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Power Resistance of Compressed Concrete Elements with Confinement Reinforcement by Means of Meshes

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ABSTRACT
The article gives fundamentals of theoretical estimating power resistance of compressed concrete elements with confinement reinforcement. Calculations are performed using non-linear deformation model of iron concrete. The author gives new formulas for estimation of limit stress in concrete core and finding relative strain of reduction in concrete straining diagram vertex. Here you can find algorithm of calculation of carrying capacity and stress-strain behaviour of a concrete element with confinement reinforcement.

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INTRODUCTION

Confinement reinforcement of columns allows to improve their carrying capacity to a significant degree. Therefore many scientists pay great attention to researches in this sphere [1-9]. But analysis of suggested methods of calculating resistibility of compressed elements with confinement reinforcement testifies that they are based on experimental dependences and have bounded area of application. Particular problems arise during calculating flexible beam columns. In this regard we need to develop a universal method of calculating resistibility of compressed elements with confinement reinforcement, which will take into account main specifics of their structural concept and stress-strain behaviour.

This article reviews theoretical aspects of power resistance of compressed concrete elements with confinement reinforcement by means of steel meshes. Also the suggested approach can be applied to any variant of confinement reinforcement [10].

2 Estimation fundamentals:

Calculating carrying capacity of compressed elements with confinement reinforcement can be performed on the basis of non-linear deformation model. This model allows to take into account main peculiarities of concrete's power resistance to the full extent, including construction's geometrical nonlinearity and physical nonlinearity of concrete and steel. Also one should consider increased resistibility and strain capacity of three-dimensionally stressed concrete core, and its cooperation with longitudinal and confinement reinforcement.

Non-linear calculation model is initially based on deformation curves "stress – relative strain" ("σ - ε ") of loading materials. These curves should reflect real work of concrete and steel in the most precise way. Analysis of different methods of constructing curves "σ - ε" showed that physical nonlinearity in equations connecting stress and strain can be considered in the best way while using variable coefficients of elasticity of concrete and steel v_b, v_s, and also variable coefficients of their lateral strain υ_b, υ_s. In this case curves analytical log remains unchanged under various duration and modes of load of elements under research.

Here it should be also noted that necessity of accounting changes in coefficients of materials' lateral strain concurrently with stress level increase is an important feature of estimating elements under research. Only in this case a precise analytical estimation of interaction between concrete and steel is possible. The correlation

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between υ_b and υ_s influences value of lateral pressure of three-dimensionally compressed concrete, which creates the so-called "charger clip effect".

Values of elastic coefficients can be calculated by formulas suggested in the work [11], depending on the level of material loading $\eta = \sigma / R$ (σ - current stress, R - material's design resistance) and their values in the beginning ν_0 and in vertex ν_u of corresponding curves - $\nu = f_1(\eta, \nu_0, \nu_u)$. Values of lateral strain coefficients are connected with current values of elastic coefficients $\upsilon = f_2(\nu)$ according to relations presented in [12-14].

3 Main calculated relations:

When centrally applied compression force loads a compressed element along the axis "z", in concrete core one sees compression stress σ_{bz}, and in core of a mesh with cross-section areas A_{sx} and A_{sy} - stretching forces $\sigma_{sx} A_{sx}$ and $\sigma_{sy} A_{sy}$ correspondingly (fig. 1). As a result of cooperation with confinement reinforcement there are lateral compression stresses σ_{bx} and σ_{by} arising in concrete. This means that confinement reinforcement works under the conditions of uniaxial tension, and concrete – under the conditions of triaxial compression. Let's assume that compression stress and strain are positive, and tensile stress and strain are negative. As an example let's study square section element with sizes $x_b \times x_b$, which is reinforced with a mesh also having square unit with size x_s.

Becase the sum of projections of internal forces to axis X equals to zero, for the studied fragment S in thickness we obtain the equation

$$\sum \sigma_{sx} A_{sx} + \sigma_{bx} x_b S = 0. \tag{1}$$

From which we can note

$$\sigma_{bx} = -\frac{\sum \sigma_{sx} A_{sx}}{x_b S} = -\frac{\psi_b \sigma_{sx} A_{sx}}{x_s S}, \tag{2}$$

where ψ_b is a coefficient considering non-uniformity of concrete core edging draft (for rectangular section ψ_b=0.75 [5]).

Considering Hooke's law for conditions of uniaxially-stretched core let's note

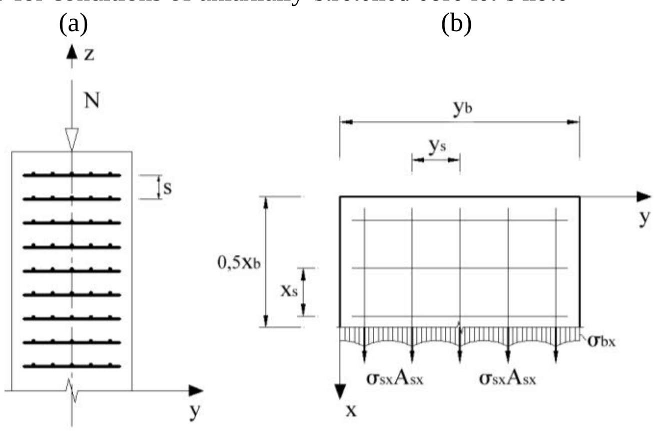

Fig. 1: Concrete element with mesh reinforcement: a – side view; б – scheme of forces in the studied fragment.

$$\sigma_{bx} = -\frac{0.75 \varepsilon_{sx} E_s A_{sx}}{x_s S} = -0.375 \mu_s \varepsilon_{sx} E_s, \tag{3}$$

where μ_s is a coefficient of confinement reinforcement.

