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Emelyanov Sergey Gennadievich

Southwest State University, Kursk, Russian Federation

Dubrakov Sergey Valerievich

Southwest State University, Faculty of Civil Engineering and Architecture, Department of Industrial and Civil Engineering, Kursk, Russian Federation

Dubrakova Ksenia Olegovna

Southwest State University, Faculty of Civil Engineering and Architecture, Department of Industrial and Civil Construction, Kursk, Russian Federation

Key words: *stability, frame-rod system, active bifurcation, passive bifurcation, calculated length*

doi:10.5937/jaes18-27801

Cite article:

Gennadievich, S. E., Valerievich, S. D., & Olegovna K. D. [2020]. Influence of the calculated length of elements on the critical parameters of stability of frame-bar structural systems. *Journal of Applied Engineering Science*, 18(3) 422 - 426.

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Original Scientific Paper

Istrazivanja i projektovanja za privredu
Journal of Applied Engineering Science

doi:10.5937/jaes18-27801 Paper number: 18(2020)3,708, 422 - 426

INFLUENCE OF THE CALCULATED LENGTH OF ELEMENTS ON THE CRITICAL PARAMETERS OF STABILITY OF FRAME-BAR STRUCTURAL SYSTEMS

Emelyanov Sergey Gennadievich[1], Dubrakov Sergey Valerievich[2], Dubrakova Ksenia Olegovna[3]*

[1]*Southwest State University, Kursk, Russian Federation*
[2]*Southwest State University, Faculty of Civil Engineering and Architecture, Department of Industrial and Civil Engineering, Kursk, Russian Federation*
[3]*Southwest State University, Faculty of Civil Engineering and Architecture, Department of Industrial and Civil Construction, Kursk, Russian Federation*

This article examines the effect of changing the design length of the elements of frame-bar structural systems operating in a constrained bifurcation.

For the criterion of the form of buckling of an element of a frame-bar structural system, the sign of the work of end moments and shear forces is taken. Using this criterion, an expression was obtained to assess the effect of changing the calculated length of the frame struts on the critical parameters of the entire system, which allows varying the geometry of the structure to influence its performance.

A two-span frame is considered, in which the central pillar is loaded with a concentrated force Pcr, and the outer pillars are loaded with forces αRcr. The type of bifurcation of the rods (constrained or forced) and the critical parameters of the stability of the system before and after changing the calculated length of its elements are determined.

Changes in the design length of elements that passively lose stability do not have a significant effect on the critical stability parameters of the frame-bar structural system. At the same time, a 30% decrease in the calculated length of the struts in an active bifurcation leads to a decrease in the critical force by 50%.

The presented rather simple algebraic dependencies allow obtaining a qualitative and quantitative assessment of the effect of the calculated length coefficient on the stability of frame-rod structural systems made of wood. It has been established that the conditions for securing elements that passively lose stability do not have a significant effect on the critical parameters of the system.

Key words: stability, frame-rod system, active bifurcation, passive bifurcation, calculated length

INTRODUCTION

It is known that the reason for the loss of stability of an entire structural system such as a truss, frame, structure is often one element or a small group of them. In this regard, an important issue in solving problems of stability of structural systems is the identification of the most dangerous elements or parts of a structure with low resistance to buckling [1-4, 9-13, 17-19]. Therefore, it is necessary to investigate the deformation of the rods under constrained bifurcation conditions and establish the criteria for the type of rod bifurcation (constrained or forced).

MATERIALS AND METHODS

Let the bar separated from the system (Fig. 1) at some critical value of the load P_{cr}. (w, t) loses stability.

Its deformation energy U_i added during bifurcation will be equal to the sum of the work of end forces and moments:

$$U_i = A_i(N) + A_i(M_i, Q_i), \quad 1)$$

The criterion $A_i(M_i, Q_i)<0$ ecomes a sign of active buckling of the bar in the structural system, i.e. the work of one longitudinal force N_i is sufficient to compensate for the increment in the potential energy of deformation of the rod U_i and the environment of the rod (in the form of support reactions) to resist its bifurcation.

The criterion $A_i(M_i, Q_i)>0$ becomes a sign of passive buckling, i.e. surrounding the rod helps its bifurcation.

Figure 1: Bar extracted from the system

* dko1988@yandex.ru

The calculation of the work of end moments and shear forces is performed using special functions of the displacement method [5-8, 14-16].

