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RELIABILITY OF RC FRAME-BRACED SYSTEMS IN DANGEROUS GEOLOGICAL CONDITIONS

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The paper considers influence of sudden transformations, linked with foundation, to reliability of reinforced concrete structural systems at buckling one of load bearing elements. Authors investigated influence of deformation value to bifurcation type for each leg of building frame. It was determined subsidence value that leads to changing of bifurcation type for rod elements of the system.Authors shown a suggested criterion for stability assessment of compressed rod elements of structural systems operated in dangerous geotechnical conditions. Such criterion can be used for assessment residual resource of a building at special impacts linked with foundation subsidence under one support.

Keywords: Subsidence soils, Frame-rod systems, Performance, Stability, Emergency

INTRODUCTION

Regions with subsidence foundations are widely distributed through the territory of Russia and neighbor countries. However the most dangerous ground conditions of the II subsidence type does not exceed 10 % of all area.

Experience of investigation of subsidence foundation accumulated in Russia and other countries shows underestimation of calculation subsidence deformations in comparison with real ones about 1.5...2.3 times [5; 7; 11; 12].At the same time, in the last years in accordance with environmental and artificial dangerous and significant deterioration of facilities in our country, the Federal law No 384-FZ “Technical regulations on the safety of buildings and structures” was accepted. This regulatory document presents new requirements for functional and structural solutions in accordance with new parameters of operational power and environmental impacts and possible accidental impacts on facilities [6; 9; 13]. However in order to explain these new requirements of the Federal law, it is necessary to provide advanced researches to investigate various accidental impacts, in particular, impacts linked with foundation subsidence.

In addition to calculation of load bearing capacity of structures operating in dangerous geotechnical conditions, researches on reliability of frame-braced systems at a support subsidence are actual problem.

Consequently, in order to satisfy new requirements of the Federal law, it is necessary to provide advanced researches of different accidental impacts, in particular, linked with foundation subsidence and it affecting to stability of each element as well as entire structural system.

Sudden structural transformations significantly, caused by foundation subsidence, affect to reliability parameters of reinforced concrete structural systems at buckling of load bearing elements [15; 16]. Such overcritical impacts accompanying with changes of geometry cause changes of critical parameters and corresponding critical forces.

At the same time an important question in solution to stability problem of structural systems at accidental impacts is determining of the most dangerous elements or structural parts with low resistance to buckling [1; 2; 3]. Therefore, at first stability analysis should be provided for entire structural system, i.e. first level calculation model should be constructed initially. Using such model, we provide analysis of stress state of all elements which require advanced investigation.

First level calculation can be carried out with elastic model since the main purpose of this calculation is assessment of stress state of entire system and finding of the most dangerous elements.

DEFINING EQUATIONS

Figure 1 shows rod excluded from rod system that loss stability.It additional deformation energy that caused by bifurcation equals to sum of works of ends’ axial and shear forces and bending moments. Let us represent it as two parts [10; 17-19]:

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

where $A_i(N_i) = N_i \cdot \Delta_i$ is work of axial compressing forces for convergence Δ_i of points it attaching,

$$A_i(M_i, Q_i) = \frac{1}{2} \cdot (M_1 \cdot Z_{1i} + Q_2 \cdot Z_{2i} + M_3 \cdot Z_{3i} + Q_4 \cdot Z_{4i}) \quad (2)$$

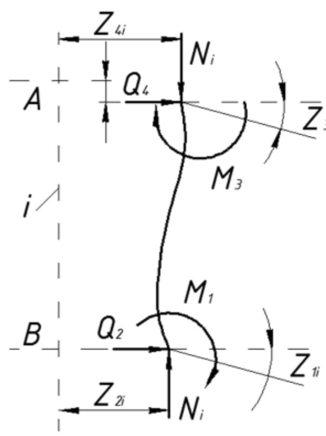

Figure 1: A rod excluded from a system

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Since overall energy of system is more than null U_i>0, then works' sum (1) always is positive. However signs of components A_i (N_i) and A_i (M_i, Q_i) can take the same or opposite signs. For compressing force it work for convergence of points is positive A_i (N_i)>0,i.e. it contributes to active rod bifurcation.Work of ends' moments and shear forces A_i (M_i, Q_i) for given loading scheme can be more, less or equal to null [1; 2; 3].

