

Residual resource of power resistance during building structures deformation

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Abstract. Modern scientific research and design developments, based on the fundamental principles of physics, mechanics and thermodynamics, are developing in a phenomenological direction. This implementation is found both in traditional integrated models of reinforced concrete using the advantages of computer technology, and in discrete models following the grid methods of solid deformable body mechanics. Discrete models in content and chronology over time are hereditary with respect to integral models. The theoretical basis for calculating the residual life of the force resistance to deformation, determines the stiffness of the cross sections of reinforced concrete elements with a maximum bending moment and with zero bending moment are presented in this article.

1 Introduction

The logical basis of phenomenological methods is the experimental-statistical assessment of the factors and consequences of the deformation and destruction processes in materials and structures, the identification and analysis of existing quantitative and qualitative relationships between them, a results generalization, followed by the formulation of the hypotheses and invariants system necessary to create an applied theory and determine the structure when solving the problems of concrete and reinforced concrete power resistance. Concrete is characterized by anisotropy of force resistance. Its use in load-bearing structures is facilitated by compensatory reinforcement. The strength resistance of reinforced concrete is collectively determined by the properties of its components and the specifics of their joint work, including the adhesion of reinforcement to concrete. At the same time, the strength resistance of concrete, reinforcement, and adhesion between them are distinguished by the nonlinearity of the relationship between stresses and strains, creep, a certain irreversibility of strains, age wear; concrete responds to changes in the physicochemical and pyrometric characteristics of the medium, on the history and time conditions of loading and impacts [1-9].

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2 Materials and method

Nonequilibrium problem statement actualizes the search for preferred specific forms of writing rheological equations of the materials mechanical state where time acts as a factor that determines the primacy of the functional-mode relationship between stresses, strains and time, and at the same time.

Real reinforced concrete structures, especially those of environmental protection, communication and communal use, have an increased risk degree of unacceptable damage caused by technogenic or biological aggressive effects (the effect is considered as corrosion damage). The problem of ensuring the state of fracture toughness (absence of cracks) for a specified period of time has the problem of predicting the moment of cracks occurrence in the stretched zones of reinforced concrete elements with the maximum in terms of quantity and significance factors of strength and corrosion content [10-18].

The basic rheological equation of the concrete force resistance has the form in the modern theory of reinforced concrete:

$$\varepsilon(t, t_0) = \sigma(t) \cdot \frac{S_M^0 \cdot [\sigma(t)]}{E_M^0(t)} + \sigma(t) \cdot S_n^0 \cdot [\sigma(t)] \cdot C(t, t) - \int_{t_0}^t S_n^0 \cdot [\sigma(t)] \cdot \sigma(t) \cdot \frac{\partial}{\partial \tau} \cdot C(t, \tau) \cdot d\tau \quad (1)$$

where $\varepsilon(t, t_0)$ - the total force relative deformation accumulated over a period of time (t, t_0) ;

$S_M^0; S_n^0$ - nonlinearity functions for instantaneous strains and for creep strains;

$$\varepsilon_M(t) = \sigma(t) \cdot \frac{S_M^0 \cdot [\sigma(t)]}{E_M^0(t)} \quad (2)$$

where $\varepsilon_M(t)$ - instantaneous relative force deformation at time t ;

$$\varepsilon_{n,cr}(t) = \sigma(t) \cdot S_n^0 \cdot [\sigma(t)] \cdot C_0(t, t) \quad (3)$$

where $\varepsilon_{n,cr}(t)$ - short-term force relative creep strain at time t ;

$$\varepsilon_n(t, t_0) = \int_{t_0}^t S_n^0 \cdot [\sigma(t)] \cdot \sigma(t) \cdot \frac{\partial}{\partial \tau} \cdot C^*(t, \tau) \cdot d\tau \quad (4)$$

where $\varepsilon_n(t, t_0)$ - the relative creep strain accumulated over the time interval (t, t_0) ;

t_0, t, τ - reference point, current time, observation time;

$\sigma(t)$ - voltage acting at time instant t .

Nonlinearity functions have many recording options; the method uses the expressions introduced in [6].

$$S^0 = 1 + V \cdot \left(\frac{\sigma}{R}\right)^2 \quad (5)$$

$$V_m = \frac{37,5}{R_{pr}} \quad (6)$$

$$m_M = 5.7 - 0.05 \cdot R_{pr} \quad (7)$$

$$V_n = \frac{45,0}{R_{pr}} \quad (8)$$

$$m_n = 5.0 - 0.07 \cdot R_{pr} \quad (9)$$

where R_{pr} - prismatic strength, MPa.

