The use of included stiffeners to strengthen the frames of one-story industrial buildings

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Abstract. The article considers issues of industrial buildings frames strengthening by the introduction of stiffening elements at the change of calculated seismicity. The principle of materials concentration in the form of stiffness elements with included connections is used. The degree of their influence on the work of building frame is estimated. In this case, the work of coating disk as an element distributing horizontal forces changes. The main dependencies for gap definition determined by the reinforced concrete frame movements, at which moments in the lower section of the columns reach the limit values, are determined. Thus, in the process of influence the seismic force will remain approximately constant, as the total stiffness will be slightly higher than the initial columns stiffness. Introduction of rigidity elements into the frame should be accompanied by corresponding measures for strengthening of foundations for steel supports.

1. Introduction

The authors propose to use the linking scheme of the frame with stiffening elements, developed by CNIIPromzdanie, PI-1 and NIIZHB to strengthen one-story industrial buildings [1-6]. In such frames, the stiffeners take up the bulk of the horizontal loads, and the row columns and the corresponding foundations work almost as centrally compressed.

In the longitudinal direction of building frames, there are steel cross or portal connectors, which should be considered as stiffeners. The possibility of placing the connectors in the transverse direction along the ends of the building is determined by the sufficient bearing capacity of the coating disk. When the stiffeners are introduced in the transverse direction, the forces in the coating disc change. These efforts become greater when the distance between the stiffeners and the stiffness ratio of the stiffeners and row columns become the greater.

2. Main provisions

2.1. Increased horizontal loads

To determine the stiffness characteristics of stiffening elements and row columns, a well-known method of calculation of interconnecting frames is used [2]. Rigid characteristics of stiffening elements are determined using the dependence of the frame deflection on the current horizontal load and the total back pressure of the frame.
\[ f = \frac{W}{\sum n_i \cdot \frac{N_i}{l g k_i \cdot l} - l} \]  

where:  
- \( W \) - horizontal load,  
- \( N_i \) - vertical load on the column,  
- \( l \) - calculated column length,  

and  
\[ k_i = \frac{N_i}{B_i} \]  

where \( B_i \) - rigidity of \( i \) column.  

We obtain the moments in the design sections using the dependence  
\[ M_i = P_i \cdot l + N_i \cdot f \]  

where  
\[ P_i = \frac{N_i}{l g k_i \cdot l} - \text{backpressure \( i \) - column} \]  

With the reinforcement associated with the planned increase in horizontal loads, it is sufficient to assign the ratio \( \frac{B_{RC}}{B_{CO}} \) in such a way that the forces in the design sections of the row columns remain at the same level as they were before the load increase.  

Writing the dependence in the form  
\[ W = f \cdot \sum n_i \cdot \frac{N_i}{l g k_i \cdot l} - l \]  

and analyzing it, it can be seen that the value of the bending moment in row columns remains unchanged at a constant deflection value. By fixing the value and increasing the stiffness of the stiffeners, it is possible to determine how much the horizontal loads can increase with the given stiffeners parameters.  

2.2. Increase in vertical loads  
During the reconstruction associated with an increase in vertical loads on the frame, the condition of maintaining the bearing capacity of the columns was used. According to the graph of the bearing capacity, it was determined by how much it was necessary to reduce the bending moment in the design section of the columns to maintain the bearing capacity. Then, placing the stiffeners and using dependencies (2) and (3), their stiffness characteristics were determined, at which the necessary reduction in bending moments occurs.  

3. Change in the calculated seismicity  
Strengthening the frames of one-story industrial buildings using stiffeners when changing the design seismicity has its own specifics. Simple introduction of stiffeners leads to an increase in seismic forces due to an increase in the rigidity of the frame [7, 8]. Therefore, the structures of stiffening elements included in the work were developed in the process of exposure to seismic forces at the stage when the stiffness of the columns decreases. Thus, at the moment of seismic forces the rigidity of the frame is equal to the initial stiffness before strengthening. At the end of the impact, the rigidity may increase slightly.
3.1. Structures of included stiffeners

The stiffeners are closed steel supports 2, surrounding two or four columns 1 (see figure 1).

