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EARLY CONCRETE CREEP AND ITS REAL MODULUS OF ELASTICITY CONSIDERATION AT CALCULATIONS OF MULTISTOREY FRAMES RAISED IN A RELATIVELY SHORT TIME

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ABSTRACT

Currently, the development of structural mechanics follows two main directions, on the one hand, the development of higher-end computational methods based on powerful software systems, on the other - the improvement of design models and original hypothesis underlying in the basis of calculation. Taking into account the material behaviour of building constructions, especially concrete, allows to find out the constructional safety resource for ready-built building as well as to correct the real internal forces distribution and related strains in the newly designed buildings. The aim of the work is research of loading history effect of the reinforced-concrete monolithic frames on its elements strain-stress distribution. The sequence of building erection as well as hardening and concrete creep as time functions are took into calculations.The algorithm taking into account the concrete creep and changes of its modulus of instantaneous elasticity is defined. Such algorithm was based on formulas obtained by Harutyunyan [1]. The program for performing calculations was made. It is based on the finite-difference method and allows taking into account mentioned above factors. The analysis by finite elements was made for results comparison.

Keywords: design scheme, reinforced concrete elements, loading history, creep of concrete, tension, internal forces, displacement.

METHODS USED IN THE CALCULATION

In all cases the calculation was made in accordance with strained scheme. The calculation program for determination of internal forces and displacements in the frame members under static loads taking into account all the above mentioned factors was made. The calculation was done by network approximation elements method [2]. This method allows entering any integral and differential relationship into the equation to characterize material properties. The method also takes into account geometrical nonlinearity in the elements of building straining. The program allows defining the desired number of intermediate sections (8, 16, 32, 64 and so on). In our research each element is divided into 8 sections. The system of nonlinear equations includes: boundary-condition equation; nodes equilibrium equation; compatibility equations for strain in the nodes; equilibrium equation for external and internal forces in the given cross-sections taking into account the axial and lateral elements strains and representing differential equations of first and second order. The finite-difference approximation is used to reduce the differential equation system to algebraic form. The system of nonlinear equations is solved by Newton method using step-by-step iteration. The criterion of calculations accuracy for the axial and lateral displacements is the successive iterations difference equal to 10-8 m. To compare results the calculation of the same frame was made by finite element method (FEM) without taking into account the above-listed factors.

STATEMENT OF PROBLEM AND BASIC DATA

The article describes the calculation of the plane six-storied single-bay monolithic frame taking into account: the sequence of erection; changes of concrete modulus of instantaneous elasticity in Harutyunyan's exponential relationship; concrete creep, according to formulas for compressed and bending elements [1].

The frame bay - 6m, the number of bays - 1, story height - 6m, the column section - 40x40sm, symmetrical reinforcement: A_s = 28, 26sm^2, h_s = 17sm; the girder section - 30x60sm, symmetrical reinforcement, As = 42, 39sm^2, h_s = 27sm. Concrete Class is B-20, the standard concrete modulus of elasticity is E_0 = 27GPa, the reinforcement modulus of elasticity is E_s = 200GPa, the uniformly distributed load through the girder is q = 30kN/m.

ERECTION SEQUENCE CONSIDERATION

The heart of the problem is in the following. In the internal forces definition in the transverse frames of civil and industrial buildings the designer works with frame design diagram with project number of stories. The girder loading of such frame by constant and temporary loads is carried out for all stories simultaneously. In real frame systems the girder mounting of the next story is carried out after floor slabs placement at the previous story. As a rule, the prefabricated wall mounting (or small sized elements storage (gypsum blocks, bricks) for the next walling) is carried out by use of the hoisting crane in case of overlying construction absence. Sometimes in the process of erection of the multistoried industrial building the heavy equipment is lifted by the building crane and is installed at the floor structure. It means that in the classical design scheme the load from underlying girder causes the internal forces appearance in the vertical members and girders of the overlying stories [3, 4]. Unlike classical scheme in the real loading the most part of