We take for unknown angles of rotation and displacement of nodes Z_1, Z_2, Zn, then the homogeneous system of equations will take the form:

$$r_{11} \cdot Z_1 + r_{12} \cdot Z_1 + \cdots + r_{1n} \cdot Z_n = 0 \; r_{21} \cdot Z_1 + r_{22} \cdot Z_1 + \cdots + r_{2n} \cdot Z_n = 0 \; \ldots \; r_{n1} \cdot Z_1 + r_{n2} \cdot Z_1 + \cdots + r_{nn} \cdot Z_n = 0 \} \quad 2)$$

$$v_i = l \cdot \sqrt{\frac{P_i}{B_{red}}}, \; (i = 1,2,3 \ldots n). \quad 3)$$

In formula (3) B_{red} is the reduced stiffness of the bar section; v_i – - parameter of the secular equation.

Determine the determinant of the system (2):

Det = 0 4)

Using the above equations, we find the critical parameters and forms of loss of stability of the considered structural system. Of interest is the assessment of the influence of the loading scheme on the nature of the bifurcation of individual struts.

It is also necessary to analyze the change in the value of the critical force in the event of a change in the calculated length of each of the frame struts. In fact, it can be expected that, under the influence of force factors, a change in the calculated length of the struts, which are losing stability passively and actively, will have a different effect on the overall bifurcation of the system.

To solve this problem, let us determine the parameter of the secular equation $vi_{кр}$, determined after the occurrence of an emergency situation associated with a change in the estimated length of the racks:

$$v_{i_{cr}} = l \cdot \sqrt{\frac{P}{B_{red}}} \quad 5)$$

The parameter of the secular equation at a given constant value of the load and a fixed value of wood moisture will be respectively equal to:

$$v_{i_0} = l \cdot \sqrt{\frac{\mathrm{P}}{B_0}}. \quad 6)$$

The ratio of the squares of the critical and initial parameters of the secular equation is directly proportional to the ratio of the corresponding critical forces:

$$\frac{{v_{i_{cr}}}^2}{{v_{i_0}}^2} = \frac{\mathrm{P}_{cr.}}{\mathrm{P}_{cr.,0}}. \quad 7)$$

The parameters vi_0 and vi_{cr} are determined when calculating the frame for stability according to the well-known rules of structural mechanics before and after changing the calculated length of the racks.

Using relation (7), it is possible to estimate the effect of changing the calculated length of the frame struts on the critical parameters of the entire system, which in turn allows, by varying the geometry of the structure, to influence its performance. The larger the value $\frac{{v_{i_{cr}}}^2}{{v_{i_0}}^2}$, the more likely the frame as a whole will lose stability.

