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Research paper

Strength Design Method of Reinforced Concrete Beam Elements along an Inclined Crack on the Transverse Forces and Bending Moments Joint Action

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Abstract

The forces scheme in the reinforced concrete elements inclined section is proposed under the transverse forces and bending moments joint action. The diagram shows the transverse and longitudinal forces perceived by the compressed concrete zone and longitudinal reinforcement, forces in the transverse reinforcement and engagement in an inclined crack. The truncated concrete wedge strength problem simulating a compressed zone over a dangerous inclined crack is solved on the plasticity theory basis. An engineering method for calculating the bending elements strength along an inclined crack is developed, which allows more fully to take into account the factors determining the strength influence and to achieve a reduction in the structures material consumption. To simplify the calculation in tabular form, the projection inclined section functions are given for various loading schemes.

Keywords: *strength, inclined section, plasticity theory, compressed zones.*

1. Introduction

Beam reinforced concrete structures working on the transverse forces and bending moments perception are widely used in practice and largely determine the concrete and steel consumption during capital construction and reconstruction.
The reinforced concrete elements calculation along an inclined cross sections is one of the important issues that require further study. In recent years significant progress has been made in this problem resolving and new directions have emerged [1 – 5]. However, the factors number influence on the bearing capacity is finally undefined. In particular, there is no mechanism allowing to determine the filling of normal and tangential stresses diagrams over a dangerous inclined crack, analytical dependencies for determine dangerous inclined crack projection on the element longitudinal axis as a function of many variables have not been derived. There is also no common opinion on the "nagel effect" phenomenon physical nature in the reinforcement intersected by an inclined crack and other factors number. Therefore, improving the methodology for calculating these elements strength is essential for the creation of effective structures, reducing their material consumption, energy intensity and cost.
The methods for calculating the elements along an inclined cross sections and the criteria for evaluating strength in their development have undergone significant changes. So in the classical method, the calculation is made by the main tensile stresses on the strength of materials dependences basis. "Truss analogy" assumes the reinforcement tensile forces and the concrete compressive forces complete perception. In this case, the bending reinforcement concrete element is represented in a truss form: parallel compressed and tensile chords and diagonals.
The classical method and the "truss analogy" do not fully take into account the reinforced concrete beam elements behavior specifics in the failure zone and, as a result, lead to a discrepancy between the experimental and theoretical strength. In the transverse reinforcement absence, the required reliability is not provided, and, if present, the actual failure load magnitude exceeds the theoretical value. Calculation perfection by the "truss analogy" method is carried out by introducing various empirical coefficients and creating new analogies (arch, thrust system) [6, 7].
Also, the external forces and internal ultimate forces equilibrium for an element bearing part cut off by an inclined crack. The theory [8] allows more rational and economical transverse reinforcement appointment. However, as ultimate efforts in the design model, only the forces in the concrete above the inclined crack and the force in the transverse reinforcement are taken into account. At the same time, according to experimental data, in the inclined section, the engagement forces in the crack, the nagel force in the longitudinal reinforcement and others factors also act, whose contribution under bending is significant [9 − 11]. Bending moments and transverse forces equilibrium equations are considered separately, that excludes the taking into account their mutual influence possibility.
In [12], a method for calculating an inclined section strength was developed, based on the joint equilibrium equations and the conditions for compressed concrete and tensile reinforcement deformation use.
The methods [9, 12, 13] consider the beam as a disk-link system consisting of rigid concrete disks (blocks) connected by compliant bonds according to the cracks and strain concentration zones ar-

rangement. In addition to the forces in the connections in the disk-link system there are the interaction forces between blocks that arise during the system deformation. The proposed disk design schemes disadvantage is the complexity and some inaccuracy in accounting for the compliant elements that are connecting blocks.
Reinforced concrete elements disk kinematic models are presented in [10, 14, 15] and the connecting rods parameters are justified taking into account their work features depending on the longitudinal and transverse reinforcement number.
Broad prospects in the solution of the issue under consideration are represented by the concrete and reinforced concrete optimization theory use [5] and discrete solutions [16].
It should be noted, that in experimental studies there are an inclined concrete element between adjacent cracks failure and a compressed zone over a dangerous inclined crack failure. It becomes necessary to determine these cases realization limits and the method use of "truss analogy" and the disk model. One of this problem solution main directions is the design schemes refinement and the factors determining the strength influence in inclined sections.

