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APPLICATION OF DIFFERENT METHODS OF CALCULATION PLANNING RESEARCH OF REINFORCED CONCRETE BEAMS STRENGTHENED BY AN INCLINED CROSS SECTIONS

In the article the calculation of the bearing capacity of the inclined cross-sections of the reinforced concrete elements using an external composite reinforcement designing by deformation model DBN V.2.6.-98: 2009 and engineering methodology presented in SNIP 2.03.01-84 are described.

Key words: reinforced concrete beam, deformation model, inclined cross sections.

Наведено розрахунок несучої здатності похилих перерізів залізобетонних елементів, підсилених зовнішнім композитним армуванням, з використанням деформаційної моделі ДБН В.2.6.-98:2009 та інженерної методики, викладеної в СНиП 2.03.01-84*.

Ключові слова – залізобетонна балка, деформаційна модель, похилі перерізи.

Statement of the problem. Due to the release of new standards of design of reinforced concrete elements [1, 2] which are based on the deformation model of calculation it is necessary to test and specify the calculation of inclined sections of reinforced concrete elements . This especially applies to the calculation of reinforced concrete elements with strengthened with inclined sections. In the application of engineering methods of calculation [3] it isn't clear guidance of the calculation of the inclined sections of reinforced structures, particularly in the application of advanced composite materials. Lack of regulatory framework, which would give a full explanation and evaluation of each method of calculation and the inability to use it without a computer causes a number of issues in the design of reinforced concrete structures.

The aims and objectives of the study. To carry out the theoretical calculation of oblique sections of reinforced concrete beams strengthened with composite materials under deformation model and to analyze the results obtained by following the same calculation method for engineering.

The theoretical justification. This work is done in compliance with current standards for the design of reinforced concrete structures [1, 2], and rules which allow to perform calculations for engineering technique [3].

Materials and design prototypes. To realize the goal of research a sample of concrete beam length 2100 mm., a width of 100 mm. and height of 200 mm is selected. For reinforcement beams the working class of the rebar is A400S fittings Ø18 mm DSTU 3760 : 2006, Constructive and crossing rebar is the class A240S DSTU 3760 : 2006 6 mm diameter , pitch transverse reinforcement 50 mm (Fig. 1). Concrete beams is accepted C25/30 . Reinforced concrete beam is designed at the rate of only providing bearing capacity of normal cross section according to recommendations [1]. Strengthening of inclined section of the beam is suggested by gluing fabric composite material Ruredil X Mesh GOLD [8] with the following characteristics : calculated resistance of tensile $f_{fd} = 5800$ MPa, tensile resistance, using transverse reinforcement fabric (calculated taking into account the maximum possible limit strain fibers [7]) $f_{fwd} = 980$ MPa , modulus of elasticity $E_{fd} = 200000$ MPa ultimate tensile strain $e_{fd} = 0,008$, thickness of material gain $d = 0,00455$ cm., material reinforcement is attached to the surface using a mineral solution Ruredil X Mesh M750 .

