IOP Conf. Series: Materials Science and Engineering 463 (2018) 022091 doi:10.1088/1757-899X/463/2/022091

Evaluation of the Influence of the Stiffeners on the Overall Stability of the Variable-Rigidity Steel Frame Using FEM

A.A. Sventikov[1], D.N. Kuznetsov[1]

[1]Voronezh State Technical University, 20 let Oktyabrya st. 84, Voronezh, Russia

E-mail: svarka@vgasu.vrn.ru

Abstract. A steel frame of I-section variable in height is calculated. Elements of the frame: wall, belt, and stiffeners were modeled using plate end plates in the SCAD Office computer complex. The steel frame has a span of 18 m, the height of the pillar is 7,280 m and the roof slope is 0.1. The calculation was made for the climatic conditions in Voronezh. The cross sections of the frame are given by the results of the calculation of the bar chart. The elements that unfold the frame from the plane are modeled as fixed junctions. The effect of transverse stiffeners in the crossbar and racks on local and general stability is considered. The values of stresses in the wall and the form of loss of local stability, as well as the shape of the loss of the overall stability of the frame system, are determined. The effect of transverse stiffeners on the forms of loss of the overall stability of the system and the value of the reliability coefficients on the stability of the system as a whole are established. The paper shows the relationship between transverse stiffeners, local wall stability and general stability for a variable-rigidity frame. Based on the analysis of the results, recommendations are given for the design and calculation of variable-rigidity steel frames using finite element-based computer systems.

1.Introduction

In modern construction practice, metal structures with low self-weight and sufficient bearing capacity are in demand. Such designs are cost-effective [8, 17]. Metal structures with a cross-section in the form of I-beam with a variable height of the wall meet the requirements of economic efficiency and have a small value of their own weight [2, 3, 5, 11, 12, 13]. Typically, individual elements with a cross-section in the form of I-beams with a variable height of the wall are combined into flat frame structures. Such frame structures by the longitudinal elements of the frame are combined into a single spatial frame of the building. The study of the load-carrying capacity of racks, bolts and frames as a whole is an important task for developing algorithms for selecting cross-sections of steel elements of building structures with variable stiffness along the length of the element. To achieve maximum economic efficiency, it is necessary to use sections with a thin and high wall, but such a design solution can lead to loss of local stability of the wall [7, 14]. There are published works describing questions connected with the study of local stability of thin-walled elements [4, 11, 18]. But in constructions with variable rigidity, the I-wall has the form of a trapezium. This circumstance complicates the problem of checking local stability [9, 13]. To solve the problems associated with the stress-strain state of the pillars, the deadbolt and the frame in general, it is necessary to use modern computer systems based on the finite element method [1, 19, 21].

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2. Statement of the problem and methodology of evaluation

The initial design for the study adopted a variable-stiffness frame with I-section cross sections 18 m span, a 7.280 m height and a roof slope of 0.1. Material of construction-steel C255. Two computational models were implemented in the environment of the SCAD Office computation complex (Version 21.1.1.1), which is based on the finite element method [10, 15]. Elements of each model: the wall, belts, stiffeners are represented in the form of triangular and quadrangular finite elements of the shell. The geometry of the first plate model contains only the cross sections and the support plate in 'Figure 1', and the second plate model additionally takes into account all the stiffeners and flanges of the transverse frame, the scheme is shown in 'Figure 2'. The longitudinal elements of the frame not lying in the plane of the frame are represented in the form of fixed nodal connections along the Y axis.

2.1. Load on the calculation scheme

The load was applied for the climatic conditions of Russia, Voronezh:

- From the weight of the coating-F_1, F_2 with a step of 1500 mm.
- From snow-F_3, F_4 with a step of 1500 mm.
- From the wind-q_w, q_w'.

