Influence of Base Deformations on Stability of Frame-Rod Structural Systems

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Abstract. Purpose of research. Investigation of changes in the critical parameters of stability of structural system elements, taking into account the geometric nonlinearity associated with the deformation of the "building-base" system. Methods. Under the influence of geometric nonlinearity associated with joint deformations of the "building-base" system, the longitudinal force of some racks ceases to contribute to the bifurcation of the rod [5-7, 9, 12, 13]. Therefore, at a certain value of strain ΔS, a single rack can go from active bifurcation to passive, which will cause structural and change the critical stability parameters of the entire system under consideration. This situation can lead to irreversible deformations and destruction of both the individual load-bearing element and the entire building. Results. Let's consider a core structural system, the Central element of which is loaded with The RCR force, and the extreme elements are loaded with the RCR forces. (Fig. 1A). We find the critical parameters of the stability of the specified frame and the form of bifurcation of its compressed struts using the given equations depending on the load application coefficient α before and after stabilization of the base precipitation.

Let's analyze the bifurcation pattern of the frame elements before and after the base deformation at the maximum precipitation of the second and third pillars at the value of the load application coefficient α=0.8. at a time when the base deformations have not stabilized, the left and right pillars lose their stability passively, the Central one actively (Fig. 3A). Analysis of the obtained calculation results showed that when the second column precipitation is 2.4 cm or more, the character of the entire structural bifurcation system changes.

Conclusion. During the theoretical research, the behavior of the elements of the frame in question during the loss of stability before and after the occurrence of an emergency situation associated with the subsidence of the base of the supports of the first and second pillars was analyzed. The dependence of the critical value of the precipitation and the difference in precipitation on the load application coefficient α for the second and third pillars of the frame was derived. Analysis of the obtained calculation results showed that when the second column precipitation is 2.4 cm or more, the character of the entire structural bifurcation system changes.

1. Introduction

It is known that the loss of stability of the entire structural system is often one of the elements or their small group. Therefore, an important issue in solving the stability problems of structural systems is the identification of the most dangerous structural elements or parts with low resistance to buckling. And if the features of the deformation of rods and structural systems under power loading have been sufficiently studied, then the features of bifurcation of structures under prolonged power loading and at the same time taking into account geometric nonlinearity caused by the difference in foundation sediments.
Meanwhile, such studies are necessary not only to study the features of the deformation of loaded structural elements, to solve the traditional safety problems of structural systems, but also to assess the residual life and protect the operating structural systems from progressive collapse caused by the loss of stability of bar structures under power loading, taking into account the difference in foundation sediments. In this regard, the study of the deformation of elements in loaded rod structural systems, taking into account the geometric nonlinearity due to the roll of the foundation, is of scientific interest and a practically important research task. The aim of the work is to study changes in the critical stability parameters of the elements of structural systems, taking into account the geometric nonlinearity associated with the deformation of the building-base system.

2. Materials and methods

It is known that sudden structural transformations associated with subsidence of the base can cause a change in the critical stability parameters of both individual elements and the entire system as a whole. Therefore, to meet the requirements of the Federal Law, a deeper study of the stability of frame-rod structural systems is necessary, taking into account the physical nonlinearity associated with the joint deformations of the building-basement system.

As a stability criterion, the sign of the work of the end moments and transverse forces is adopted. Moreover, the negative value of the specified work:

\[ A_i(M_i, Q_i) < 0, \]  

serves as a sign of "active" bifurcation, and its positive value:

\[ A_i(M_i, Q_i) > 0, \]  

says that the core loses stability "passively" [1-4, 8, 10, 11, 14, 16-21].

Under the influence of geometric nonlinearity associated with joint deformations of the building-basement system, the work of the longitudinal force of some racks ceases to contribute to the bifurcation of the rod [5-7, 9, 12, 13, 23]. Therefore, at a certain strain value \( \Delta S \) a separate rack can go from active to passive bifurcation, which will cause structural and change critical stability parameters of the entire system under consideration. This situation can lead to irreversible deformations and destruction of both the individual load-bearing element and the entire building. The transition of a separate rack of a frame-rod structural system from active bifurcation to passive will occur when the work of the longitudinal force compensates for the work of the end moments and transverse forces:

\[ A_i'(N) - A_i'(M_i, Q_i) > 0. \]  

The work of the longitudinal force \( A_i'(N) \) is defined as the product of the difference in the base draft of the specified force:

\[ A_i'(N) = \Delta S \cdot \frac{v^2 \cdot E \cdot I_{min}}{I^2}. \]  

The operation of the end moments and transverse forces can be represented as:

\[ A_i(M_i, Q_i) = i \cdot \sum C \cdot \varphi_{j,i}(v_i) \cdot Z_i, \]  

where \( \varphi_{j,i}(v_i) \) – the value of the displacement method functions for compressed-curved rods; 
\( C \) – a constant determined by the rules of construction mechanics depending on the geometry, loading scheme of the structure and the rigidity of its elements.
The critical difference is the precipitation with the expressions taken into account (3-5) can be determined by the formula (6):

\[ \Delta S = \frac{l^2 \cdot \sum C \cdot \varphi_{ij}(v_i) \cdot Z_i}{v^2}. \]  

(6)

3. Results and discussion

Let's consider a core structural system, the Central element of which is loaded with \( P_{cr} \), and the extreme elements are loaded with the \( \alpha P_{cr} \). (fig. 1a). We find the critical parameters of stability of the specified frame and the form of bifurcation of its compressed struts using the given equations depending on the load application coefficient \( \alpha \) before and after stabilization of the base precipitation. The frame is calculated using the displacement method using the numerical method of successive approximations.

