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# STRENGTH CALCULATION COMPRESSED REINFORCED CONCRETE ELEMENTS FROM HPC

Norms DBN V.2.6-98: 2009 «Concrete and reinforced concrete structures. Basic provisions» [1] include a number of fundamentally new approaches for calculating the strength, rigidity and bearing capacity of concrete structures and their elements.

As a basis for calculation on the action of bending moments and longitudinal forces adopted deformation model (DM), which, excepting balance equations, using deformation condition in the form hypothesis of flat sections and complete charts state of the concrete.

DM with extreme strength criterion (DM with ESC) [2] has significant advantages over existing deformation models. It allows calculate the strength of reinforced concrete elements in the normal section in the ultimate state, and getting their stress-strained state parameters, including when applying a wide range of concrete strength classes (from C 8/10 до C 90/105 and more).

DM with ESC is an alternative model in comparison with known DM empirical criterion of strength. Therefore, improving the methods of calculating the strength of compressed reinforced concrete elements in the normal section based on DM with ESC, which is based on the equations of solid mechanics and takes into account the physical and mechanical properties of materials and their real work in the boundary condition (considering and high-strength concrete) is an urgent task.

The modern construction of high-rise buildings, bridges, tunnels and so requires the use of large quantities of high-strength concrete. High strength, gas and water resistance, corrosion resistance and resistance to aggressive environments allocate this material in many cases, out of competition when compared to traditional building materials.

The existing in Ukraine norms for designing reinforced concrete structures and their elements are absent recommendations for calculating the strength of reinforced concrete elements from the high-strength concrete and also determination of their physical and mechanical characteristics, and therefore necessary improving the calculation method using a high strength concretes and holding of experimental researches on laboratory samples.

The development of calculation methods reinforced concrete structures of high-strength concrete based on a full consideration of characteristics of their stress-strain state, characteristics strength and deformation properties of materials is the actual problem whose solution will provide significant economic effect.

The research was limited by the task of verification of durability of normal section.

Physical relationships:

a) for concrete – complete diagram of compression is presented as approximation recommended by FIB

$$\sigma_c = R_c (K\eta - \eta^2)/[1 + (K-2)\eta], \qquad (1)$$

b) for reinforcement – we use analytical expressions of compression (tension) stress-strain diagram are divided into two known types: with the physical yield point $\sigma_y$ and with the conventional yield point $\sigma_{0,2}$. In case with the reinforcement having the physical yield point $\sigma_y$ and the amount of reinforcement being very small, it is sometimes necessary to consider the part of strengthening *BC*, which can be approximated by quadratic function in the range of $\varepsilon_{yu} \le \varepsilon_s \le \varepsilon_{su}$. On the interval BC $\varepsilon_{yu} \le \varepsilon_s \le \varepsilon_{su}$ the area of consolidating is approximated with a parabola

$$\sigma_s = \frac{\sigma_{su}}{(1-\varepsilon_{yu}/\varepsilon_{su})^2} - \left[\left(1-\frac{\sigma_y}{\sigma_{su}}\right)\left(2-\frac{\varepsilon_s}{\varepsilon_{su}}\right)\frac{\varepsilon_s}{\varepsilon_{su}} + \frac{\sigma_y}{\sigma_{su}} + \left(\frac{\varepsilon_{yu}}{\varepsilon_{su}}\right)^2 - 2\frac{\varepsilon_{yu}}{\varepsilon_{su}}\right], \qquad (2)$$

where $\varepsilon_{yu}$ is deformation at the end of ground of fluidity (point *C*) $\sigma_{su}, \varepsilon_{su}$ it is the tension (border of durability) and deformation in the point of maximum *C* a diagram $\sigma_s - \varepsilon_s$.