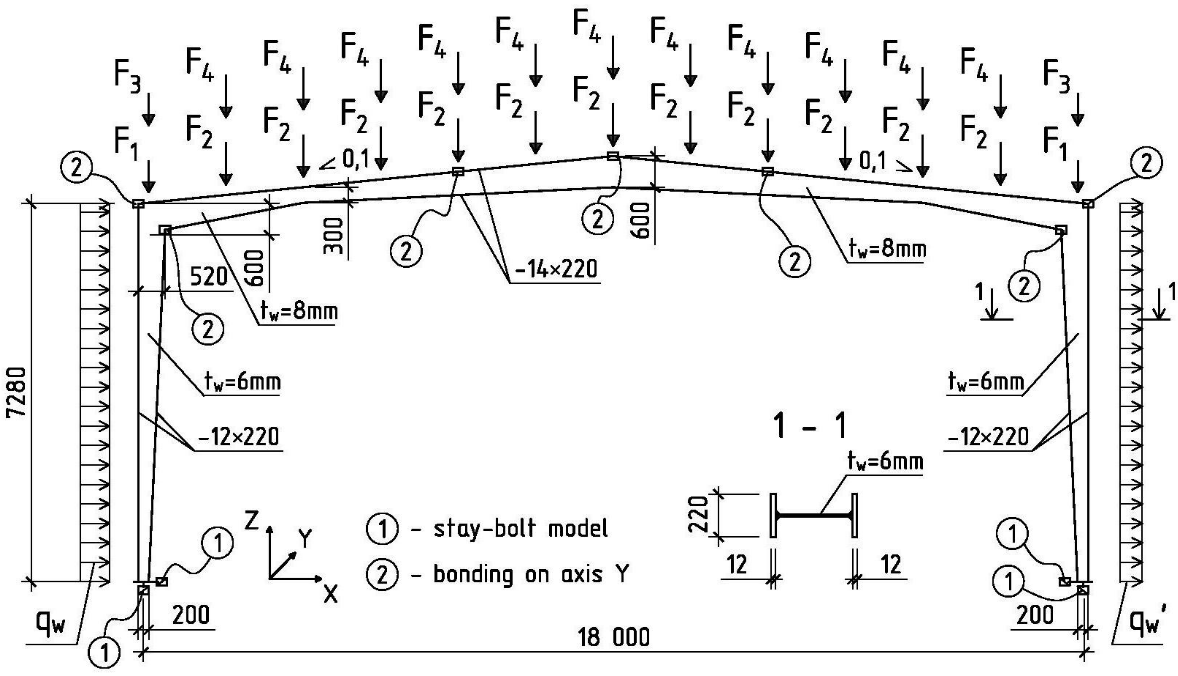

Figure 1. Calculation scheme No. 1, without stiffeners.

The step of the concentrated load F_1, F_2, F_3, F_4 corresponds to the step of runs and is 1500 mm. Three combinations are considered with loads of their own weight, snow and wind.