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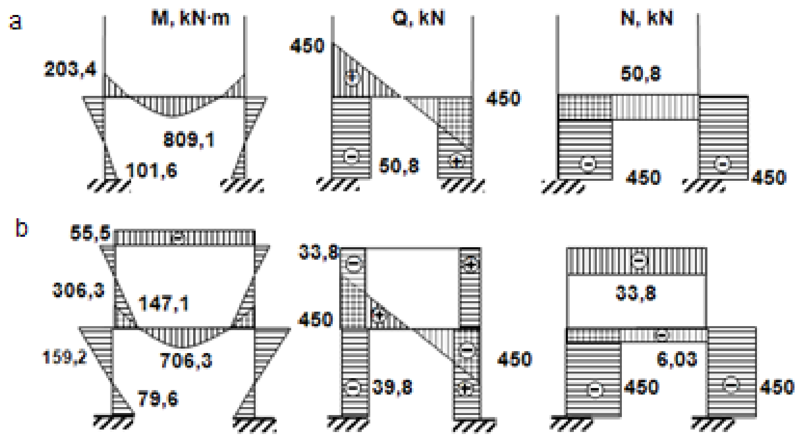

Figure-1. Results of frame calculation for girder loading of the 1st floor:
a - in the absence of overlying girder; b - taking into account the girder of the 2nd floor.

constant load (in case of equipment - a part of temporary load) doesn't have an effect on forces in the top stories constructions. At the Figure-1 there is two-storied single-bay frame with distributed internal forces for two variants of design diagrams: 1 - girder loading of the first floor in the absence of overlying girder (it is really happened from a constant load effect); 2 - loading of the same girder in the usual (classical) design diagram.

Comparison of the bending moment curves shows that the presence of overlying girder, as expected, makes included in the work the 2nd floor construction. It unloads the vertical members of the 1st floor and reduces the bay moment of the girder under review. In real loading of the frame the bending moments at the top and the supporting section of the 1st floor vertical members are greater than at the classical scheme by 27-28%, the maximum moment in the bay girder of the first floor more by 14.5%, but the moment at support of the girder is less by 33 %. Of course, in the real building the loadings are applied in several stages so this effect will be less noticeable because than half of all the load (part of the constant and the whole temporary load) will be applied to the finished frame. Loading sequence consideration of precast reinforced-concrete frame was studied earlier in [2, 5]. In this work the monolithic frame calculation is being built in a relatively short time will be done.

The periodicity of frame floor erection at 9 days intervals is accepted for the calculation. It actually corresponds to the terms of the building erection of the monolithic hotel at Astrakhan. The zero reference point is a day. At this period the first floor columns are erected, the second floor columns are erected on the 9th day, the third floor columns are erected on the 18th day, etc. The girders are erected on the 5th, 14th, 23rd days, etc. When the formwork is removed from the first floor monolithic slabs and girder (and in fact the beginning of its operation under load) there are two overlying girders with slabs are already erected. The time of the next girder loading is taken 18 days, i.e. for girder and column of the first floor it will be the 23rd day from the zero reference point, for girder and column of the second floor it will be the 32rd day, etc. at intervals in 9 days. The girder of the sixth floor is erected on the 50th day and begins to work on the 68th day.

HARDENING AND CONCRETE CREEP CONSIDERATION

In recent years the volume of monolithic construction increased greatly both in Russia and abroad. The possibility of reducing building terms by increasing the concrete work speed (about 3…5 days per floor) plays a key role in the monolithic construction. There is a question: what kind of effect does concrete loading have on VAT at early terms, when the concrete structure is not fully formed and the strength and stiffness are far from standard values?

There are two variants for calculation: 1- taking into account the modulus of instantaneous elasticity increasing through its maturing in the process of "aging", 2 - the concrete maturing with the phenomena of creep simultaneously.