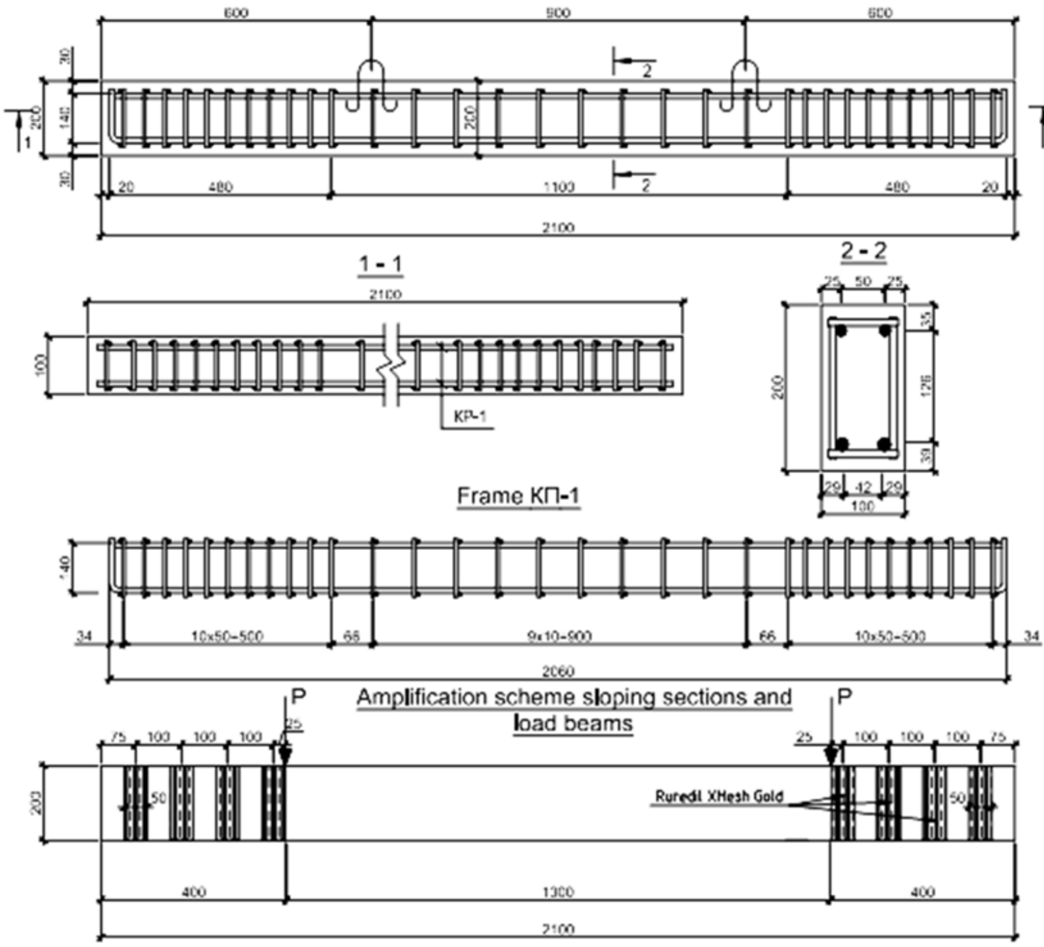

Fig. 1. Reinforcement and dimensions of the projected beam..

The methodology and results of the calculation strength of normal sections according to deformation model. The calculation was performed for rectangular reinforced concrete elements using nonlinear equations (1) and (2) of DBN B.2.6-98: 2009 [1], which were solved by selecting technique:

$$\frac{b \cdot f_{cd}}{\bar{c}} \cdot \sum_{k=1}^{5} \frac{a_k}{k+1} \cdot g^{k+1} + \sum_{i=1}^{n} s_{si} \cdot A_{si} - N = 0 \tag{1}$$

$$\frac{b \cdot f_{cd}}{\bar{c}^2} \cdot \sum_{k=1}^{5} \frac{a_k}{k+2} \cdot g^{k+2} + \sum_{i=1}^{n} s_{si} \cdot A_{si} \cdot (x_1 - z_{si}) - M = 0 \tag{2}$$

where - b - width of the cross-section of calculation element; f_{cd} - design strength of concrete in compression; c - curvature of the curved axis in section; $\bar{c}$ - relative curvature; a_k - coefficients of the polynomial; g - strain relation of concrete of compressed zone to the limit deformation of concrete of compressed zone; s_{si} - tension in any fixture; A_{si} - sectional area of any reinforcement; x_1 - the height of the compressed zone of concrete; z_{si} - distance to any rod fittings to the most compressed brink section.

After computing the critical values of the bending moment of the beam and the charts derived strains of compressed concrete and stretched reinforcement strain were obtained (Fig.2). The value of the moment at which the critical values of stretched reinforcement strain are reached is $M_s = 20,73$ kN, and destruction of the compressed zone of concrete beams is $M_c = 21,78$ kN.

