimensions of elements and parts in mm.](image)

**Figure 3.** Dimensions of elements and parts in mm.

As a result of numerical modeling of the described structure to strengthen the supporting parts of a ferro-concrete beam by means of an unweighted frame made of angles, the diagrams of bending moments and shear forces were obtained for the attempts №1 and № 10 [14, 15].

**Table 1.** Transverse forces and moments in beam sections from concentrated loads with an unweighted reinforcement frame

| Attempt No. | Applied loads (t), on distance L/4 [m] | Moment (max) in unreinforced field [kN*m] | Moment (max) in reinforced field [kN*m] | Shear force (max) in unreinforced field [kN] | Transverse force (max) in reinforced field [kN] | Beam collapse [yes/ no] |
|-------------|--------------------------------------|------------------------------------------|----------------------------------------|---------------------------------------------|-----------------------------------------------|------------------------|
| 1           | 6 on the left F₁, 6 on the right F₂   | 105.5                                    | 101.1                                  | 64.43                                       | 73.79                                         | no                     |
| 2           | 6 on the left F₁, 7 on the right F₂   | 113.13                                   | 104.65                                 | 66.89                                       | 81.19                                         | no                     |
| 3           | 7 on the left F₁, 7 on the right F₂   | 119.74                                   | 115.76                                 | 74.24                                       | 83.66                                         | no                     |
| 4           | 7 on the left F₁, 8 on the right F₂   | 127.69                                   | 119.01                                 | 76.71                                       | 90.9                                          | no                     |
| 5           | 8 on the left F₁, 8 on the right F₂   | 134.14                                   | 129.85                                 | 84.05                                       | 93.46                                         | no                     |
| 6           | 8 on the left F₁, 9 on the right F₂   | 141.95                                   | 133.12                                 | 86.4                                        | 100.79                                        | no                     |
Figure 4 shows a diagram of bending moments in a beam for the attempt № 1 with the equivalent concentrated forces F1 and F2, and Figure 5 shows the diagram of shear forces for the same attempt.

### Attempt (1)

#### Moment diagram (kN.m)

| Section | Moment (kN.m) |
|---------|--------------|
| 7       | 148.3        |
| 8       | 156.1        |
| 9       | 162.5        |
| 10      | 170.46       |

The following Figures 6 and 7 obtained by the attempt № 10, show the diagram of bending moments and the diagram of shear forces during the beam collapse, respectively.

### Figure 4. Plot of bending moments in a beam at sections, Attempt № 1

### Figure 5. Plot of shear forces in a beam at sections, Attempt № 1

The following Figures 6 and 7 obtained by the attempt № 10, show the diagram of bending moments and the diagram of shear forces during the beam collapse, respectively.

### Figure 6. Bending moments plot in a beam at sections
Figure 7. Plot of transverse forces at beam collapse

The analysis of Table 1 gives a possibility to state that the influence degree of equivalent and not equivalent concentrated forces applied to the beam on its state, assessed by the means of bending moments and shear forces in the beams, will be different. To assess this effect, let us consider the difference in moments in the experimental field of a beam reinforced with an unweighted frame and a beam without reinforcement, expressed as a percentage, which is reflected in Table 2.

Table 2. Influence degree assessment of the reinforcing brackets on the maximum moments in the beam

| Attempt No. | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| The difference of moments in the reinforced field and without, [%] | 4.17 | 7.7 | 3.32 | 6.79 | 3.2 | 6.22 | 2.83 | 5.06 | 2.58 | 5.08 |

Summary
Reinforcement of the ferro-concrete roof beam’s supporting part with unloading brackets, in the form of a pair of bar elements, increases the bearing capacity of the ferro-concrete beam, and with the same loads on both sides of the supporting parts of the beam, the bending moment is increased by 4.17% at minimum load values and by 2.58% at maximum load values. Whereas at unequal loads, the unloading brackets’ influence is increased and reaches, at their minimum values, up to 7.7% and at maximum loads - up to 5.06%.

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