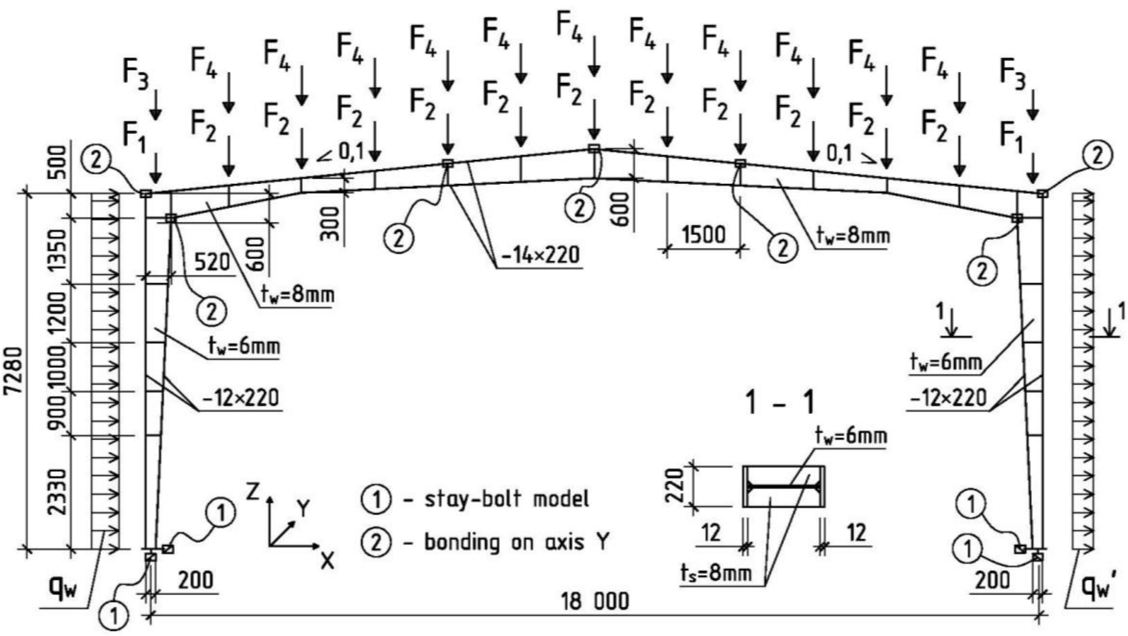

Figure 2. Calculation scheme No. 2, with stiffeners.

2.2. Method of evaluation

The criterion for estimating the local stability of the wall and the stability of the frame is the value of the reliability coefficient for stability. The reliability factor for stability describes numerically how many times it is necessary to increase the design load with respect to the critical load in order to cause a loss of stability. The minimum value of the reliability factor for the stability of the system as a whole is 1.3 for calculations in computer systems. The forms of loss of stability of thin-walled frame elements for two variants of the design scheme are also a criterion for visual estimation and analysis of the results of calculations [6, 16, 20].

3. Analysis of numerical calculation results

Let us consider the results of the stability test for two variants of the design schemes for the combined effect of a combination of loads: own weight, snow and wind. In total three forms of loss of general stability are considered.

It can be seen from the calculation results that the forms of stability loss for the model without allowance for the stiffeners and for the model with stiffeners have significant differences. For the calculation scheme No. 1, without the stiffeners in the first form, the loss of general stability is accompanied by the buckling of the wall in the right junction of the bolt and the post, as well as by the torsion of the cross-section of the frame in the indicated node 'Figure 3'. For the design scheme No. 2, taking into account the presence of stiffeners, the local stability of the wall is not lost, and the first form of buckling of the frame is accompanied by torsion of the cross-section of the right-hand column in the middle sections along the height with the deformation of the crossbar 'Figure 4'. The second form of loss of stability for both options is mirrored in relation to the first form and occurs on the left side of the frame. The third form of loss of stability for the design scheme No. 1 is accompanied by the buckling of the wall in the right junction of the bolt and the post, but the wall protrudes in the opposite direction in comparison with the first shape and is accompanied by torsion of the crossbar and the column 'Figure 5a'. In the third form, the buckling losses for the calculation circuit No. 2 of deformation occur in the compartment located on the right side under the junction of the bolt with the stand and is accompanied by loss of local stability of the compartment wall and deformation of the inner shelf of the compartment 'Figure 5b'.

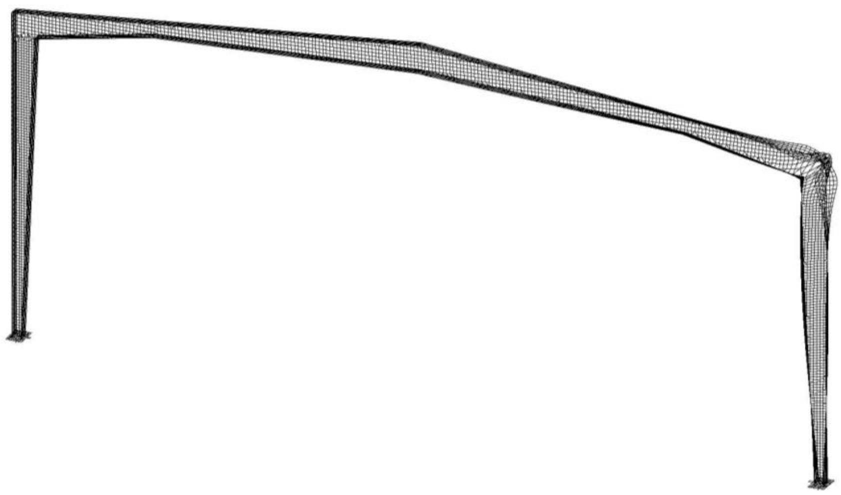

Figure 3. Calculation scheme No. 1, the first form of loss of general stability.