In the first case it means that work of axial force N_i is not enough to compensate increment potential energy of rod deformation and neighbor elements (as support reactions) contribute to it buckling.It is case of "passive" or "coerced" bifurcation. Case, when work of moments and shear forces is negative A_i (M_i, Q_i) <0, presents, that neighbor elements resist to it it bifurcation and, consequently, rod loss stability "actively" involving in this process overall system [1; 2; 3].

When work of moments and shear forces equals to null A_i (M_i, Q_i) = 0, state ofi –th rod and all system is equally stable. Consequently, sign of work (2) may be used as criterion of assessment of type of rod buckling. At the same time inequality:

$$A_i (M_i, Q_i) < 0 \tag{3}$$

is attribute of "active" bifurcation of this rod for given loading scheme, and inequality:

$$A_i (M_i, Q_i) > 0 \tag{4}$$

is attribute of "passive" bifurcation. Equality:

$$A_i (M_i, Q_i) = 0 \tag{5}$$

Is attribute of equally stable state of rod and frame. Values of work A_i (M_i, Q_i), representing the energy contributions of the neighbor elements to the bifurcation of each i-th rod, give quantity assessment of active or passive bifurcation of considering rod (or some part of a system).

In the case of accidental impact linked with foundation subsidence under column footing, work of axial force can change it sign A_i (N_i)<0, ceasing to contribute to active bifurcation of the rod. Work of ends' reactions A_i (M_i, Q_i) does not change it values in this case.

It is necessary to obtain criterion for assessment of bifurcation for case of accidental impact linked with foundation subsidence. Such criterion should allow describing behavior whether one element or entire system.

For rod elements subjected to active bifurcation, expression (6) becomes a bifurcation criterion, that allows evaluating possibility of bifurcation type changing (from active to passive).

$$|A_i (N)| > |A_i (M_i, Q_i)| \tag{6}$$

Accounting sign of work, expression (6) can be written as follows:

$$A_i (N) + A_i (M_i, Q_i) > 0 \tag{7}$$

Expression (7) takes in account work of axial force for displacement of support in the case of foundation subsidence:

$$A'_i(N) = S_{sl} \cdot P_{кр.} \tag{8}$$

$$S_{sl} \cdot \frac{\nu^2 \cdot i}{l^2} + A_i(M_i, Q_i) > 0. \tag{9}$$

QUANTITATIVE ANALYSIS

Let us consider two span frame in which central leg and outer legs loaded with forces Pcr (fig. 2a). Let us determine bifurcation type for rod (active or passive).In order to calculate frame, we used quasi-static method, displacement method and step-iteration procedure.

(a)