Moreover, in the recommendations of the Concrete and Reinforced Concrete Research Institute formulas are presented in tabular form in table 1.

Table 1. Nonlinearity parameters according to the Concrete and Reinforced Concrete Research Institute recommendations.

Nonlinearity parameters	Numerical values of nonlinearity parameters for concrete classes B						
	12,5	15	20	30	40	50	60
V_m	3,1	2,6	2,0	1,3	1,0	0,8	0,7
m_M	5,0	5,0	4,7	4,3	3,8	3,4	3,0
V_n	3,72	3,11	2,35	1,6	1,22	1,22	1,22
m_n	4,0						

In the interests of applied calculations and the use of the formula for multidimensional problems, a quasilinear equation [19-30] of the form is introduced as

$$\varepsilon(t, t_0) = S^0 \cdot [\sigma(t)] \cdot \frac{\sigma(t)}{E_T^L(t)} \quad (10)$$

or

$$\varepsilon(t, t_0) = S^0 \cdot [\sigma(t)] \left\{ \sigma(t) \left[\frac{1}{E_M^0(t)} + C_n(t, t) - \int_{t_0}^t \frac{\sigma(\tau)}{\sigma(t)} \frac{\partial}{\partial \tau} C_n(t, \tau) d\tau \right] \right\} \quad (11)$$

where

$$\frac{1}{E_{t,L}(t,t_0)} = \frac{1}{E_M^0(t)} + C_n(t, t) - \int_{t_0}^t \frac{\sigma(\tau)}{\sigma(t)} \frac{\partial}{\partial \tau} C_n(t, \tau) d\tau \quad (12)$$

$E_{t,L}(t, t_0)$ - linear temporary deformation modulus;

$S^0 \cdot [\sigma(t)]$ - a single nonlinearity function calculated at time t for which the parameter V is determined by the formula

$$V = \frac{42,5}{R_{pr,l}} \quad (13)$$

And m is taken $m = 4.0$.

Such a simplification provides at least 97% of the accuracy for the calculations [25-34]. It should be recalled that for $\sigma = \text{const}$

$$\frac{1}{E_{t,L}(t,t_0)} = \frac{1}{E_M^0(t)} + C_n(t, t) \quad (14)$$

$$\varepsilon(t, t_0) = S^0 \cdot [\sigma(t)] \frac{\sigma(t)}{E_{t,L}(t,t_0)} \quad (15)$$

3 Results and discussion

The stiffness of reinforced concrete elements sections is determined relative to the axis passing through the gravity center of the reduced section, since the calculated stiffness value is the smallest. It should be noted that in the physically linear formulation of the problem, the desired center of gravity is located on the neutral axis of the section.

Based on the condition that bending the stiffness of the damaged beam element relative to the gravity center of the section

$$D^* = \sum_{K=1}^n A_K E_K^* r_K^2 \tag{16}$$

where A_K - sectional area of the Kth component;
 E_K^* - temporary deformation modulus of component K at the level of its gravity center, taking into account damage;
 r_K – the distance between the gravity center of the reduced section and the gravity center of the Kth component, we write

$$r_K = r_{V,sec} - r_{V,K} \tag{17}$$

where

$$r_{V,sec} = \frac{\sum_{K=1}^n A_K E_K^* r_K}{\sum_{i=1}^n A_K E_K^*} \tag{18}$$

or

$$r_{V,1} = \frac{5}{8} \delta \tag{19}$$

$$r_{H,V} = h_0 - \left(Z^* + \delta + \frac{1}{2} \rho \right) \tag{20}$$

$$r_{S,V} = h_0 - Z^* \tag{21}$$

as well as

$$E_{t,i}^* = E_{t,L_i}^* K(r_{V,i}) = \frac{E_{t,L} K(r_{V,i})}{S^{V,0}(r_{V,i})} \tag{22}$$

(here the damage function and the nonlinearity function are fixed at the level of the gravity center of the transition region). Then, taking into account the formula, we obtain

$$K(r_{V,1}) = 0,86 \tag{23}$$

$$S^0(r_{V,1}) = 1 + V \tag{24}$$

That is

$$E_{1,t}^* = \frac{0,86 E_{t,L}(t,t_0)}{1+V} \tag{25}$$

In addition, for intact zone H

$$E_{H,t}^* = \frac{E_{t,L}(t,t_0)}{1+V} \tag{26}$$

and for tensile reinforcement, the strain modulus is E_S .