Changing of the modulus of instantaneous elasticity of concrete in the process of its maturing is set by an exponential function [1]:

$$E_b(t) = E_0 \cdot \left(1 - e^{-\alpha t}\right) \quad (1)$$

The concrete creep consideration is carried out by coefficients $B_z(t_1, t)$, got on the basis of functional connections for compression and bending [1]. It is to be noted that in this method such coefficients are used to define more exactly the concrete and reinforcement intensity of stress. In this case elastic and instantaneous stresses are multiplied by these coefficients. In this article based on the Equation (2)

$$B_z\sigma_b = B_z(E_b \cdot \varepsilon) = (B_z E_b) \cdot \varepsilon \quad (2)$$

Hardening and concrete creep consideration can be produced at each stage of loading by multiplying of the concrete modulus of elasticity $E_b(t)$ by coefficient $B_z(t_1; t)$:

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$$B_z(t_1,t) = 1 - \frac{\gamma\mu E_s n_0 \varphi(t_1)}{1+\mu n_0 m(t_1)} \int_{t_1}^{t} e^{-\int_{t_1}^{\tau}\left(\gamma + \frac{\gamma\mu E_s n_0 \varphi(u)}{1+n_0\mu m(u)} + \frac{\mu n_0 m'(u)}{1+\mu m(u)}\right)du} d\tau \quad (3)$$

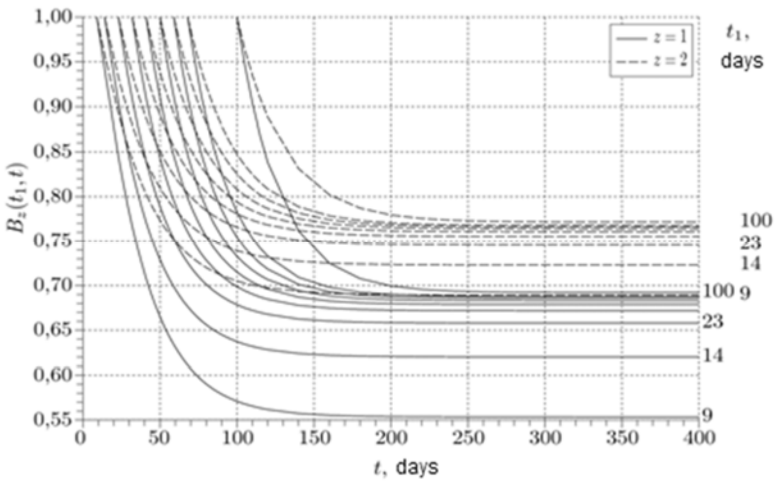

Figure-2. Coefficients of creep (solid line is for B_1, dashed - B_2).

In the above expressions: t_1 - age of concrete at the time of loading; t - age at the time of observation; μ - cross-section coefficient of reinforcement; $\varphi(t) = C_0 + A_1/t$ - function taking into account concrete creep measure; C_0 - limit concrete creep measure of the material; A_1, γ - constant parameters of concrete creep measure; $m(t) = E_s/E_b(t)$ - the ratio of the reinforcement and concrete modulus of elasticity (the age of concrete t- days); n_0 – coefficient taking into account for bending (z = 1) and for tension-compression (z = 2):

$$n_0 = \begin{cases} 1 + h_s^2 \cdot A_b / I_b, & \text{if } z = 1; \\ 1, & \text{if } z = 2. \end{cases}$$

We define the values of constants (for heavy concrete of natural hardening): $C_0 = 0,09 \cdot 10^{-7}$ kPa^{-1}; $\gamma = 0,026$; $A_1 = 4,83 \cdot 10^{-7}$ day/kPa; $\alpha = 0,03$ day^{-1}.

The coefficient B_1 takes into account the bending, B_2 - for tension-compression. At Figure-2 there are graphs for B_1 and B_2, depending on the age of concrete at loading (t_1 = 9, 14, 23…100 days):

Graphs for concrete modulus of elasticity depending on the age of concrete at the time of loading taking into account the coefficients of creep are shown in Figure-3.