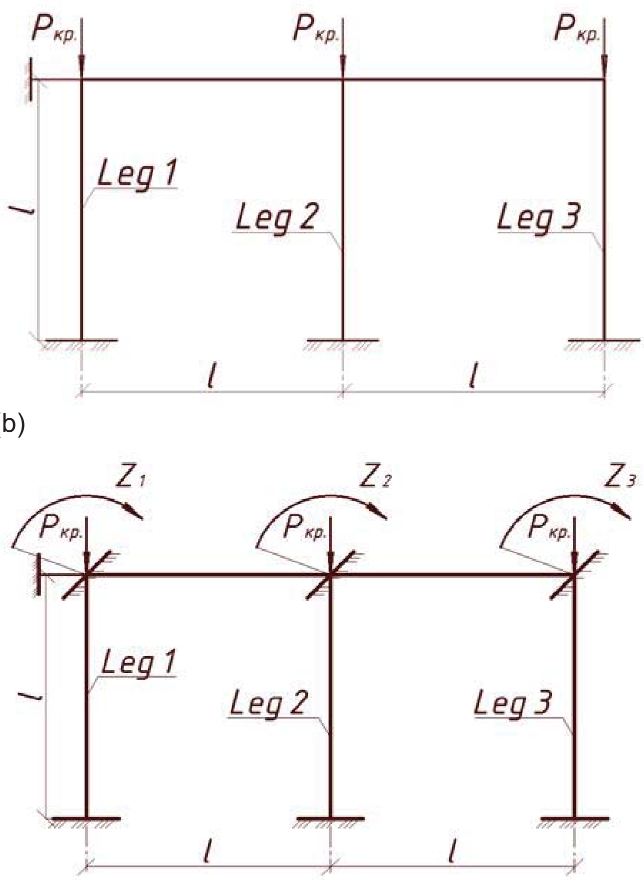

Figure 2: Calculation scheme for frame (a) and equivalent system of the displacement method (b)

We performed calculations of works of ends' moments and shear forces using special functions of the displacement method.If we accept rotation angles as variables Z1, Z2, Z3 (fig. 4.6), homogenous system of equations takes the form:

$$\left.\begin{aligned} r_{11} \cdot Z_1 + r_{12} \cdot Z_1 + r_{13} \cdot Z_3 = 0 \\ r_{21} \cdot Z_1 + r_{22} \cdot Z_1 + r_{23} \cdot Z_3 = 0 \\ r_{31} \cdot Z_1 + r_{32} \cdot Z_1 + r_{33} \cdot Z_3 = 0 \end{aligned}\right\} \tag{10}$$

Where

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

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$$Det = (8 \cdot i + 4 \cdot i \cdot \varphi_2(v_1)) \cdot (8 \cdot i + 4 \cdot i \cdot \varphi_2(v_2) \cdot (4 \cdot i + 4 \cdot i \cdot\cdot \varphi_2(v_3)) + 16 \cdot i^3 - (8 \cdot i + 4 \cdot i \cdot \varphi_2(v_1)) \cdot 4 \cdot i^2 - 4 \cdot i^2 \cdot (4 \cdot i + 4 \cdot i \cdot\cdot \varphi_2(v_3)). \quad (11)$$

$$8 \cdot [(2 + \varphi_2(v_1)) \cdot (2 + \varphi_2(v_2)) \cdot (1 + \varphi_2(v_3))] - 2 \cdot [3 + +\varphi_2(v_1) + \varphi_2(v_3)] = 0. \quad (12)$$

where B_{red} is reduced stiffness of rod cross section; v_i is parameter of secular equation.

Determinant of the system (10) can be found from following expression.

After transformation of expression (11), characteristic equation for critical force P_{cr} (w, t) takes the form. Further let us determine unknown values of rotation angles and displacements Z1, Z2, Zn. For investigated rod system we carried out plotting of diagram of internal power factors: bending moments, axial and shear forces. Let us find value of determinant of the system of canonic equations of the displacement method that depend on parameter of secular equation v_i. Using iteration method for each rod element of structural system we determine initial parameter of secular equation v_{i0}, for which determinant equals to null.

Applying mentioned equations, we find critical parameters and modes of buckling for considering system. It is interesting assessment of accidental impact (foundation subsidence under one of the supports) affecting to bifurcation character of rods of the structural system. Really it may expect that power factors in condition of foundation subsidence cause changing of passive type of bifurcation to active or conversely, i.e. inequality $A_i<0$ or $A_i>0$ changes it sign respectively.

In order to solve this problem, we find length factors of frame legs and work of bending moments and shear forces for the primary scheme. Work of each frame leg equals:

$$A_i(M_i, Q_i) = 2 \cdot i \cdot \varphi_{2,i} \cdot Z_i. \quad (13)$$

For the first leg: A_1 (M_1,Q_1) = -0,293·*i*, work of ends' moments and shear forces the second leg: A_2 (M_2,Q_2) = -0,723·*i*, the third leg: A_3 (M_3,Q_3) = 1,526·*i*. Consequently, the first and the second frame leg loss stability actively, third – passively.