Further

$$r_{C,T,1} = r_{V,sec} - r_{V,1} \tag{27}$$

$$r_{C,T,H} = r_{V,sec} - r_{H,1} \tag{28}$$

$$r_{c,TS} = r_{v,sec} - r_{S,V} \quad (29)$$

and working areas of components

$$A_1 = \frac{2}{3} b \delta \quad (30)$$

$$A_H = b \rho \quad (31)$$

$$A_S = \omega_S A_{S0} \quad (32)$$

In this way,

a) the stiffness of the normal section with the maximum bending moment after substitution in the formula

$$D_{min}^* = \frac{2}{3} b \delta E_{1,t}^* (r_{v,sec} - r_{v,1})^2 + b \rho E_{H,t}^* (r_{v,sec} - r_{v,H})^2 + \frac{\omega_S A_S E_S}{\Psi_{max}} (r_{v,sec} - r_{v,H})^2 \quad (33)$$

where $\Psi^* \leq 1$ - is the coefficient of participation in the force resistance according to the stiffness of the undamaged concrete of the stretched zone (in the zone of the maximum moment $\Psi^* = 1$);

b) the stiffness of the normal section with zero bending moment, with the maximum stiffness, is calculated in a linear setting relative to the neutral zone of the axis, taking into account the elimination of parts of the section due to corrosion damage

$$D_{max}^* = \frac{2}{3} b \delta E_{t,L} r_1^2 + b \rho E_{t,L} r_H^2 + \frac{\omega_S A_S E_S}{\Psi_{min}} \quad (34)$$

where

$$\left. \begin{aligned} r_1 &= x - \frac{5}{8} \delta; \\ r_H &= \frac{1}{2} P; \\ r_S &= h_0 - x. \end{aligned} \right\} \quad (35)$$

Intermediate stiffness values are calculated similarly, but sequential refinement procedures are required.

For practical use, it is permissible to use working approximate approximations

- for lateral bending

$$\frac{1}{D^*} = \frac{1}{D_{max}^*} + \left(\frac{1}{D_{min}^*} - \frac{1}{D_{max}^*} \right) \frac{M}{M_{np}^*} \quad (36)$$

$$D^* = \left[\frac{1}{D_{max}^*} + \left(\frac{1}{D_{min}^*} - \frac{1}{D_{max}^*} \right) \frac{M}{M_{np}^*} \right]^{-1} \quad (37)$$

-for eccentric compression

$$D^* = D_{max}^* \left[1 - \left(1 - \frac{D_{min}^*}{D_{max}^*} \right) \left(\frac{M}{M_{np}^*} + \frac{P}{P_{np}^*} \right) \right] \left(\frac{P}{P_{np}^*} + \frac{M}{M_{np}^*} \right) \quad (38)$$

When $\frac{P}{P_{np}^*} + \frac{M}{M_{np}^*} \leq 1$, moreover, at large moments, the compressive force is neglected, and at high compressive forces, the moment is neglected [35–36].

For example, for a single-span pivotally supported beam loaded with a uniform load $q = \text{const}$, when

$$M = \frac{q}{2}V(1 - V) - \frac{qV}{2} - \frac{qV^2}{2} \text{ и } \frac{d^2u}{dx^2} = -\frac{M}{D^*} \quad (39)$$

expression for the greatest deflection in the middle of the span

$$U_{\max} = (1 + \eta)U_{\max}^0 \quad (40)$$

$$\text{where } U_{\max}^0 = \frac{5}{384} \frac{ql^2}{D_{\max}^*}; (1 + \eta) = 1 + \frac{11}{100} \frac{ql^2}{M_{np}} \left(\frac{D_{\max}^*}{D_{\min}^*} - 1 \right) > 1 \quad (41)$$

4 Conclusions

The theoretical basis for calculating the residual life of the force resistance to deformation, determines the stiffness of the cross sections of reinforced concrete elements with a maximum bending moment and with zero bending moment are presented in this article. The sections stiffness of reinforced concrete elements is determined relative to the axis passing through the gravity center of the reduced section, since the calculated stiffness value is the smallest.

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