The estimated stiffness of the frame elements is determined by the formulas:

$$EI\,(t_1;t) = E_{b1}(t_1;t) \cdot I_b + E_s I_s;$$

$$EA\,(t_1;t) = E_{b2}(t_1;t) \cdot A_b + E_s A_s.$$

At Figure-4 there are graphs for column stiffness in bending and tension-compression depending on the current time and time of loading:

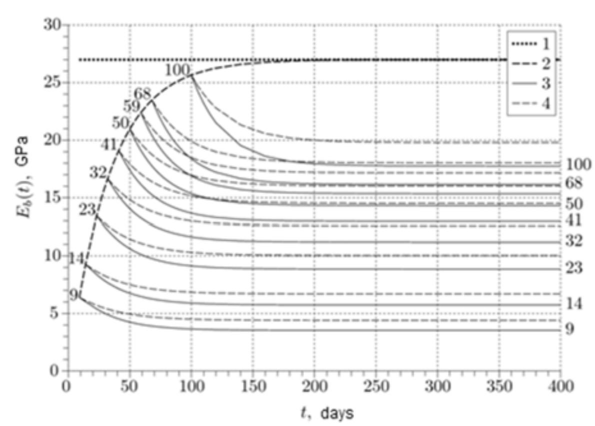

Figure-3. The concrete modulus of elasticity E_b:

1 - standard value;

2 - hardening consideration: $E_b(t) = E_0 \cdot \left(1 - e^{-\alpha t}\right)$;

3 - bending taking into account creep: $E_{b1}(t_1;t) = E_{b0}(t_1) \cdot B_1(t_1;t)$;

4 - tension-compression taking into account creep: $E_{b2}(t_1;t) = E_{b0}(t_1) \cdot B_2(t_1;t)$.

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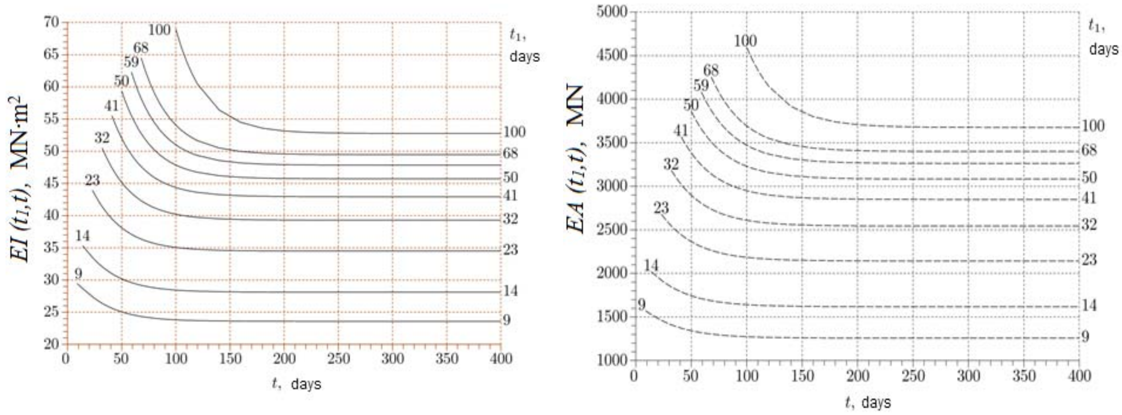

Figure-4. The column stiffness dependence on the current time and time of loading: on the left - bend EI(t_1;t); on the right - tension-compression EA(t_1;t).

ANALYSIS OF ACCOUNTING RESULTS OF MONOLITHIC FRAME

The pre-testing accounting was performed without taking into account the loading sequence by the finite element method (FEM) (the program "SCAD-office") and by network approximation element method (Figure-5). The practical agreement of results indicates accuracy of calculations made by the proposed program. The bending moments increase is due to the calculation performed on the deformed scheme: axial forces taking into account eccentricity make an additional bending. The calculation results for all variants, taking into account the frame loading history are shown in Figure-6.