Let us consider accidental impact subjected by foundation subsidence under the first leg. Work of axial force executing at support displacement partially compensates work for convergence of end sections of the element.In this case mentioned work should be taken in account for assessing of compressed legs' stability. Inequality (14) becomes criterion of active bifurcation of rod element.

$$A_i(M_i, Q_i) + A'_i(N_i) < 0, \quad (14)$$

Where A'_i (N_i)is component of axial forceN_iwork for leg displacement in the case of emergency situation appearing (foundation subsidence).

Analyzing expression (14), we determine critical value of subsidence $S_{sl,кр}$, when leg 1 of considering frame transmit to passive bifurcation state changing process loss of stability for entire system:

$$S_{sl,кр.} = \frac{A_i(M_i, Q_i)}{P}, \quad (15)$$

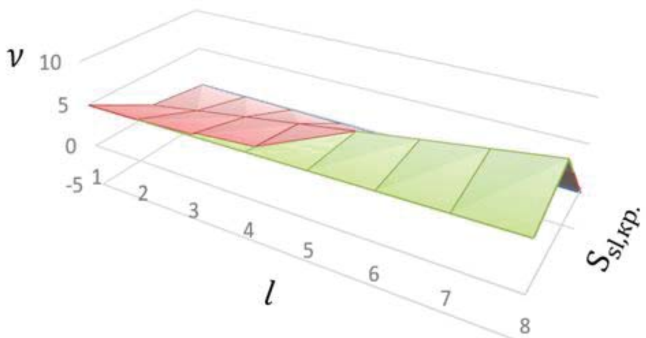
Taking in account work of the first leg A_1 (M_1,Q_1)=-0,293·*i*:

$$S_{sl,кр.} > \frac{0{,}293 \cdot l^2}{v^2}. \quad (16)$$

In order to illustrate expression (16), figure3 (a) shows dependence between critical subsidence value $S_{sl,кр.}$ and leg length and coefficient of axial bending. Figure3 (b) presents analysis of dependence of $S_{sl,кр.}$ from leg length for coefficient values *v*=5,2 and *v*=4,8.

Let us analyze behavior of legs of considering frame during buckling process before and after accidental impact linked with foundation subsidence under the first leg for element's length *l*=3 m. As it was presented above, the first and the second legs of the frame buckling actively, third – passively. Figures show active bifurcation with solid line and passive – with dashed line. For foundation subsidence under support of the first leg more than 8 cm bifurcation for corresponding element changes its type (fig. 4 b). At the same time leg 3 of considering frame transmits to active bifurcation.

(a)



(b)

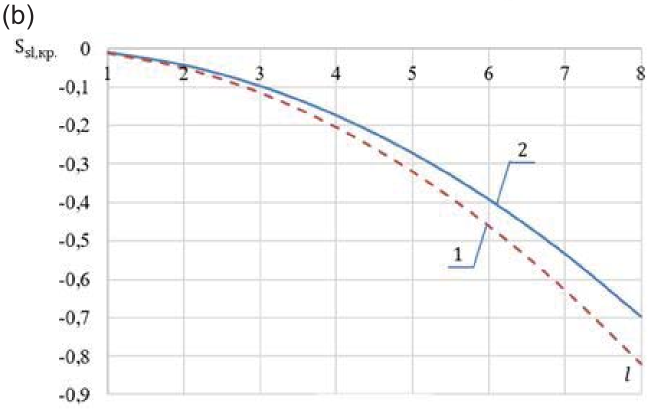
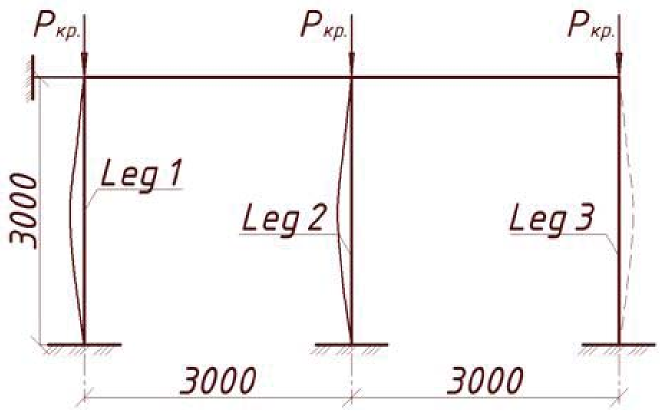