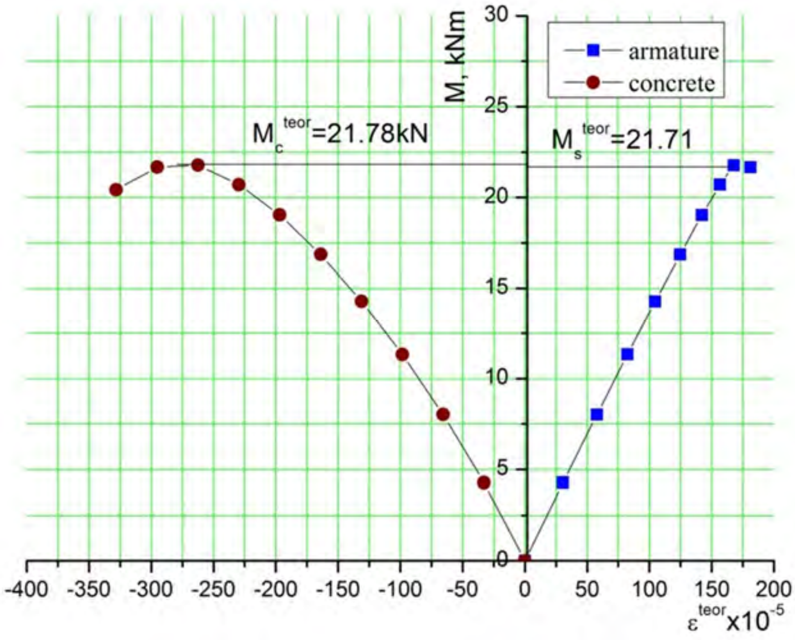

Fig. 2. Strain of compressed concrete and reinforcement are stretched by calculation.

Methodology and results of calculating of the strength of inclined section according to deformation model. Calculation of oblique sections is performed according to the recommendations DBN B.V.2.6-156: 2010 [2]. The need of additional reinforcement is determined by the relationship:

$$V_{Rd} \le V_{Ed} \tag{3}$$

where $V_{Ed} = M / a = 21{,}71 / 0{,}3 = 72{,}37$ kN - design value of the transverse force in the section from the effects of external loading; V_{Rd} - design value of the transverse forces that can be accepted by inclined section.

According to the standards [1] it is assumed that the shear force is seen only with concrete. In the case when it is not sufficient transverse reinforcement is installed and the calculation is carried out based on the condition that the lateral force perceives only transverse reinforcement. For the further reinforced beams it is necessary to pay attention to material gain in the calculation. Therefore, the value of the transverse forces that can be accepted by inclined section will be determined by the formula:

$$V_{Rd} = V_{Rd,s} + V_{Rd,f} \tag{4}$$

Shear force which can be accept by transverse reinforcement is determined from the dependence (5):

$$V_{Rd,s} = \frac{A_{sw}}{s_w} \cdot z \cdot f_{ywd} \cdot \cot q \tag{5}$$

where q - the angle between the compressed concrete elements and conventional beam axis which is perpendicular to the transverse force (the angle q is limited, the limit values $\cot q$ are taken within $1 \le \cot q \le 2,5$); z - shoulder of internal pair for the element with constant height of cross section, which corresponds to the bending moments in the element under consideration (in the calculation of shear of reinforced concrete elements, in the absence of axial forces approximately value can be taken $z = 0,9 \cdot d = 0,9 \cdot 16,1 = 14,49$ cm); $A_{sw} = 2 \cdot 0,126 = 0,252$ cm^2 - sectional area of transverse reinforcement; $s_w = 50$ mm. - step transverse rods; $f_{ywd} = 170$ MPa - resistance calculated yield strength of transverse reinforcement.

For a similar consideration of additional cross reinforcing the following hypothesis should be taken:

- pasted composite material works as an external transverse reinforcement [4];

- bond strength is not less than the strength of the material gain;
- hypothesis "plane sections» is accepted.

According to the accepted hypotheses strength of oblique sections through the composite material is determined from the formula:

$$V_{Rd,f} = \frac{A_{fw}}{s_f} \cdot z \cdot f_{fwd} \cdot \cot q \qquad (6)$$

where $A_{fw} = (0,00455 \cdot 5) \cdot 2 = 0,0455$ см^2 – sectional area of the external fittings; $f_{fwd} = 980$ MPa - estimated resistance of the composite tensile reinforcement Ruredil X Mesh Gold; $s_f = 100$ mm – step of reinforcement elements.