2. Results analysis and discussion

An important the reinforced concrete elements calculation development aspect of along inclined cross sections at the destruction stage is the strength criterion application for concrete to evaluate the forces perceived by concrete over an inclined crack.
There are two main options for applying this criterion for determining normal and tangential forces in concrete. One of them includes determining the forces in the ultimate stress diagrams area the vertical section passing through the inclined crack top. And the other one considers the loads determination in concrete through the modeling inclined prism work that is under uniaxial compression in the resultant normal and tangential forces action direction in the concrete above the inclined crack. The criterion for the prism failure is the achievement by the main compressive stresses of the concrete compression strength value.
The plasticity theory on plastic bodies models [17, 18] and the failure mechanics, based on the brittle body model [19] are used to determine the ultimate load. For quasi-brittle materials, which include concrete, it is advisable to use the model that is more consistent with the element experimental behavior the failure. According to the experimental studies data under compressive average stresses, the plasticity theory is more acceptable. It is successfully applied as an ultimate equilibrium method for calculating the statically indeterminate structures strength [20 − 22] and for determining the massive elements ultimate load [10, 17, 21].
On the variational method basis, solutions were obtained for the concrete and reinforced concrete elements strength problem under shear and crushing [23 − 26], the results of which have found experimental confirmation [27, 28].
The purpose of this work is to improve the methodology for calculating the reinforced concrete elements strength along an inclined cross-section to the joint transverse forces and bending moments action using the concrete plasticity theory.
To evaluate the beam element bearing capacity, the authors propose a design scheme, shown in Fig. 1.
This task unknown to:
H – load parameter (the concentrated F and uniformly distributed load q function);
V_c and N_c – forcers perceived by a compressed concrete zone over a dangerous inclined crack;
V_s and N_s – forcers in the longitudinal reinforcement at the point of its intersection by inclined crack;
F_{crc} – engagement force in an inclined crack;
geometric characteristics: x – compressed zone height; l_{crc} – the inclined crack length; c – inclined section projection on the element longitudinal axis; c_o – inclined crack projection on the longitudinal axis.

To unknowns search for, equations are used: $\sum X = 0$; $\sum Y = 0$; $\sum M = 0$; relation $V_c = f(N_c)$ – is obtained from the strength problem solution of a compressed zone over an inclined crack; V_s, F_{crc} – are determined by the studies analysis results; $V_s = f(c_s, f_{ctd})$; $F_{crc} = f(f_{ctd})$; $c_o = f(c, l_{elm}, d, \rho_f, E_s, E_c)$;

$x = f(c_o, d)$; $\frac{\partial H}{\partial c} = 0.$

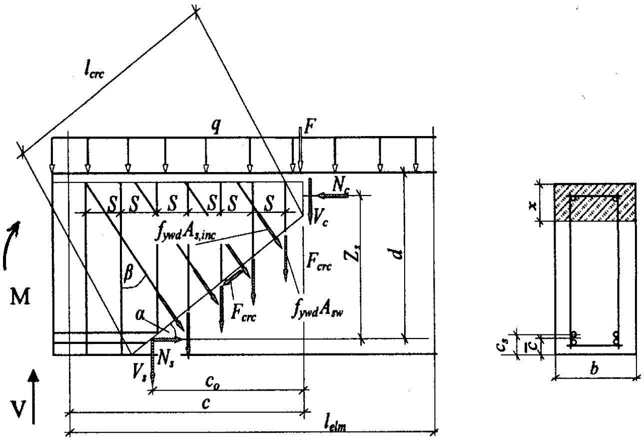


Fig. 1: Forces scheme in the reinforced concrete element inclined section toward the longitudinal axis on the transverse force and bending moment action