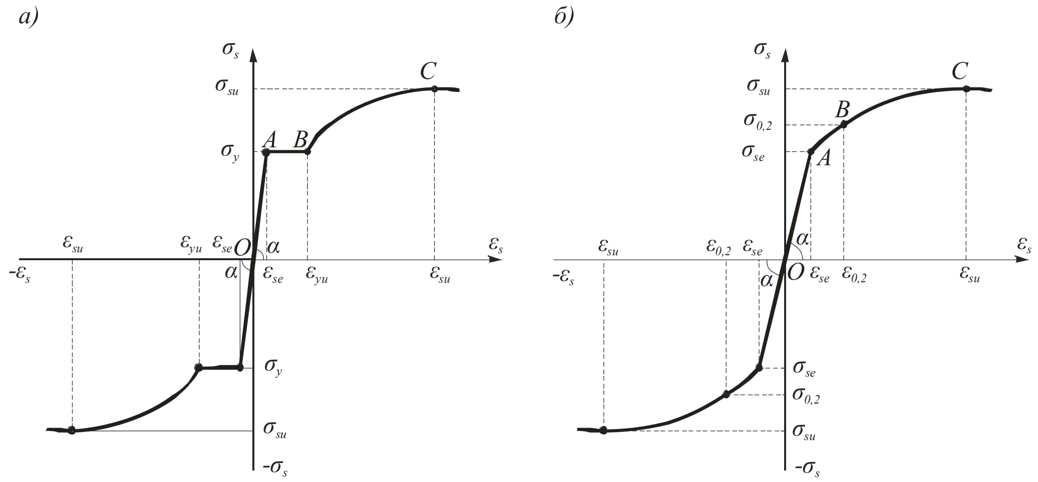


*Fig 1 – Diagram of tension (compression) of* reinforcement *with the physical (a) and conditional (b) scopes of fluidity*

The reinforcement without the yield point is presented in the diagram with linear and quadratic parts.

$$\begin{cases} 0 \le \varepsilon_s \le \varepsilon_{se}, \quad \sigma_s = E_s \varepsilon_s, \\ \varepsilon_{se} \le \varepsilon_s \le \varepsilon_{0,2}, \sigma_s = -\alpha\varepsilon_s^2 + \beta\varepsilon_s + \gamma, \\ \varepsilon_{0,2} \le \varepsilon_s \le \varepsilon_{su}, \sigma_s = -a\varepsilon_s^2 + b\varepsilon_s + c, \end{cases} \qquad (3)$$

in which

$$\begin{cases} \alpha = p - q, \quad \beta = 2p\varepsilon_{0,2} - q(\varepsilon_{se} + \varepsilon_{0,2}), \quad \gamma = \sigma_{0,2} - p\varepsilon_{0,2}^2 + q\varepsilon_{se}\varepsilon_{0,2}, \\ p = (\varepsilon_{0,2} - \varepsilon_{se})/(\varepsilon_{0,2} - \varepsilon_{se})^2, \quad q = \sigma'_{0,2}/(\varepsilon_{0,2} - \varepsilon_{se}), \\ \sigma'_{0,2} = -2a\varepsilon_{0,2} + b, \end{cases} \tag{4}$$

$$a = (\sigma_{su} - \sigma_{0,2})/(\varepsilon_{su} - \varepsilon_{0,2})^2, \; b = 2a\varepsilon_{su}, \; c = \sigma_{su} - a\varepsilon_{su}^2, \tag{5}$$

where the initial parameters of armature is the modulus of elasticity $E_s$, proportionality limit $\sigma_{se}$, conventional yield point $\sigma_{0,2}$, strength limit $\sigma_{su}$ and proper by him deformations – $\varepsilon_{se}, \varepsilon_{0,2}, \varepsilon_{su}$.

1. Geometrical relationships are based on the hypothesis of plane sections, that allows to express through deformation $\varepsilon_{cu}$ the deformation of the compressed of concrete $\varepsilon_c$ at the level of fibres with coordinate $\varsigma$, as well as deformations of tensile and compressed reinforcement:

$$\varepsilon_b = \varepsilon_{cm} \cdot \zeta / y; \tag{6}$$

$$\varepsilon_s = \varepsilon_{cm} \cdot (h_0 / y - 1); \tag{7}$$

$$\varepsilon'_s = \varepsilon_{cm} \cdot (1 - a'/y), \tag{8}$$

Where $y$ –height of concrete compressed part, $a'$ –distance between the resultant in the reinforcement of the concrete compressed zone and the nearest edge section, $h_0$ –working height of the section.

2. Equilibrium equations

$$\Sigma M_0 = 0; \; F\left[k_M \pm k_N\left(y - y'_c\right)\right] - \sigma_s A_s\left(h - y - a\right) - N_c y_N = 0, \tag{9}$$

$$\Sigma X = 0; \; \pm F k_N + \sigma_s A_s - \sigma'_s A'_s - N_c = 0, \tag{10}$$

$k_M$, $k_N$ – cargo coefficients

$$N_b = \iint_{A_b} \sigma_b(\alpha,\zeta) dx d\zeta = \int_0^y \sigma_b(\alpha,\zeta)\left(\int_{b_1(\zeta)}^{b_2(\zeta)} dx\right) d\zeta = N_b(\alpha, y); \tag{11}$$

$$y_N = \left(\iint_{A_b} \sigma_b(\alpha,\zeta)\zeta \, dx d\zeta\right) / N_b = \left(\int_0^y \sigma_b(\alpha,\zeta)\zeta\left(\int_{b_1(\zeta)}^{b_2(\zeta)} dx\right) d\zeta\right) / N_b = y_N(\alpha, y) \tag{12}$$

where $N_c$ – the resultant of the compressed zone of concrete; $y_N$ dis from a zero line of deformations to the point of applying effort $N_c$.