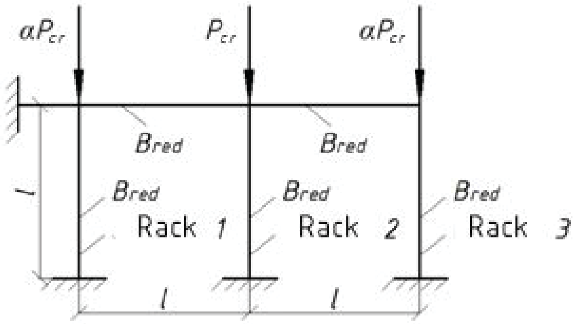


Figure 2: Design scheme of the frame

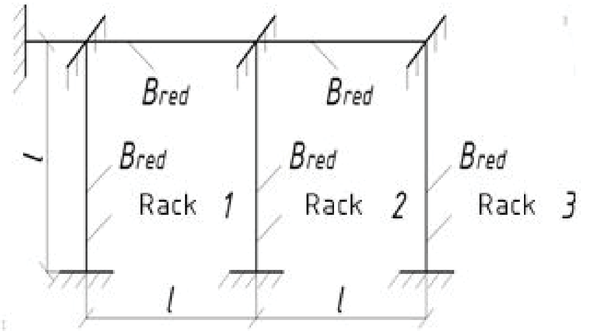


Figure 3: Basic system of the displacement method

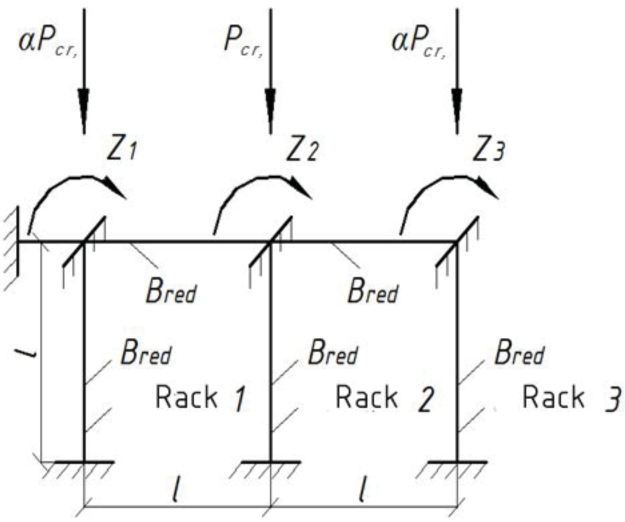


Figure 4: Equivalent displacement method system

Results. As an example, consider a wooden two-span frame in which the central pillar is loaded with a concentrated force P_{cr} and the outer pillars are loaded with forces αP_{cr} (Fig. 2).

Let us define the type of the rod bifurcation (constrained or forced). The calculation of the frame is performed by a quasi-static method of displacement using a step-iterative procedure. The calculation of the work of the end moments and shear forces is performed using special functions of the displacement method. If we take as unknown angles of rotation of nodes Z_1, Z_2, Z_3 (Fig. 4), the homogeneous system of equations will take the form:

$$r_{11} \cdot Z_1 + r_{12} \cdot Z_1 + r_{13} \cdot Z_3 = 0 r_{21} \cdot Z_1 + r_{22} \cdot Z_1 + r_{23} \cdot Z_3 = 0 r_{31} \cdot Z_1 + r_{32} \cdot Z_1 + r_{33} \cdot Z_3 = 0 \} \quad 8)$$

where

$$r_{11} = 8 \cdot i + 4 \cdot i \cdot \varphi_2(v_1); \quad r_{22} = 8 \cdot i + 4 \cdot i \cdot \varphi_2(v_2); \quad r_{33} = 4 \cdot i + 4 \cdot i \cdot \varphi_2(v_3);$$
$$r_{12} = r_{23} = 2 \cdot i;$$
$$r_{13} = r_{31} = 0; v_i = l \cdot \sqrt{\frac{P_i}{B_{red}(w,t)}}, \quad (i = 1,2,3).$$

where B_{red} is the reduced stiffness of the bar section; v_i – parameter of the secular equation.

The determinant of system (8) is determined by the following expression:

$$Det = (8 \cdot i + 4 \cdot i \cdot \varphi_2(v_1)) \cdot (8 \cdot i + 4 \cdot i \cdot \varphi_2(v_2) \cdot (4 \cdot i + 4 \cdot i \cdot\cdot \varphi_2(v_3)) + 16 \cdot i^3 - (8 \cdot i + 4 \cdot i \cdot \varphi_2(v_1)) \cdot 4 \cdot i^2 - 4 \cdot i^2 \cdot (4 \cdot i + 4 \cdot i \cdot\cdot \varphi_2(v_3)) \quad 9)$$

Using the above equations, we find the critical parameters and forms of loss of stability of the considered structural system.

It is also necessary to analyze the change in the value of the critical force in the event of a change in the calculated length of each of the frame struts. In fact, it can be expected that, under the influence of force factors, a change in the calculated length of the struts, which are losing stability passively and actively, will have a different effect on the overall bifurcation of the system.

To solve this problem, let us determine the parameter of the secular equation vi_{cr}, determined after the occurrence of an emergency situation associated with a change in the estimated length of the racks:

$$v_{i_{cr}} = l \cdot \sqrt{\frac{P}{B_{red}}} \quad 10)$$

The parameter of the secular equation at a given constant value of the load and a fixed value of wood moisture will be respectively equal to:

$$v_{i_0} = l \cdot \sqrt{\frac{\mathrm{P}}{B_0}}. \quad 11)$$

The ratio of the squares of the critical and initial parameters of the secular equation is directly proportional to the ratio of the corresponding critical forces:

$$\frac{{v_{i_{cr}}}^2}{{v_{i_0}}^2} = \frac{\mathrm{P}_{cr.}}{\mathrm{P}_{cr.,0}}. \quad 12)$$

The parameters vi_0 and vi_{cr} are determined when calculating the frame for stability according to the well-known rules of structural mechanics before and after changing the calculated length of the racks.

Using relation (12), it is possible to estimate the effect of changing the calculated length of the frame struts on the critical parameters of the entire system, which in turn allows, by varying the geometry of the structure, to influence its performance. The larger the value $\frac{{v_{i_{cr}}}^2}{{v_{i_0}}^2}$ the more likely the frame as a whole will lose stability.