![Figure 1. Design (a) and equivalent (b) scheme of the frame-rod structural system.](image)

Taking the unknown angles of rotation of the nodes \( Z_1, Z_2, Z_3 \) we calculate the operation of the end moments and transverse ones using the functions of the displacement method. Then the homogeneous system of equations will take the form:

\[ r_{11} \cdot Z_1 + r_{12} \cdot Z_1 + r_{13} \cdot Z_3 = 0 \]
\[ r_{21} \cdot Z_1 + r_{22} \cdot Z_1 + r_{23} \cdot Z_3 = 0 \]
\[ r_{31} \cdot Z_1 + r_{32} \cdot Z_1 + r_{33} \cdot Z_3 = 0 \]

where

\[ r_{11} = 8 \cdot i + 4 \cdot i \cdot \varphi_2(v_1); \quad r_{22} = 8 \cdot i + 4 \cdot i \cdot \varphi_2(v_2); \quad r_{33} = 4 \cdot i + 4 \cdot i \cdot \varphi_2(v_3) \]
\[ r_{12} = r_{23} = 2 \cdot i; \quad r_{13} = r_{31} = 0; \quad v_i = l \cdot \frac{P_i}{\beta_{red}}, \quad (i = 1, 2, 3), \]  

where

\[ \beta_{red} \] is given the rigidity of the cross section of the rod; \( v_i \) – parameter of the century equation.

The determinant of the system (7) is defined by the expression (8):

\[ Det = (8 \cdot i + 4 \cdot i \cdot \varphi_2(v_1)) \cdot (8 \cdot i + 4 \cdot i \cdot \varphi_2(v_2)) \cdot (4 \cdot i + 4 \cdot i \cdot \varphi_2(v_3)) \]
\[ i^3 - (8 \cdot i + 4 \cdot i \cdot \varphi_2(v_1)) \cdot 4 \cdot i^2 - 4 \cdot i^2 \cdot (4 \cdot i + 4 \cdot i \cdot \varphi_2(v_3)). \]  

(8)

Next, we calculate the rotation angles of the nodes of the frame in question. In the given two-span structural system, we determine the values of bending moments, longitudinal and transverse forces, make up the determinant of the system of equations of the displacement method, and write the parameter of the century equation for each of the compressed elements.

Next, using the numerical method of successive approximations, we determine the parameters of the secular equation, in which the determinant written for the frame under consideration before the base of one of its supports subsidence is equal to zero for different values of the load application coefficients \( \alpha \).

Similarly, we determine the critical parameters of system stability after the occurrence of the given emergency. Comparing the work of the frame elements before and after the subsidence of the base of its
supports, we estimate the effect of soil deformations of the compressible thickness on the bifurcation features of the individual rack and the entire structural system. Let's calculate the value of the base drawdown, at which the elements can move from active bifurcation to passive. We determine the critical stability parameters of the system under study after changing the type of bifurcation of its rack.

The critical difference calculate the sediment, based on the condition that at the time of transition from active buckling to the passive work of the end moments and shear forces of the element compensates work longitudinal force $A_i(N)$.

To solve this problem, we will find the estimated length of the struts, the work of bending moments and transverse forces for the elements of the reduced frame before an emergency occurs due to the subsidence of the base of one of the supports. The operation of each rack is equal to:

$$A_i(M_i, Q_i) = 2 \cdot i \cdot \varphi_{Z_i} \cdot Z_i.$$  

Therefore: $A_1(M_1, Q_1) = -0,293 \cdot i$, operation of the end moments and transverse forces of the second rack: $A_2(M_2, Q_2) = -0,723 \cdot i$, for the third: $A_3(M_3, Q_3) = 1,526 \cdot i$. At the same time, the first and second elements of the frame lose their stability actively and the third one passively until the negative properties of the Foundation soil are revealed.

Let us analyze the behavior of the elements of the examined frame in the process of buckling before and after occurrence of emergency situations related to the drawdown of the base supports the first and second racks. The value of the precipitation difference, at which the bifurcation character of the specified frame elements changes, is determined by the formula (6).

Figure 2 shows a graph of the dependence of the critical value of the sediment difference for the frame-rod structural system under consideration on the load application coefficient to illustrate the expression (5)$\alpha$.

![Figure 2](image)

**Figure 2.** Dependence of the critical value of precipitation and the difference of precipitation on the load application coefficient $\alpha$ for the second (a) and third racks (b) of the frame.

The graphs show that the influence of the difference in precipitation on the critical stability parameters of the frame-rod structural system under consideration is necessary for a span length of 6 meters or more for buildings with a steel frame, 8 meters or more for monolithic buildings. For these buildings with shorter spans, the difference in precipitation is limited in accordance with current regulations.

Let's analyze the bifurcation pattern of the frame elements before and after the base deformation at the maximum draught of the second and third pillars at the value of the load application coefficient $\alpha=0.8$. 

At a time when the deformations of the base have not stabilized, the left and right pillars lose their stability passively, the Central one actively (fig. 3a). An analysis of the calculation results showed that with a second column draft of 2.4 cm or more, the nature of the entire constructive bifurcation system changes.

Figure 3. Forms of loss of stability of the uprights of the frame before (a) and after stabilization of the settlement of the base (b).

The first and third racks move to active bifurcation, involving the second rack in the overall loss of stability. In this case, the critical force value is reduced by 40%, which can lead to the destruction of the frame in question.

4. Conclusions
During the theoretical research, the behavior of the elements of the frame in question during the loss of stability before and after the occurrence of an emergency situation associated with the subsidence of the base of the supports of the first and second pillars was analyzed. The dependence of the critical value of the draft and the difference in the draft on the load application coefficient \( \alpha \) for the second and third pillars of the frame was derived. Analysis of the obtained calculation results showed that when the second column precipitation is 2.4 cm or more, the character of the entire structural bifurcation system changes.

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