Frames are rigidly fixed in a reinforced concrete clip fortification of foundations. Disc springs 4 are fixed to the frame at column header, through which horizontal seismic forces should be transmitted to the stiffening elements.

![Figure 1. Structure of stiffening element in the form of stiffening elements, surrounding reinforced concrete columns (1 - reinforced concrete column; 2 - steel support; 3 - steel stop; 4 - disc spring; 5 - foam band; 6 - steel guide, pipe).](image)

The springs 5 are installed in such a way that there is a gap between them and the column surface. Therefore, the elements of rigidity are not included in the work immediately, but when cracks in the columns are formed and the column's stiffness falls. The gap size is determined by the movement of the reinforced concrete frame, at which the moments in the lower section of the columns reach the limit values. In this case, the total displacement of reinforced concrete columns, consisting of the displacement of the reinforced concrete frame before the inclusion in the work of the steel ring and after its inclusion, excludes the achievement in the concrete reinforcement column ultimate deformation and possible damage. The gap value was determined from the condition:

\[
\delta = \frac{M_u \cdot l^2}{3 \cdot B}
\]

where:
- \(M_u\) - the maximum allowable moment,
- \(B\) - bending stiffness of the column.

The stiffness of steel supports is selected so that the total stiffness of the reinforced concrete frame and the total stiffness of steel supports are of the same order. This ensures that the total stiffness of the frame is always the same. At the initial moment, the rigidity of the framework is determined by the stiffness of reinforced concrete columns and after reaching the moment of limiting values in the columns and the formation of plastic joints in the lower sections of the columns with fixed forces, the stiffness of the framework will be determined by the total stiffness of steel supports and reinforced concrete columns with plastic joints. As a result, in the process of influence the seismic force will remain approximately constant, because the total stiffness will slightly exceed the initial stiffness of the columns. However, the gap size is determined from the condition of achieving the limit forces in the calculated sections using the calculated characteristics of the material. The probability of plastic hinge appearance is extremely low and, therefore, after the stiffness elements inclusion in the work, rigidity of the frame should increase. In this case the seismic load on stiffening elements will also increase. That is why steel supports should be calculated with some reserve.

Introduction of stiffening elements into the frame should be accompanied by appropriate measures to strengthen foundations for steel supports.
4. Stiffness elements arrangement
When choosing the stiffeners placement scheme they should be arranged in such a way as to minimize the impact on existing technology in the reinforced buildings and to strengthen without stopping production. For this purpose, it is advisable to place the stiffening elements on the temperature joints and external building axes (see figure 2). Moreover, the placement of stiffening elements at temperature joints makes it possible to create stiffening elements by combining the neighboring columns this or that way.

![Figure 2](image-url)  
*Figure 2. The scheme of the stiffeners in the building plan: KC - reinforced concrete columns (RC); SE – stiffeners elements.*

5. Conclusions
1. When placing the included stiffening elements in the plan of the building it is necessary to take into account the peculiarities of the existing production technology, as well as the possibility of strengthening without stopping production. Moreover, it is recommended to place the stiffness elements close to the building axes of symmetry, which has a positive impact on the work of the building coating disk, which is the main distribution element of horizontal forces under seismic loads.

2. The parameters and dimensions of steel through supports of stiffening elements should be determined taking into account the influence of support lattice on given support flexibility. Support stiffness should be approximately equal to the stiffness of reinforced concrete column.

3. For smooth seismic forces transfer to the supports, it is recommended to use disc springs reducing the dimensions of steel supports.

4. The size of the gap between the reinforced concrete column and the stiffness element is determined by the stiffness of the reinforced concrete column and its maximum load-bearing capacity, taking into account the formation of cracks in dangerous sections of the column and is 40-50 mm.
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