Consider the change in the calculated lengths of each of the frame struts, replacing the rigid support with a hinged-fixed one. The design diagram of the frame for this case is shown in Figure 5.

The based and equivalent systems of the displacement method are developed similarly to those presented above (see Fig. 3, 4). The homogeneous system of equations will take the form:

$$r_{11} \cdot Z_1 + r_{12} \cdot Z_1 + r_{13} \cdot Z_3 = 0 r_{21} \cdot Z_1 + r_{22} \cdot Z_1 + r_{23} \cdot Z_3 = 0 r_{31} \cdot Z_1 + r_{32} \cdot Z_1 + r_{33} \cdot Z_3 = 0 \} \quad 13)$$

$$r_{11} = 8 \cdot i + 4 \cdot i \cdot \varphi_1(v_1); r_{22} = 8 \cdot i + 4 \cdot i \cdot \varphi_2(v_2);$$
$$r_{33} = 4 \cdot i + 4 \cdot i \cdot \varphi_2(v_3); r_{12} = r_{23} = 2 \cdot i;$$

where

$$r_{13} = r_{31} = 0; v_i = l \cdot \sqrt{\frac{P_i}{B_{red}(w,t)}},$$
$$(i = 1,2,3).$$

The determinant of system (13) is determined by the expression:

$$Det = (8 \cdot i + 4 \cdot i \cdot \varphi_1(v_1)) \cdot (8 \cdot i + 4 \cdot i \cdot \varphi_2(v_2) \cdot (4 \cdot i + 4 \cdot i \cdot \varphi_2(v_3)) + 16 \cdot i^3 - (8 \cdot i + 4 \cdot i \cdot \varphi_1(v_1)) \cdot 4 \cdot i^2 - 4 \cdot i^2 \cdot (4 \cdot i + 4 \cdot i \cdot\cdot \varphi_2(v_3)). \quad 14)$$

Similarly, the calculation of the change in the critical stability parameters of the considered frame-bar structural system (see Fig. 2) was performed when the calculated lengths of the racks 2 and 3 were changed.

The results of this calculation are shownin Figure 6. The vertical lines limit the zones of active and passive bifurcation of racks 1 and 3, rack 2 actively loses its stability, regardless of the value of the load application parameter α.

From the analysis of Figure 6, it can be concluded that with a value of α≤0.756, the left and right struts of the structural system passively lose their stability. In the case when the

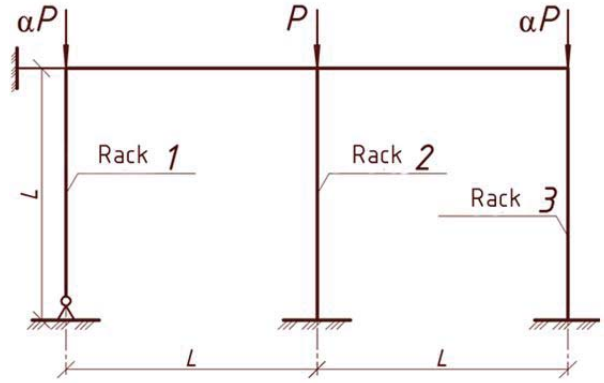


Figure 5: Design scheme of the frame when changing the design length of the rack 1

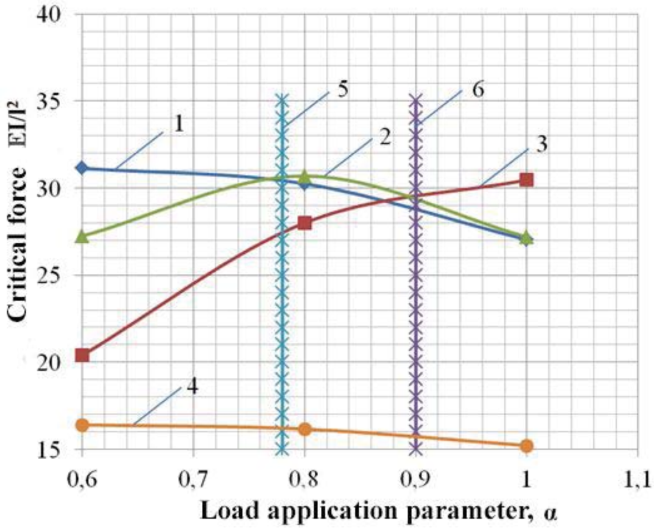


Figure 6: Graph of the dependence of the value of the critical force $P_{cr.,0}$ on the load application parameter α when changing the calculated length of the struts of the frame-rod system, indicating the nature of the bifurcation: 1 - the calculated length of all frame elements is the same, 2 - a decrease in the calculated length of the rack 3 by 30%; 3 - reduction of the estimated length of the rack 1 by 30%; 4 - reduction of the estimated length of the rack 2 by 30%; 5 - border of transition of rack 3 from passive loss of stability to active; 6 - border of the transition of rack 1 from passive to active buckling

