

Using rigidity elements to strengthen one-storey buildings frames

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Abstract. The study focuses on strengthening industrial buildings frames by introducing rigidity elements. Materials concentration principle in rigidity elements in the form of reinforced concrete columns is used and the influence degree on a building frame operation is estimated. This changes the performance of the overlay disk as an element that distributes horizontal forces. The paper describes basic dependencies determining the correlation between rigidity characteristics of rigidity elements and ordinary columns. They are determined by reinforced concrete frame movements when the lower section columns moments reach limit values. In resulting exposure rigidity elements accept basic horizontal efforts, and ordinary columns work as centrally compressed. Calculation results are presented as graphs of force variation depending on correlation between rigidity characteristics of rigidity elements and ordinary columns. The paper outlines that after introducing rigidity elements they act as basic distributing horizontal loads element. The overlay disk has the final load bearing capacity and regulates the limit distances between rigidity elements. The introduction of rigidity elements into the building frame should be accompanied by appropriate measures to strengthen structure foundations. The research proves that this method of one-storey industrial buildings frames reinforcement enables to use materials and technologies during reconstruction more efficiently.

1 Introduction

In NIIZhB [1-4] it was proposed to use a linkage frame with rigidity elements, designed by TsNIIPromzdaniy, PI-1, and NIIZhB for reinforcement of single-storey industrial buildings. In such frameworks, the rigidity elements (RC) perceive the bulk of the horizontal loads, and the ordinary columns (CO) and the corresponding foundations operate as centrally compressed.

In the longitudinal direction of buildings frames, there are usually steel cross or portal links, which are considered to be rigidity elements. The possibility of placing bonds in the transverse direction along the ends of the building is determined by the sufficient bearing capacity of the cover disc. When introducing rigidity elements in the transverse direction,

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the forces in the cover disc change. The longer the distance between the rigidity elements and rigidity ratio of the rigidity elements (B_{RC}) and ordinary columns (B_{CO}). the greater these forces.

2 Materials and methods

2.1 To determine the rigidity characteristics of the rigidity elements and ordinary columns, we use well-known technique [5] for calculating bonded frameworks. The rigidity characteristics of the rigidity elements are determined using the dependence of the frame deflection on the acting horizontal load and the total frame resistance:

$$f = \frac{W}{\sum n_i \cdot \frac{N_i}{\frac{\text{tg } k_i \cdot l}{k_i} - l}}; \quad (1)$$

where: W - horizontal load;
 N_i – vertical load on column;
 l - estimated column length;

$$k_i = \sqrt{\frac{N_i}{B_i}} \quad (2)$$

where: B_i – rigidity i–st column;

The moments in the calculated cross sections are obtained using the dependence

$$M_i = P_i \cdot l + N_i \cdot f \quad (3)$$

$$P_i = \frac{N_i}{\frac{\text{tg } k_i \cdot l}{k_i} - l}$$

resistance i–st column;

In case of reinforcement associated with the planned increase in horizontal loads, it is sufficient to designate the B_{RC} / B_{CO} ratio so that the forces in the calculated cross sections of ordinary columns remain at the same level as before the load increases.

Write the relationship as:

$$W = f \cdot \sum n_i \cdot \frac{N_i}{\frac{\text{tg } k_i \cdot l}{k_i} - l} \quad (4)$$

and analyzing it, we can see that the value of the bending moment in the ordinary columns remains unchanged with a constant deflection value. By fixing the value and increasing the rigidity of the rigidity elements, we can determine how much at these rigidity elements it is possible to increase the horizontal loads.

2.2 In the reconstruction associated with the increase in vertical loads on the frame, retaining condition of load-bearing capacity of the columns was used. According to the load capacity graph, it was determined how it is necessary to reduce the bending moment in the calculated section of the columns to maintain the load capacity. Then, placing the rigidity elements and using the dependences (2) and (3), their rigidity characteristics were determined, under which the necessary reduction of the bending moments occurs.

2.3 One of the factors determining the possibility of using the method of single-storey industrial buildings frames reinforcement by introducing rigidity elements is the load-bearing capacity of the cover disc.

After the rigidity elements are introduced into the structure of the frame, the main distribution element of the horizontal loads becomes the cover disc, in which considerable horizontal forces arise. The cover disc has a finite load-bearing capacity and regulates the limiting distances between the rigidity elements.

The bearing capacity of the cover disc is determined by the strength of the joints of the slab cover and the rafter structures. Forces at the junction nodes can be determined by the design scheme shown in Figure 1, but the formulas for calculation should be modified due to different transverse frames rigidity. Moreover, this design scheme does not take into account the compliance of the slab covers.

Therefore, in order to determine the forces at the junction nodes of the slab covers and rafter structures under horizontal loads in the plane of the cover disk, the calculation model developed in the NIIAB [6,7] was used. The design scheme is flat (Figure 1), but providing the appropriate rigidity characteristics of the elements takes into account the spatial nature of the slab covers.