So, for example, in the case of clean bent ($F = M, k_M = 1, k_N = 0$) equa (11) and (12) assume the view

$$\sum M_0 = 0; M - N_c \cdot y_N - \cdot\sigma'_s \cdot A'_s \cdot (y - a') - \cdot\sigma_s \cdot A_s (h_0 - y) = 0; \tag{13}$$

$$\sum X = 0; \sigma_s \cdot A_s - N_c - \sigma'_s \cdot A'_s = 0; \tag{14}$$

Using dependences (4) -(14) we will get the system of equalizations with the unknown $M, \alpha, y$.

$$\begin{cases} M - \sigma_s(\alpha, y) \cdot A_s(h_0 - y) - \sigma'_s(\alpha, y) \cdot A'_s(y - a') - N_b(\alpha, y) \cdot y_N(\alpha, y) = 0 & (15) \\ \sigma_s(\alpha, y) \cdot A_s - N_b(\alpha, y) - \sigma'_s(\alpha, y) \cdot A'_s = 0 & (16) \end{cases}$$

For the determination of the unknown $M, \alpha, y$ we use equations (15), (16) and an additional condition, like as ESC of normal section. Finally we will get the optimization task of the nonlinear mathematical programming on the conditional extremum with an objective function (extremall) at limitations-equalities (15) (16).

In fig. 2 and 3 the curves of dependence of durability of bent RCE are shown, accordingly, in a normal section and deformation $\varepsilon_{cu}$ from the class of durability of concrete $C$ and percent of reinforcement the values of which are calculated according to the methods on the basis of DM with ESC.