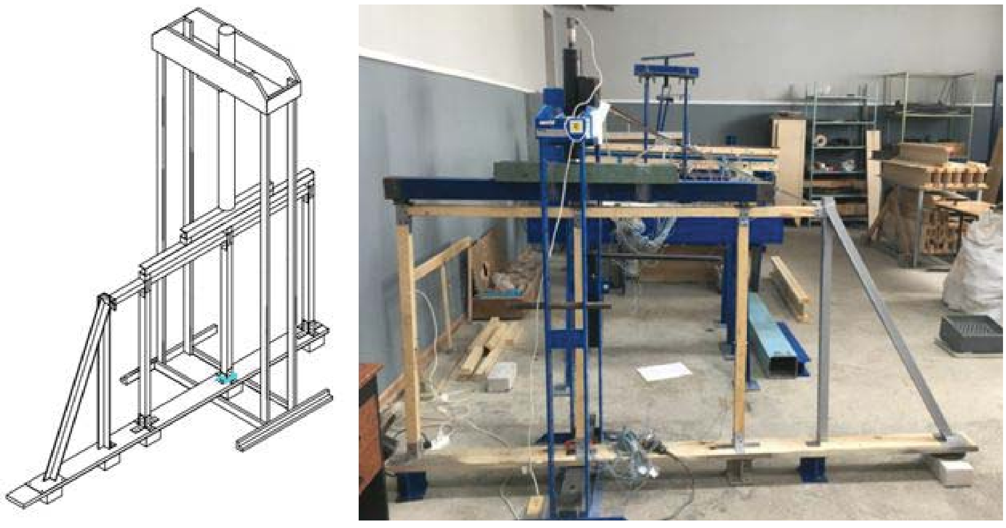
load application parameter α exceeds the values of 0.756, the post 3 of the frame under consideration goes over to active bifurcation, with α > 0.9, all the posts lose their stability actively. At the same time, with a value of α≤0.9, when the post 1 passively loses its stability, a change in its calculated length leads to a decrease in the critical force by an average of 15%. In the case when the load application parameter α exceeds the value of 0.9, a change in the calculated length of element 1 leads to an increase in the maximum value of the compressive force by 5%.

At the same time, at a value of α≤0.76, when the post 3 loses its stability passively, a change in its calculated length leads to a decrease in the critical force by an average of 6%. In the case when the load application parameter α exceeds the value of 0.76, a change in the calculated length of element 3 leads to an increase in the maximum value of the compressive force by 2%.

In this case, a change in the calculated length of the second leg leads to a decrease in the critical force by an average of 50%

EXPERIMENTAL RESEARCH

In order to test the developed methodology on the basis of the Southwestern State University, experimental studies of the influence of the calculated length on the stability of frame-rod structural systems made of wood were carried out. To achieve this goal, three series of three frames in each were designed with the following parameters: material - spruce wood, grade I, rack height - 1 m; spans - 0.67 m (Fig. 7). The calculated length was varied due to the rigidity of the support nodes. In the first series, all frame units are



a) b)

Figure 7: Scheme (a) and general view (b) of the test setup

rigid; in the second series of hinged-fixed, the support of the left pillar was adopted, in the third - the right one. The tests were carried out with a loading coefficient α = 0.85, therefore, in the second group of structures, the calculated length of the rack, which loses its stability actively, changes, in the third - passively.

As a result of the experiment, after statistical data processing, it was found that the critical force Pcr. for frames of the first series it is 4.23 kN, for the second - 3.09 kN, for the third - 4.19 kN.

CONCLUSION

The presented rather simple algebraic dependences make it possible to obtain a qualitative and quantitative assessment of the influence of the calculated length coefficient on the stability of frame-rod structural systems made of wood. At the same time, it was found that the conditions for fixing elements experiencing passive bifurcation do not significantly affect the overall stability of the system.

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Paper submitted: 04.08.2020.
Paper accepted: 07.09.2020.