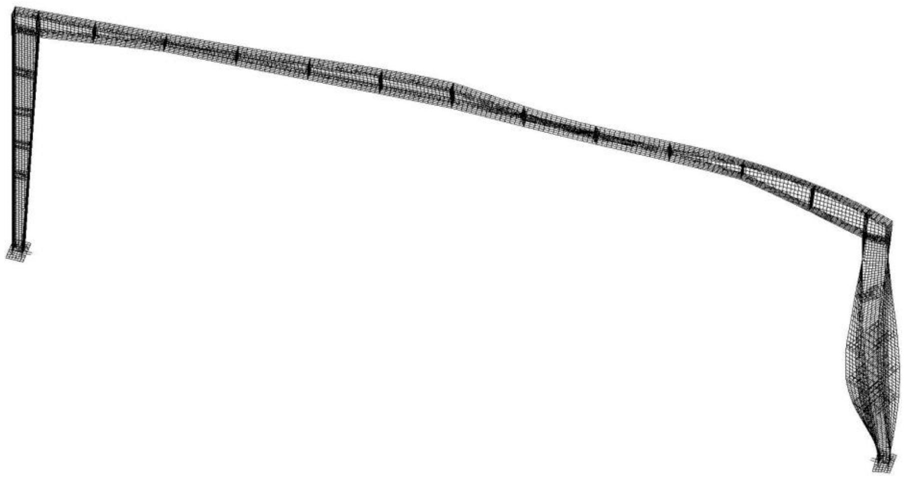

Figure 4. Calculation scheme No. 2, the first form of loss of general stability.

a) b)

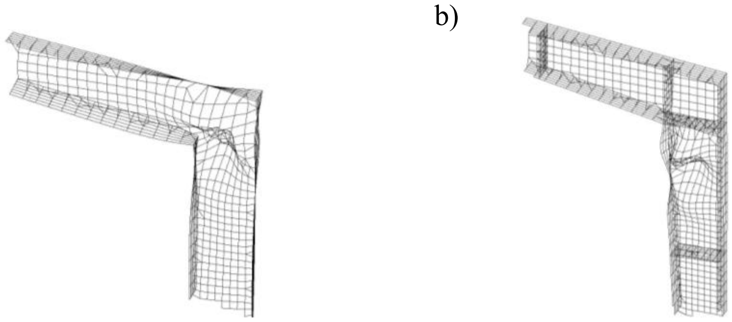

Figure 5. The third form of loss of general stability: a) -scheme No. 1, b) -scheme No. 2.

The values of the reliability coefficients for the overall stability of the variable-rigidity frame for the two variants of the design schemes are given in table 1. The calculation is carried out for three forms of stability loss.

Table 1. Values of reliability coefficients on the overall stability of the frame for the two options of the calculation schemes, taking into three forms of loss of stability.

	1st form	2nd form	3rd form
Calculation scheme No. 1	0.965	1.123	1.536
Calculation scheme No. 2	2.617	2.970	4.026

From the values of table 1, we can conclude that the design scheme No. 2 has large values of reliability coefficients for the overall stability, and the values of 0.965 and 1.123 of the calculation scheme No. 1 for the first and second forms are less than the limit value 1.3 specified in the standards.

4. Conclusions

Based on the results of the conducted studies of frame construction using a software package based on the finite element method, the following conclusions can be drawn:

4.1. When preparing the design scheme for variable-rigidity frame structures using plate-like finite element types, it is necessary to take into account such structural elements as stiffeners, support plates, flanges, etc. If in the first calculation this presents complexity, then it is necessary to make an additional calculation after construction.

4.2. In this paper, the relationship between transverse stiffeners, local wall stability, and overall stability for a variable-rigidity frame is shown.

4.3. To solve the problems of local stability and the overall stability of the system, it is necessary to use not only analytical methods, but also modern software complexes based on the finite element method, with respect to variable rigidity frames.

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