The value V_{Rd} should not exceed the value of $V_{Rd,\max}$ because in that case the destruction of conventional compressed concrete cross according to occurs [2]. The value $V_{Rd,\max}$ is determined from the dependence:

$$V_{Rd,\max} = \frac{a_{cw} \cdot b_w \cdot z \cdot n_1 \cdot f_{cd}}{\cot q + \tan q} \qquad (7)$$

де $f_{cd} = 17$ MPa - design value of the compressive strength of concrete; a_{cw} - factor which takes into account the level of stress in the compressed zone is determined depending on the average compressive stress in the concrete caused by the calculated axial force; $n_1 = 0,6$ - factor of reduction of strength of concrete cracked in shear; $b_w = 10$ cm - the smallest width of the cross-sectional area in tension.

According to the recommendations [7] value $\cot q$ is suggested to be accepted 2,5. In the case when $V_{Rd} \ge V_{Rd,\max}$ value $\cot q$ should be reduced, as long until the condition is $V_{Rd} \le V_{Rd,\max}$. It is recommended to reduce $V_{Rd,s}$ the coefficient $g_{sw} = 0,75$, which takes into account the degree of the use of the estimated strength of the internal transverse reinforcement by strengthening the inclined sections of the external composite reinforcement [5, 7].

According to the methodology outlined above estimation of carrying capacity of not-reinforced oblique cross-sections of reinforced concrete beams and similar from an external composite reinforcement was done. The calculation made using the recommendations [2] showed that the bearing capacity of oblique cross-sections without amplification by the main reinforcement is $V_{Rd,s} = 27,84$ kN, and a value $V_{Rd,\max} = 74,9$ kN. Carrying capacity of oblique cross-sections of beams, perceived by the system Ruredil X Mesh Gold $V_{Rd,f} = 6,46$ kN.

According to the results of the calculation there is not the condition [1] $V_{Rd} = 34,3 кН \le V_{Ed} = 72,37 кН$, than carrying capacity of oblique section is exhausted during testing earlier than the carrying capacity of normal cross section is exhausted.

Methodology and results of calculating the strength of inclined sections according to engineering methodology. For the calculation the same conditions as in the calculation of the deformation model were taken. The calculation was performed according to the recommendations [3, 6]. Shear force that can be perceived by concrete elements reinforced with composite materials is determined by the formula:

$$Q \le Q_b + Q_{sw} + Q_{fw} \qquad (8)$$

where - Q - shear force of the external load; Q_b - lateral force perceived by concrete; Q_{sw} - lateral force is perceived by transverse reinforcement placed in a normal to the longitudinal axis of the element plane that intersects the inclined section; Q_{fw} - lateral force perceived by external reinforcement placed in a normal to the longitudinal axis of the element plane intersects the inclined section. The value Q_b is determined from the ratio:

$$Q_b = \frac{j_{b2} \cdot \left(1 + j_f + j_n\right) \cdot R_{bt} \cdot b \cdot h_0^2}{c} \tag{9}$$

where - $j_{b2} = 2$ - factor for the effect of the type of concrete; $j_f = 0$ - factor for the effect of compressed shelves in tee and I-cells (taken not more than 0.5); $j_n = 0$ - factor for the effect of longitudinal squeezing effort; $c = 30$ cm. - the length of the projection of the most dangerous inclined section on the longitudinal axis of the element; $b = 10\,cm., h_0 = 16{,}1\,cm.$ - the width and height of the working section; $R_{bt} = 1{,}2$ MPa - design value of concrete strength on the axial stretching. The value Q_{sw} is determined from the dependence :

$$Q_{sw} = \frac{R_{sw} \cdot A_{sw}}{S_w} \cdot c_0 \tag{10}$$

where $R_{sw} = 170$ MPa - estimated strength of transverse reinforcement in liquid limit;

$A_{sw} = 2 \cdot 0{,}126 = 0{,}252$ cm^2 - sectional area of transverse reinforcement;

$S_w = 50$ mm – step of transverse reinforcement;

$c_0 = \sqrt{\frac{f_{b2} \cdot \left(1 + f_n + f_f\right) R_{bt} \cdot b \cdot h_0^2}{q_{sw}}} = 18$ cm - length of the projection of the least dangerous inclined section on the longitudinal axis of the element.