Figure 3: Dependence between critical subsidence value $S_{sl,кр.}$ and two parameters: отдвухпараметров: leg length and coefficient of axial bending (a), dependence from one parameter: leg length (b) for coefficient values v=4,8(1) and v=5,2 (2)

(a)



(b)

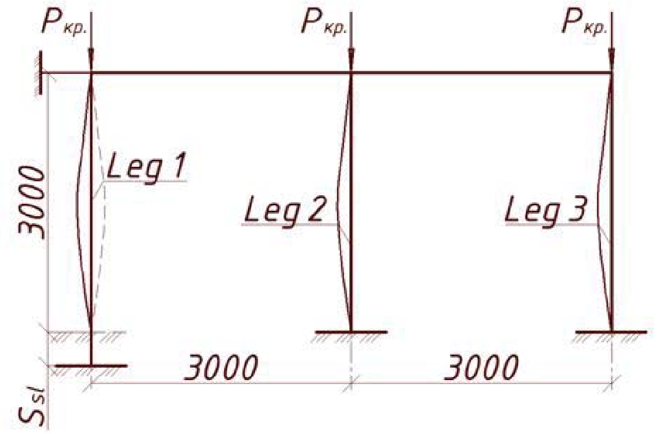
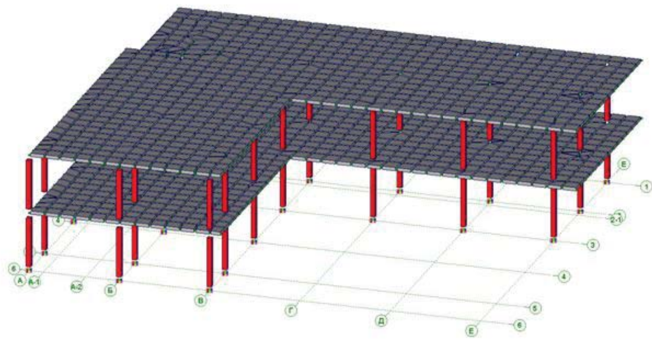


Figure 4: Modes of frame buckling before (a) and after emergency situation(b)

(a)



(b)

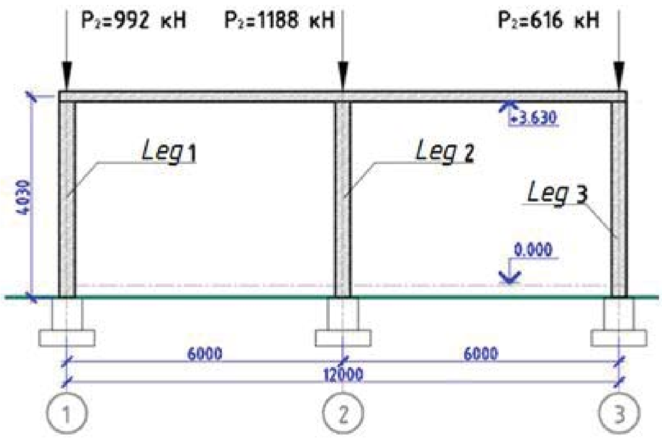


Figure 5: Finite element model for building frame (a); structural scheme конструктивнаясхемафрагментакаркасаздания (b)