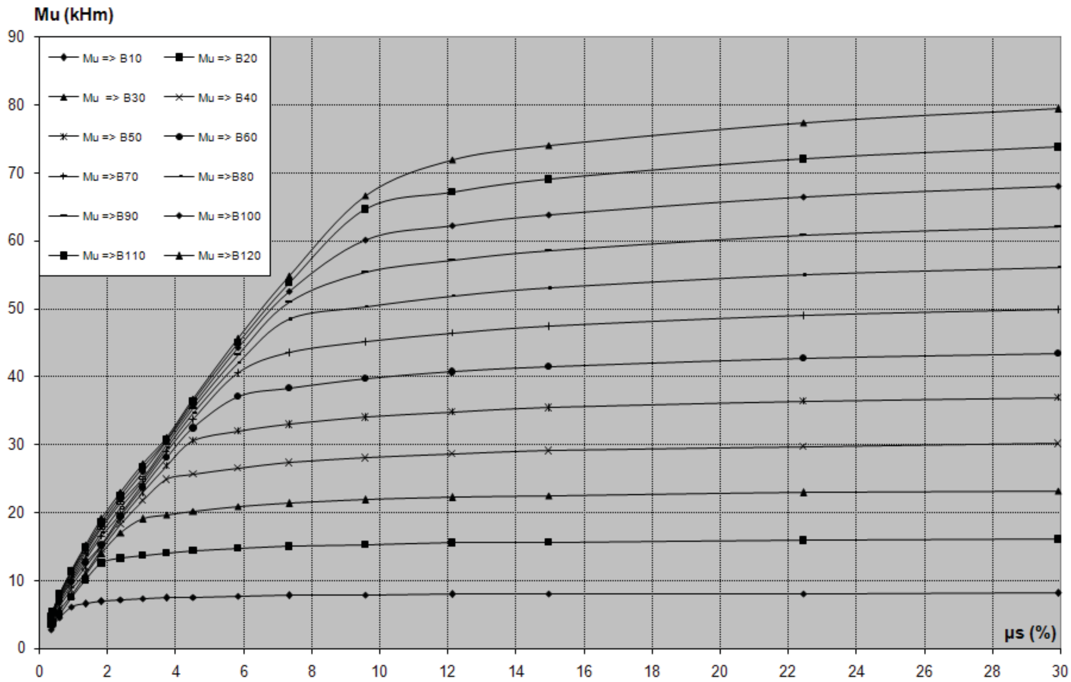


*Fig. 2 – Change durability in the normal section of Mu from $\mu_s$*

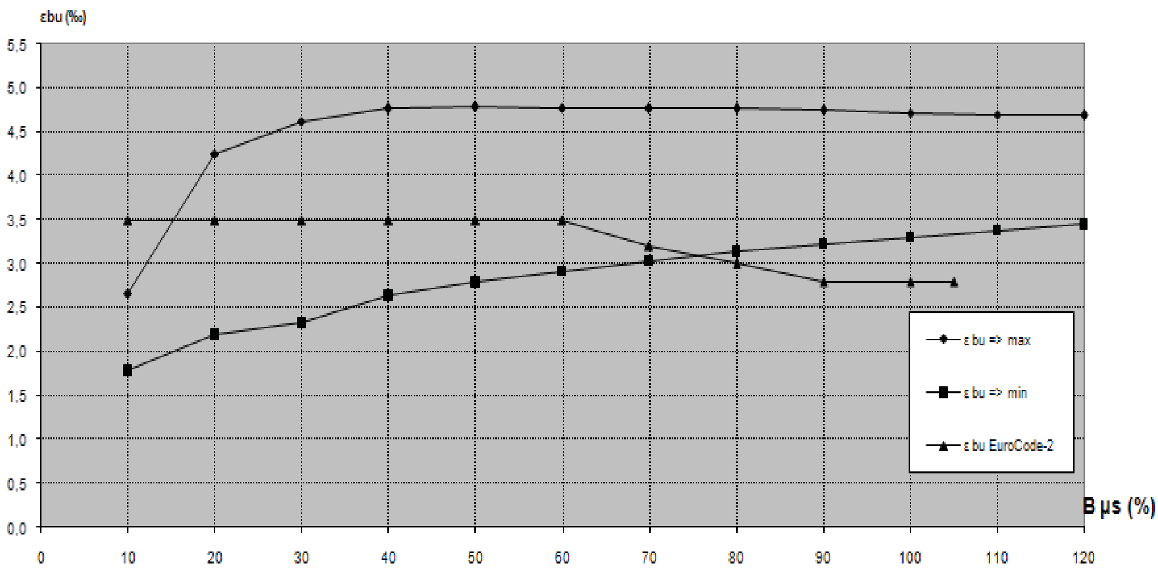


*Fig. 3 – Change of deformations in the most compressed fibre of concrete from the class of concrete In and percent of reinforcing $\mu_s$*

## CONCLUSIONS

1. The class of concrete substantially influences the durability of bent RCE Reinforcement modification also substantially influences the durability of RCE, but only to the limit of 15%. The subsequent increase of reinforcing percent in a normal section with the concrete of small and middle durability practically does not influence the durability of RCE. For high strength concretes the subsequent increase of reinforcing percent influences the durability of RCE not more than 7% (fig. 3).

2. Ultimate deformation $\varepsilon_{cu}$ depends not only on the parameters of concrete but also the character of tense deformed state RCE, the amount of reinforcement $A_s$ and $A_s'$, forms of section, the character of diagram of reinforcement, preliminary tension and other factors, that are taken into account only in DM with ESC. Therefore in general $\varepsilon_{cu}$ is not the criterion value which determines the state of destruction only of concrete, but is one of parameters of the ultimate state of normal section of RCE and it cannot be constant, as it is accepted in Eurocode-2.

3. A decline of ultimate deformations in Eurocode-2 of the compressed concrete $\varepsilon_{cu}$ for RCE from high strength concrete is probably stipulated for by their high fragility and accepted with the purpose of providing of their reliability. It does not agree with the experiments and calculations on DM with ESC. The account of high fragility of such RCE would be more appropriately to execute by introduction of coefficients of reliability or low coefficients of working conditions in the calculations, but not by reduction of ultimate deformation $\varepsilon_{cu}$ as it is accepted in Eurocode-2.

*Literature*

*1. DBN V.2.6-98: 2009 Construction of buildings and structures. Concrete and reinforced concrete structures. The main provisions. - K.: Ministry of Regional Development, 2010. - 71 p.*

*2. Shkurupiy, A. The application a deformation model with extreme criterion for calculating the strength of reinforced concrete elements from high-strength concrete / A. Shkurupii, P. Mitrofanov // Bulletin of the Odessa State Academy of Civil Engineering and Architecture. - Odessa: Zovnishreklamservis, 2012. - № 46. - P. 377 - 387.*

*3. Mitrofanov, V. Algorithms for solving normal sections strength of reinforced concrete elements on the basis of extreme criteria / V. Mitrofanov, P. Mitrofanov // Scientific Bulletin of the construction. - Vol. 69.- Kharkov: HGTUSA HOTO ACS, 2012. – pp 137 – 149*

*4. Shkurupiy, A. Limit stress-strain state and strength of compressed reinforced concrete elements / A. Shkurupii, P. Mitrofanov // Resource-economical materials, structures, buildings, technologies. - Rivne: NUWMNRU, 2013 - Vol. 25 - P. 480 – 487.*