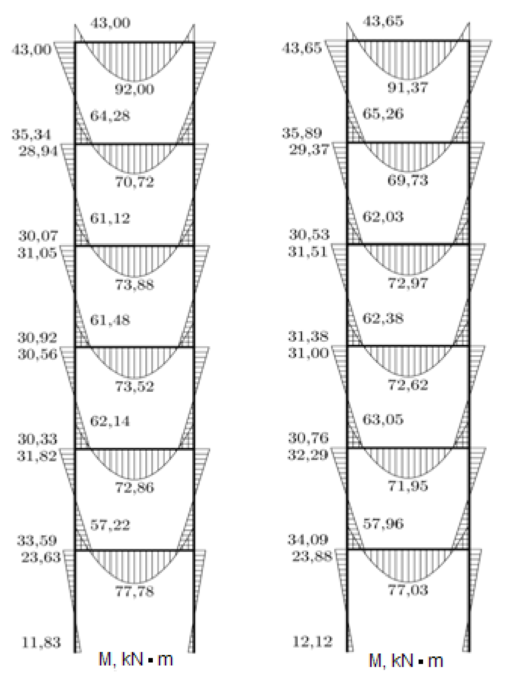

Figure-5. Bending moment curve: on the left - calculated by the FEM; on the right - calculated by the network approximation element method.

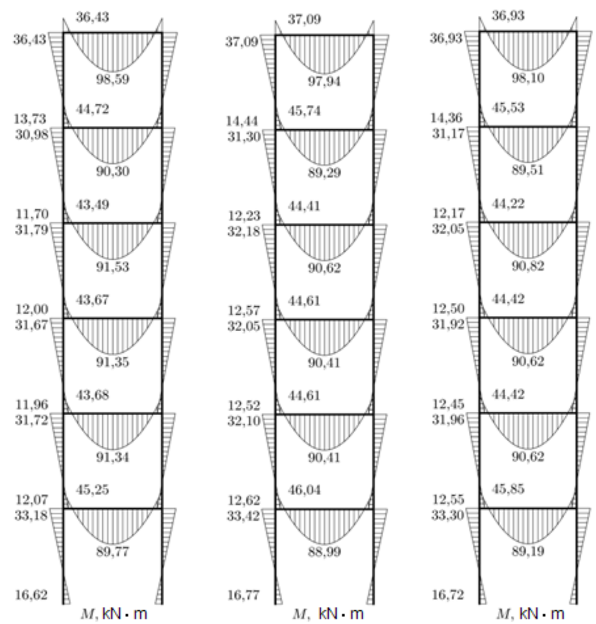

Figure-6. Bending moment curve taking into account the loading sequence: on the left - with the constant $E_b = E_0$; in the middle - taking into account the hardening of concrete; on the right - taking into account the hardening and creep.

On Figure-5: Bending moment curve in the classical calculation with simultaneous girder loading of all the floors by distributed loading: on the left - calculated by the FEM; on the right - calculated by the network approximation element method taking into account design diagram deformation.

On Figure-6: Bending moment curve taking into account the loading sequence: on the left - with the constant $E_b = E_0$; in the middle - taking into account the hardening of concrete; on the right - taking into account the hardening and creep.

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The comparison Figures 5 with 6 shows the most change of bending moment value in comparison with the classical calculation takes place in the first floor vertical posts - moment at support is increased by 41, 7%, upper section moment is increased by 40, 4%, girder moment at support is decreased by 20…28%, simultaneous moment increase in the middle of the girder is 16…24%.

At Figure-6 the curve comparison can form an impression that hardening and creep consideration does not give any important result, but it is false impression. In quite equable elastic module decreasing along frame elements (taking into account coefficients of creep B1 and B2) internal forces does not obtain any noticeable change, but displacement increase is quite great (Figure-7).

At Figure-7 the first and second graphs are coincided. They were got for six-storied frame simultaneously loaded at all floors by uniform loading q = 30 kN/m. The 3-5 graphs takes into account the loading sequence. Stress analysis of the most loading frame elements shows the high stress increase in the reinforcement of supporting column sections and girder middle sections (Figure-8).