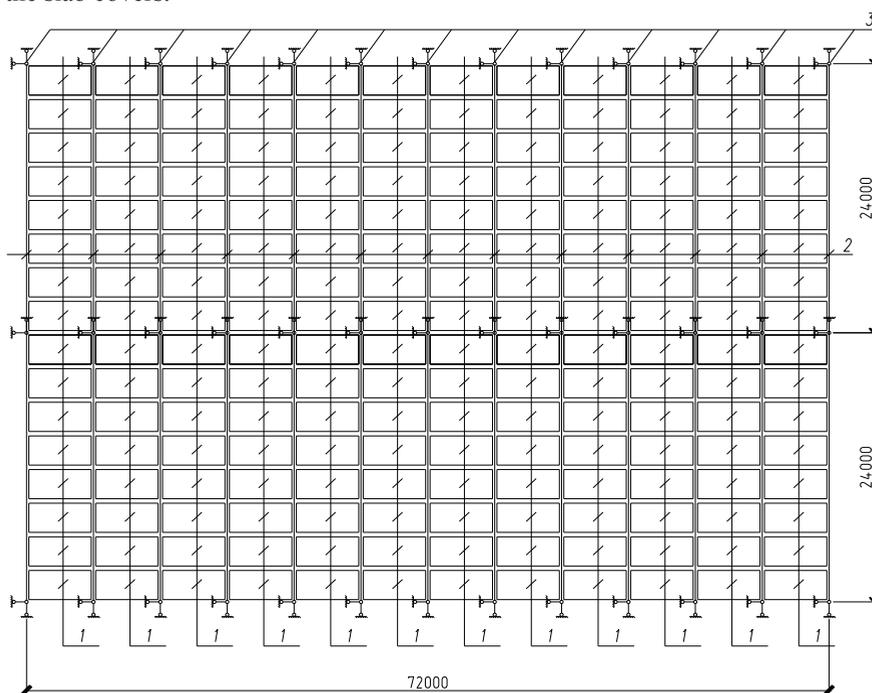


Fig. 1. Calculation scheme of the cover disk

The calculation scheme includes the following elements:

- 1- slab covers (modeled with a wall of equivalent thickness)
- 2, 3- rafter structures and columns (modeled by rods of finite rigidity)

The nodes of conjugation of slabs and roof structures are modeled absolutely rigid. In addition, the scheme takes into account the fastening of the plates to the rafters on three or four sides.

We designate the thickness of the beam-wall of equivalent rigidity from the condition of equality of deformations of a spatially operating ribbed plate and a beam-wall according to the formula:

$$\delta_E = \frac{2 \cdot l \cdot (1 + \mu)}{c_{PL} \cdot b \cdot k \cdot E_b} ; \quad (5)$$

where: δ_E – equivalent beam-wall thickness;
 c_{PL} – compliance of the slab cover in its plane;
 l, b – length and width of the beam-wall;
 E_b – модуль упругости бетона- concrete modulus of elasticity;
 k – coefficient of elastic modulus decrease;

The plate deformability is determined by the spatial calculation of the plate using the finite element method. Loading the scheme by a horizontal load under the assumption of elastic work, it is possible to determine the forces at the junctions of the slab covers and the rafter structures and estimate the carrying capacity of the cover disc.

3 Results

3.1 Reinforcement of a one-storey single-span building with dimensions in design 24x72 m in height to the bottoms of supporting structures, 7.2 m covering with a spacing of 6 m columns was made. Columns were taken in rectangular cross-section 300x300 mm, reinforced with armature 4 diameter 12 mm in class A-III. The vertical load acting on the columns is assumed to be 750 kN. The total horizontal load on the building frame is assumed to be 42 kN. The results of the calculation are shown in Figure 2

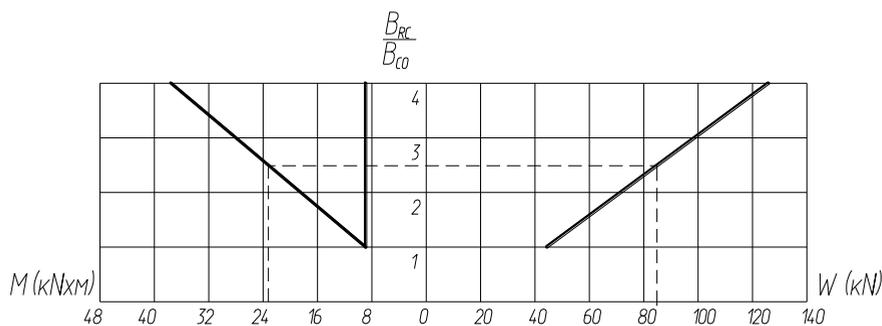


Fig. 2. Graphs of the dependence of the horizontal load and bending moments from the relationship B_{RC}/B_{CO} .

It can be seen from the graph that to double the horizontal load, it is necessary to assign the ratio $B_{RC} / B_{CO} = 2.5$. In this case, the bending moments in the ordinary columns remain the same, and in the rigidity elements they increase in 3 times.