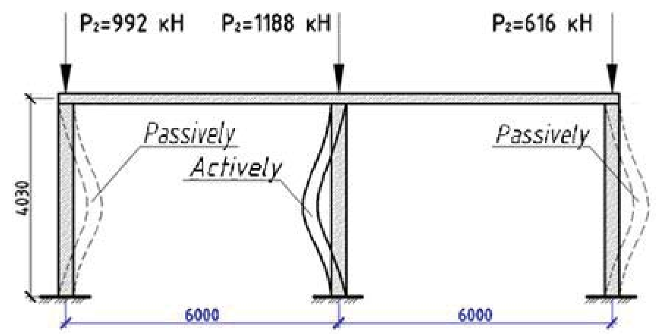
IMPLEMENTATION RESULTS

Suggested technique of reliability analysis for reinforced concrete frame-braced at emergency situation linked with foundation subsidence under one of the legs is implemented in Southwest state University for designing of public building in Kursk.Design static calculation of finite element model presented in figure 5, a is carried out using software SCAD. Critical parameters (fig. 5, b) are determined for the most loaded building frame fragment. These parameters characterize buckling process for system and changing of bifurcation type for legs at considering emergency situation.Secondary calculation model loaded with external concentrated loads determined with SCAD software.

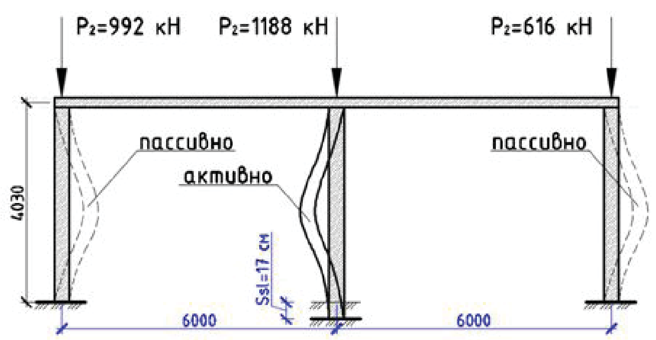
Let us analyze legs' behavior of the most loaded building frame fragment of considering building during buckling before and after emergency situation linked with foundation subsidence under all supports (figure 6).

As it is shown in figure 6 (a), before considering emergency situation the first and the third legs of building frame loss stability passively, and the second one – actively. After foundation subsidence under the second support bifurcation of elements do not change its type (fig. 4, b). At the same time similar failure with leg 1 for deformation value more than 13 cmleads to buckling mode changing for the first and the second elements.

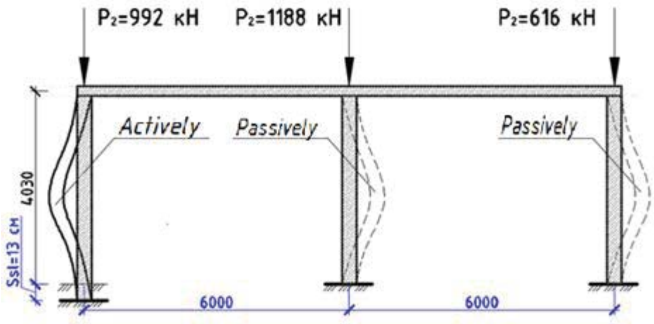
(a)



(b)



(c)



(d)

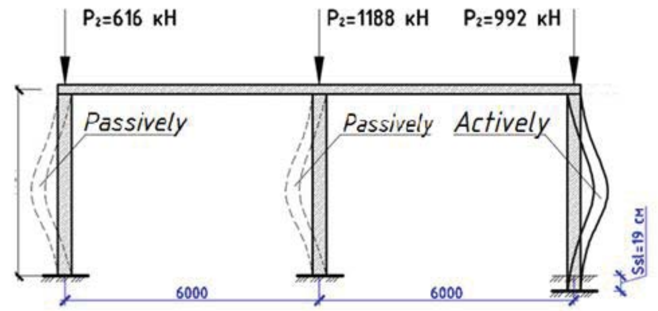


Figure 6: Buckling modes for building frame legs before (a) and after foundation subsidence under the first (b), the second (c) and the third (d) supports

CONCLUSIONS

Suggested criterion for assessing stability of compressed elements of structural systems, operating in dangerous geotechnical conditions, allows to provide respectively simple evaluation of resistance resource of such elements for emergency situations linked with foundation subsidence under one of the supports. Analysis of obtained results shows that bifurcation type whether of the elements or entire system can be changed for some value of subsidence.

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