Analysis of high-rise constructions with the using of three-dimensional models of rods in the finite element program PRINS

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Abstract. The necessity of new approaches to the modeling of rods in the analysis of high-rise constructions is justified. The possibility of the application of the three-dimensional superelements of rods with rectangular cross section for the static and dynamic calculation of the bar and combined structures is considered. The results of the eighteen-story spatial frame free vibrations analysis using both one-dimensional and three-dimensional models of rods are presented. A comparative analysis of the obtained results is carried out and the conclusions on the possibility of three-dimensional superelements application in static and dynamic analysis of high-rise constructions are given on its basis.

1 Introduction

High-rise buildings belong to objects with a high level of responsibility, so at the analysis of such structures by the finite element method it is necessary to use design schemes that are as close as possible to the real constructive schemes. This is especially actual for bar structures and combined systems containing rods, plates, shells and solid elements, since often in the analysis of such systems the calculation schemes are constructed using one-dimensional models of rods based on the classical theory of beam bending. The disadvantages of such approach are well known (see, for example, [1]). These include the transfer of force at a point, the inability to take into account warping and change of the shape of the cross section, the complexity of accounting for physical and geometrical nonlinearity, and a number of others. In modern software systems, such as NASTRAN [2], ANSYS [3], ABAQUS [4] et al, the combined models of rods are used. In these models, an approximation of the coordinates and displacements of points lying on the axis of the rod is specified, the coordinates and displacements of internal points are found using the hypothesis of plane sections and then, the characteristics of the finite element necessary for calculation are obtained using the three-dimensional theory. A theoretical description of such models can be found in [5-9]. However, in the final analysis, all characteristics are reduced to points lying on the axis of the rod. Thus, some of the shortcomings inherent in one-dimensional models are preserved. Completely to get rid of the drawbacks inherent in one-dimensional models, it is possible by using 3D elements to model the rods. Direct modeling of each rod by volume elements is associated with large overhead costs, since it leads to a sharp increase in the number of degrees of

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freedom of the structure. The output can be found in the use of the superelement method. However, with the traditional use of this method, when all the characteristics of the modeled object are brought to the nodes lying on the surface of this object, certain problems may arise during the preparing of the input data for the calculation. Therefore, it is desirable to have special superelements, in which the necessary characteristics would be reduced to nodes lying in the end sections. This idea is implemented in the computer program PRINS[1]. To date, it has been tested and proved itself in linear and nonlinear static calculations of rod systems [10].

2 Methods

In this paper the possibility to use the previously developed superelements [10] in the calculation of high-rise construction is shown. The free vibration analysis of the spatial frame depicted in Fig. 1 and Fig. 2 was performed for this purpose. The frame was calculated by the aid of the program PRINS using two version of rod models – three-dimensional (version 1) and one-dimensional (version 2). The material used was concrete with the elasticity modulus $E = 3,2 \times 10^7$ KPa, Poisson ratio $\nu = 0,2$ and mass density $2300 \; \kappa g / \textit{м}^3$ .The cross-sections of all rods were assumed to be the same in the form of rectangles with side dimensions 30×30 cm. The height of one floor of the frame was assumed equal to 3.3 m. The support sections of the columns were assumed to be absolutely clamped.

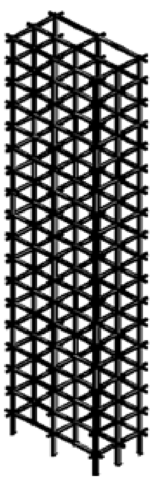

Fig.1. The spatial frame

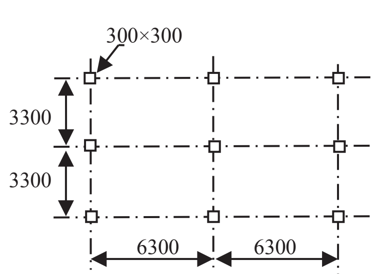

Fig.2. The mesh of columns

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In the first version of the design scheme superelements of rods of rectangular cross section proposed in [10] were used. Without going into the details of the implementation, we note that the superelement is formed from three-dimensional solid 8-node finite elements with arbitrary partition by cross-section and height, as shown in Fig.3,a. From the user point of view, the superelement looks like a three-dimensional body, all characteristics of which are brought to the nodes lying in the end sections (Fig. 3,b). Intermediate nodes are excluded at the stage of the stiffness matrix, mass matrix and the load vector forming.

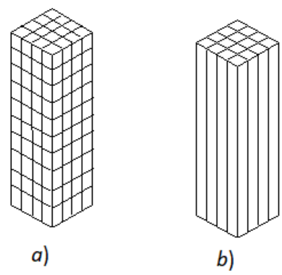


Fig.3. The superelement of the rod: *a*) partitioning of the rod on the volume finite elements; *b*) configuration of the grid after illumination of intermediate nodes

Fig. 4 shows the superelement design scheme of the first floor. Connections in the nodes were carried out as shown in Fig.5. In this case, a special volumetric module with the same mesh of nodes and made of the same material as the superelements to be connected was inserted into the node. Obviously, this way of elements connecting in the design scheme is as close as possible to the connection of these elements in a real construction. It allows you to take into account the rigidity of nodal connections, as well as the complex stress state in the connected elements in the vicinity of the nodes.