Stress state of concrete in elastic and elastic-plastic stages of work given that $\sigma_{bx} = \sigma_{by}$ and $\varepsilon_{bx} = \varepsilon_{by}$ can be described by the known ratios of generalized Hooke's law

$$\varepsilon_{bz} = \frac{1}{\nu_b E_b}(\sigma_{bz} - 2\upsilon_{zx}\sigma_{bx}); \tag{4}$$

$$\varepsilon_{bx} = \frac{1}{\nu_b E_b}\left(\sigma_{bx} - \upsilon_{zx}\sigma_{bz} - \upsilon_{xy}\sigma_{bx}\right). \tag{5}$$

From the equation (5) taking into account compatibility of strains of steel and concrete ($\varepsilon_{sx} = \varepsilon_{bx}$) and relation (3) we will obtain the formula

$$\varepsilon_{sx} = -\frac{\upsilon_{zx}}{q\nu_b E_b}\sigma_{bz}, \tag{6}$$

in which $q = 1 + p(1 - \upsilon_{xy})$; $p = 0.375\alpha\mu_s/\nu_b$; $\alpha = E_s/E_b$.

Having inserted the expression (3) into (4) and using the formula (6) we will find out

$$\varepsilon_{bz} = \chi\frac{\sigma_{bz}}{\nu_b E_b}, \tag{7}$$

where $\chi = 1 - 2p\upsilon_{zx}^2/q$.

The numerical analysis we carried out showed that under $\mu_s > 0$ $p > 0$, q>1, $0 < \chi < 1$. Thus, presence of confinement reinforcement leads to compressed element stiffening.

Coordinates of parametritic point (vertex) of confinement reinforcement curve "σ_s - ε_s" are accepted according to current norms. For the concrete core curve "σ_{bz} - ε_{bz}" these coordinates are not known before starting calculation. They considerably depend on correlation of major compression stresses σ_{bz}, σ_{by} and σ_{bx}. In centrally compressed concrete elements with confinement reinforcement, in any point of which uniform lateral pressure is created, the limit stress σ_{bzu} can be calculated by formula obtained theoretically in the work [11]

$$\sigma_{bzu} = R_{bu} + k\sigma_{bxu}, \tag{8}$$

where R_{bu} is concrete's resistibility under unixial compression; k is a lateral pressure coefficient, which depends on edging draft level $m = \sigma_{bxu}/\sigma_{bzu}$ and calculated by formula

$$k = \frac{1}{0.1 + 0.9m}. \tag{9}$$

From the coordinated solution of equations (8) and (9) we obtain formula for finding concrete core's resistibility

$$\sigma_{bzu}/R_{bu} = \frac{1-\rho_s}{2} + \sqrt{\left(\frac{1-\rho_s}{2}\right)^2 + 9\rho_s}, \tag{10}$$

where ρ_s is a constructional coefficient of confinement reinforcement calculated by formula

$$\rho_s = \psi_b\mu_s\frac{\sigma_y}{R_{bu}}, \tag{11}$$

in which σ_y is a yield point of confinement reinforcement under tension.

For finding out concrete's relative strain ε_{b00} in curve vertex "$\sigma_{bz} - \varepsilon_{bz}$" for elements with confinement reinforcement the following formula was obtained theoretically

$$\varepsilon_{b00} = \varepsilon_{b0}(1 + 2\rho_s)\frac{\sigma_{bzu}}{R_{bu}}, \tag{12}$$

where ε_{b0} is a relative strain of uniaxially compressed concrete in curve vertex, accepted on the instruction of regulatory documents.

Implementation of the suggested calculation method is based on step iterative method and is performed in two stages. At the first stage for a short centrally compressed element with confinement reinforcement one plots by means of a calculation a curve "σ_{bz} - ε_{bz}" for a three dimensionally stressed concrete core. For steel one takes a curve "σ_s - ε_s", obtained under axial tension, as a basis.

In calculations it is recommended to increase gradually concrete's axial strain ε_{bz} and to find corresponding stress σ_{bz} from the formula (7). Relative strain ε_{bz}, which corresponds to axial stresses achieving the value σ_{bzu}, should be accepted as such which is equal to revised value ε_{b00}. This done one should recount the elastic coefficient ν_b in the curve vertex

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$$\nu_{bu} = \chi \frac{\sigma_{bzu}}{\varepsilon_{b00} E_b} . \qquad (13)$$

Value of the coefficient ν_{bu} influences values of current coefficients ν_b, υ_{zx} and υ_{xy}. So then one should repeat iteration process until achieving required accuracy of calculations.

At the second stage one calculates carrying capacity of a beam column of required flexibility. During this known relations of calculation according to non-linear deformation model are used [12].

4 Conclusion:

Given material shows that a universal method of calculating power resistance of compressed elements with confinement reinforcement has been obtained theoretically. In the context of this method from the perspective of non-linear deformation model unified approach we developed the algorithm of calculating carrying capacity and estimating stress-strain behaviour of concrete element with confinement reinforcement.

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