In the reinforcement installed at exposed face of column stresses obtained by common scheme with standard elastic module are equal: from axial force - 22, 46 MPa, from bending moment - 5, 44 MPa. The sum total is 27, 9 MPa. With consideration for concrete creep and its elastic module change the stresses increase is ceased for 150 days. The stresses are equal: from axial force - 69, 4 MPa, from bending moment - 20, 2 MPa. The sum total is 89, 6 MPa. Therefore the stresses in the reinforcement column are increased by 62 MPa. It is about 20% of design strength for reinforcement Class-A-III.

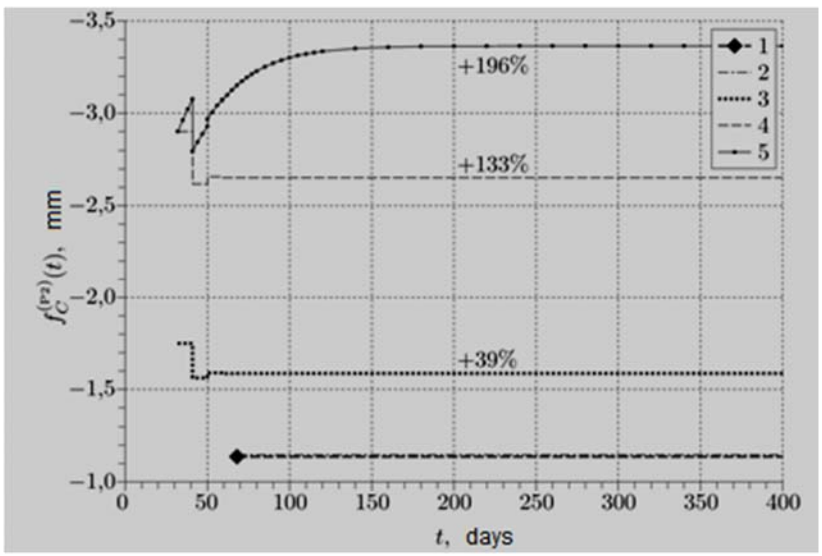

Figure-7. Girder pitch of deflection of the second floor:
1-by FEM; 2- by network approximation elements method (classical calculation);
3- taking into account erection sequence; 4- taking into account hardening of concrete;
5- taking into account hardening of concrete and concrete creep

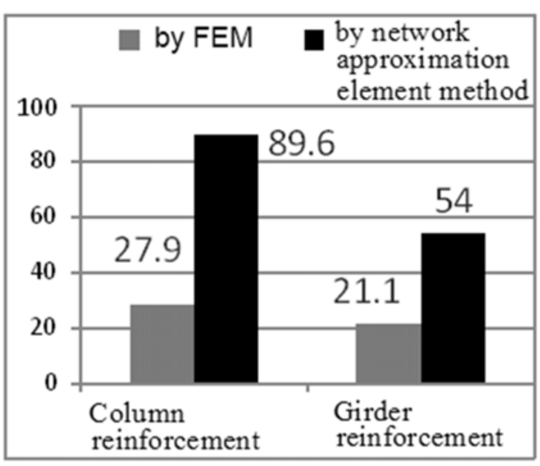

Figure-8. Stress in the reinforcement of supporting column sections and girder middle sections, MPa (from loads at the construction phase).

CONCLUSIONS

a) The consideration of erection sequence of monolithic frame gives about 40% difference between internal forces obtained by loads taking into account at erection stage and internal forces obtained by the classical calculation. The most worry is the first floor column and middle girder sections. In the multispan frames the supporting girder sections of the tail bays are also overloaded.
b) The consideration of loading history of monolithic concrete constructions, erected in a relatively short

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time, shows the decrease of constructional reliability resource of such buildings.

c) The offered method of step-by-step loading allows finding secondary stresses value in the reinforcement of the most important constructional elements.

d) The stresses in the analyzed examples are increased from 50 to 70 MPa. It is about 15…20% of design strength for reinforcement Class-A-III.

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