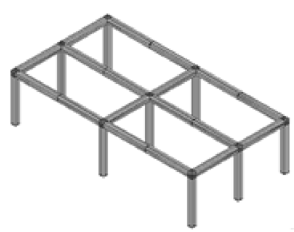


Fig.4. Design scheme of the first floor of frame with three-dimensional elements

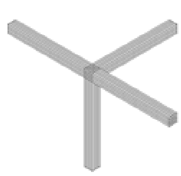


Fig.5. Nodal connection

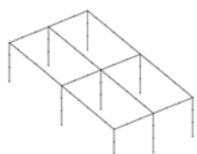


Fig.6. Design scheme of the first floor of frame with one dimensional elements

As for the design scheme using the one-dimensional elements, shown for the first floor in Fig. 6, the typical for such cases the problem of elements connecting in nodes arise. Consider, for example, a node in which two elements of a crossbar and a column are connected (see Fig. 7). In a one-dimensional scheme, the elements must be represented by their axes; the crossbars will be represented by axes 1- $2'$ and $2''$-3, and the column – by axis $2'''$ - 4. But in this case the nodes $2'$, $2''$ and $2'''$ on the design scheme will be spaced, and the elements will not be linked, which is unacceptable.

This problem can be resolved in one of two ways. In the first one, you can enter rigid inserts between the nodes $2'$ and 2, $2''$ and 2, $2'''$ and 2, in the second - "tighten" the nodes $2'$, $2''$ and $2'''$ to node 2 and assume that the crossbars are represented by axes 1-2 and 2-3, and the column – by the axis 2-4. Both ways are bad. In the first case, the non-existent in the construction elements are introduced into the node, which stiffen it, in the second, the calculated length of the rods increases, which increases its flexibility. In both cases, the node is considered absolutely rigid, which, as a rule, is not true.

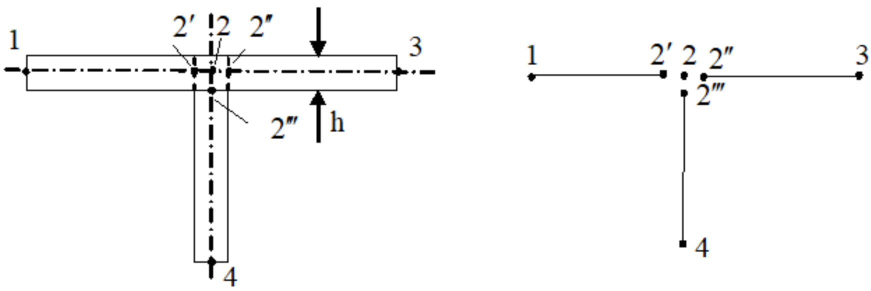


Fig.7. Connection of elements in the nodes of the design scheme with one-dimensional models of rods

In the calculations performed, the second method of connecting of one-dimensional elements in the nodes was used. This suggests that the rigidity of the construction using a design scheme with one-dimensional elements will be somewhat smaller than in the scheme with three-dimensional superelements.

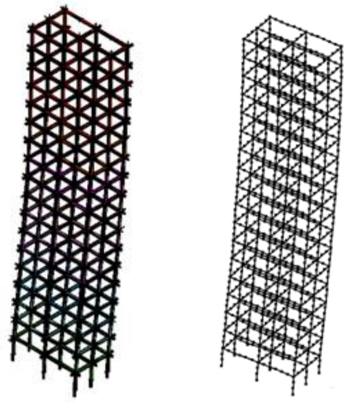
3 Results

The results of the calculation in the form of natural frequencies for the first three tones are given in Table 1.

Table 1. Natural frequencies of frame

Mode number	Natural frequencies, Hz		Divergence, %
	Variant 1	Variant 2	
1	0,439	0,411	6,38
2	0,489	0,452	7,57
3	0,590	0,551	6,61

Fig.8 and 9 show the modes of natural vibrations for the first and third tones.



a) *b*)

Fig.8. First mode of vibration: a) version 1; b) version 2

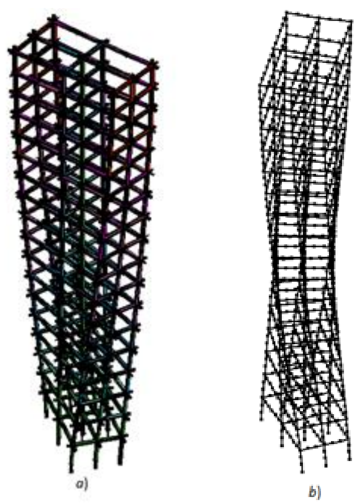


Fig.9. Third mode of vibration: a) version 1; b) version 2

4 Discussion

It can be seen from the Table 1 that the results obtained with the use of one-dimensional and three-dimensional finite elements coincide on the whole, and the frequencies in the second variant are somewhat lower than in the first. There is a simple explanation for this. When using one-dimensional elements, the rods are connected to each other at points lying on the axes of the rods without taking into account the rigidity of the nodal joints, as a result of which the calculated lengths of the rods are somewhat high and the rigidity of the structure is somewhat understated. This leads to a decrease in the frequencies of natural oscillations.

Fig. 8 and 9 show the modes of natural oscillations for the first and the third tones, obtained in the first and second variants of calculation, respectively. As can be seen from the figures, the shapes practically coincide. The number of degrees of freedom of the construction with the use of volume superelements naturally increases. However, taking into account the incomparable cost of the machine time spent for the calculation, and the cost of the construction itself, as well as the possibility to substantially approximate the design scheme to the real object, this deficiency should be considered secondary.

Conclusion

Thus, superelements of rectangular bars used in the program PRINS have adequate rigid and dynamic characteristics and can be recommended for use in static and dynamic calculations of high-rise building. This is especially important at the nonlinear calculations, when it becomes necessary to take into account the warping and changes in the shape of the cross-sections of the rods.

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