The value Q_{fw} is determined from the dependence :

$$Q_{fw} = \frac{R_{fw} \cdot A_{fw}}{S_f} \cdot c_0 \tag{11}$$

The calculation showed that the values of the transverse force in non-strengthened beams is $Q = Q_b + Q_{sw} = 20{,}74 + 34{,}57 = 55{,}31$kN, while the bearing capacity of composite material reinforcement is $Q_f = 4{,}01$ кН. Making a calculation of oblique cross-sections using engineering methods, it should be noted that the value of carrying capacity is defined as the amount of carrying capacity concrete and transverse reinforcement. In the deformation model a new principle is used, which is based on the perception of the transverse force only by concrete, but if this is not possible it is necessary to design the reinforcement, which would perceive lateral force.

Estimating the carrying capacity of inclined sections according to the dependence [8] $Q = 72{,}37\,кН \geq Q_b + Q_{sw} + Q_{fw} = 59{,}32\ kN$, this means that bearing capacity is not provided, what was needed.

Analysis of the results of calculation of the strength of the inclined sections. Significant differences in the results obtained in the calculation effort should be paid attention to which can be accepted by composite rebar. Due to this divergence there is necessity of experimental studies of bearing capacity of reinforced inclined sections to clarify and improve the methodology of calculation of bearing capacity of inclined sections of concrete structures reinforced by composite materials.

Table 1.

Analysis of the results of calculation of oblique sections of reinforced concrete beams

Type of beams	The value of the transverse force, kN	
	Calculated by the method of engineering	Calculated by the deformation model
Non-strengthened beams	55,31	27,84
Reinforced composite tissue	59,32	34,3

Analyzing the results it can be noted that the engineering calculations showed significantly higher values of bearing capacity of inclined sections as for the non-strengthened and strengthened by external reinforcement results. It depends on the strength of concrete in the inclined section of carrying capacity, which is not included in the deformation method.

Table 2.

Theoretical effect of strengthening of the inclined sections of reinforced concrete beams

Type of beams	The value of the transverse force kN.		The effect of reinforcement, %
	Non-strengthened beams	Reinforced composite tissue	
Calculated by the method of engineering	55,31	59,32	7
Calculated by the deformation model	27,84	34,3	18

Through comparison of the bearing capacity of inclined sections calculated by different methods it can be stated that the results of the effect of strengthening from the application of composite materials Ruredil X Mesh GOLD relate to each other in the range of accuracy 7-18%. Accuracy of the results are satisfactory, but the obtained values require experimental confirmation.

Conclusions

1. The previous calculation of bearing capacity of inclined sections of beams strengthened by composite materials showed the theoretical effect of their use in the 7-18% and does not depend significantly on the adopted method of calculation.
2. The discrepancy between the different methods of calculating of bearing capacity of inclined sections of the beams is large, which is a rather significant drawback in choosing the method of calculation and requires further experimental investigation of the matter.

*1. DBN B.2.6 -98 : 2009 Concrete and reinforced concrete construction, Minbudrehion Ukraine , Kyiv, 2011. 2. DSTU B.V.2.6-156 : 2010 Concrete and reinforced concrete construction with heavy concrete Minbudrehion Ukraine , Kyiv, 2010. 3. SNIP 2.03.01-84 * Concrete and concrete structures NIIZHB State Building USSR Moscow, 1986 . 4. Kvasha V.G. Calculating the strength of the inclined sections of reinforced concrete beams reinforced pasted materials / / Resursoekonomni materials , structures , buildings and facilities: Collected Essays. Exactly, 2011. - Issue 22 - s.801 - 807. 5. Melnyk S. V. Calculating the strength of the inclined sections of reinforced concrete beams reinforced materials vuhleplastykovymy Single dose load / / Resursoekonomni materials, structures, buildings and facilities: Collected Essays. Exactly, 2012. - Issue 23 - s.494 - 501. 6. Murin A. J. The strength , hardness and fracture toughness of reinforced concrete beams reinforced with external composite reinforcement : Dissertation . candidate. Technical sciences .. : 05.23.01 . Lviv, 2011.-163 p. 7. Melnyk S. V. Working on inclined sections reinforced concrete elements under bending small cyclic loadings and improve methods of payment: dis .. kand. tehn . sciences: 05.23.01 . Lviv, 2011. – 184p. 8. Materials from the official site Ruredil: http://www.ruredil.it/ENG/PDFCatalghiENG/RXMeshGold.pdf.*