3.2 In the reconstruction associated with the increase in vertical loads on the frame, retaining condition of load-bearing capacity of the columns was used. According to the load capacity graph, it was determined how it is necessary to reduce the bending moment in the calculated section of the columns to maintain the load capacity. Then, placing the rigidity elements and using the dependences (2) and (3), their rigidity characteristics were determined, under which the necessary reduction of the bending moments occurs.

The results of the calculations are shown in Figure 3.

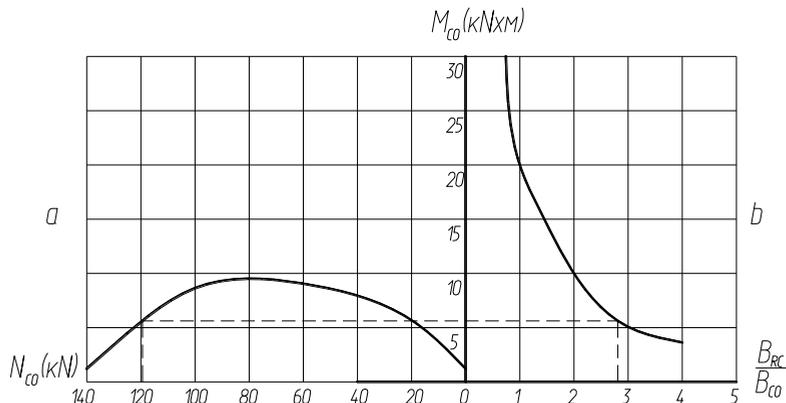


Fig. 3. Graphs of the bearing capacity of columns (a) and the dependence of the bending moments of M_{CO} from the relationship B_{RC}/B_{CO} (b)/

It can be seen from the graphs that when the vertical load is increased up to 1200 kN, the load-carrying capacity of the columns is retained at a bending moment of 56 kNm (Figure 3.a). The ratio of flexural rigidity of B_{RC} / B_{CO} columns at which this condition is satisfied is 2.9 (Figure 3.b). Using the B_{RC} / B_{CO} ratios, it is possible to determine the nature of the change in the forces in the cover disk and estimate its bearing capacity.

Two- and three-sided columns with lateral reinforcement can be used as the rigidity elements. It is possible to install guys, frame installation by combining the main and half-timbered columns, as well as the inclusion of wall panels.

3.3 Calculations of a 48x72 m cover disk were carried out when the rigidity elements were placed along the contour and at the ends of the building. The horizontal load acts in the plane of the transverse frame.

Based on the results of the calculation, it can be concluded that in case the elements are introduced into the frame structure, the forces in the cover disc increase as the rigidity parameters of the rigidity elements increase to a certain value of B_{RC} / B_{CO} , after which they gradually decrease. This is explained by the fact that after the introduction of rigidity elements into the structure of the framework along the contour or along the ends of the building, the cover disk scheme can be represented as a beam on elastically submissive and rigid supports (Figure 4.a.b.c).

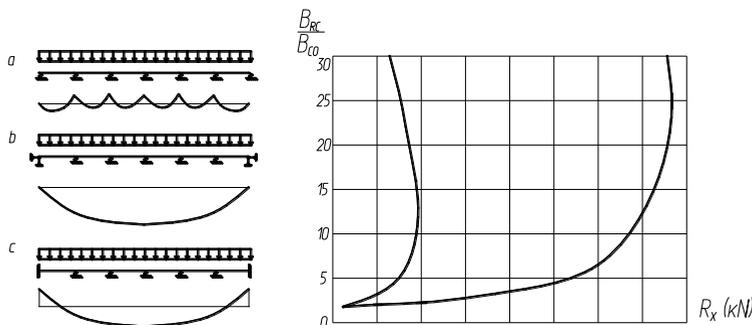


Fig. 4. The design schemes of the cover disk and the graphs of the dependence of the forces on the ratio B_{RC}/B_{CO} /

4 Conclusions

4.1 To increase the horizontal load during the reconstruction of the building, it is necessary to assign the ratio $B_{RC} / B_{CO} = 2.5$. In this case, the bending moments in the ordinary columns remain the same, and in the rigidity elements they triple.

4.2 When the vertical load is increased up to 1200 kN, the bearing capacity of the columns is retained at a bending moment of 56 kNm. The ratio of flexural rigidity of B_{RC} / B_{CO} columns, at which this condition is satisfied, is 2.9. Using the B_{RC} / B_{CO} ratios, it is possible to determine the nature of the change in the forces in the cover disk and estimate its bearing capacity.

4.3 As the B_{RC} increases, the effect of resiliently supports on the distribution of forces decreases, and fixed supports prevent not only the displacement, but also the rotation of the cover disc. For the rigidity elements arrangement along the building contour, the ratio at which the reduction of efforts takes place, $B_{RC} / B_{CO} = 12-13$, when the rigidity elements are positioned along the ends of the building $B_{RC} / B_{CO} = 29-30$.

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