An element with length l_{elm} is considered, within which the transverse force and the bending moment do not change their sign.
To determine the compressed zone strength over a dangerous inclined crack, a concrete wedge with a cut vertex, loaded with compressive and shearing forces is considered as model. The plasticity theory mathematical apparatus and the characteristic lines method is used [17].
For heavy concrete, the Balandin-Geniev strength condition is taken, which is the rotation paraboloid in the principal stresses space σ_1, σ_2, σ_3, and on the plane σ_1 and σ_2 it is the ellipse. This condition is simple and at the same time sufficiently is close to the experimental data.
In an arbitrary orthogonal coordinate system xy that does not coincide with the principal stress axes, the strength condition is written in the form

$$\sigma_x^2 - \sigma_x\sigma_y + \sigma_y^2 + 3\tau_{xy} - (f_c - f_{ct})(\sigma_x + \sigma_y) - f_c f_{ct} = 0. \quad (1)$$

In equation (1), there are three unknown quantities σ_x, σ_y, τ_{xy} for the determination of which additional conditions are necessary. They are the differential equilibrium equations for the plane problem.

$$\left.\begin{aligned} \frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} = 0 \\ \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \sigma_y}{\partial y} = 0 \end{aligned}\right\}. \quad (2)$$

(1) and (2) together represent a equations complete system that determine a plane stress state with given stresses at the body boundary.
For the solving problems convenience, the stress state parameters $p = \frac{\sigma_1 + \sigma_2}{2}$, $t = \frac{\sigma_1 - \sigma_2}{2}$ and characteristics $k = \frac{1}{\sqrt{3}}\sqrt{f_c^2 - f_c f_{ct} + f_{ct}^2}$, $T_o = \frac{f_c - f_{ct}}{2}$ are introduced
Stresses at an arbitrary site are defined as

$$\left.\begin{aligned}\sigma_x &= p + t\cos\theta\\ \sigma_y &= p - t\cos\theta\\ \tau_{xy} &= t\sin 2\theta\end{aligned}\right\}, \quad (3)$$

where θ is the angle between the X axis positive direction and the larger principal normal stress σ_1 direction at the point considered.

After the transformation, two quasilinear first-order partial differential equations system with respect to the unknowns t and θ is obtained:

$$\left.\begin{aligned}&\left(\frac{3t}{2T_0-p}+\cos 2\theta\right)\frac{\partial t}{\partial x}+\sin 2\theta\frac{\partial t}{\partial y}-\\ &-2t\left(\sin 2\theta\frac{\partial\theta}{\partial x}-\cos 2\theta\frac{\partial\theta}{\partial y}\right)=0\\ &\sin 2\theta\frac{\partial t}{\partial x}+\left(\frac{3t}{2T_0-p}-\cos 2\theta\right)\frac{\partial t}{\partial x}+\\ &+2t\left(\cos 2\theta\frac{\partial\theta}{\partial x}+\sin 2\theta\frac{\partial\theta}{\partial y}\right)=0\end{aligned}\right\}, \quad (4)$$

where $t=\frac{1}{\sqrt{3}}\sqrt{k^2-4T_o\left(p-T_0\right)-p^2}$.

On the hyperbolic ellipse part, that is, in the hyperbolic system case, the solution is reduced to constructing the characteristic lines fields [17].

Two differential equations systems are obtained that determine the two characteristic lines families fields z = *const* and u = *const* and the relation between the unknown functions t and θ on the last:

on $z = const$

$$\left.\begin{aligned}&\frac{\partial y}{\partial x}=tg\left(\theta+\gamma\right)\\ &-\arcsin\left(\frac{5}{3}-\frac{8}{3}\frac{t^2}{k^2}\right)-\frac{1}{2}\arcsin\left(\frac{5}{3}-\frac{2}{3}\frac{k^2}{t^2}\right)+2\theta=C_1\left(z\right)\end{aligned}\right\}; \quad (5)$$

on $u = const$

$$\left.\begin{aligned}&\frac{\partial y}{\partial x}=tg\left(\theta-\gamma\right)\\ &-\arcsin\left(\frac{5}{3}-\frac{8}{3}\frac{t^2}{k^2}\right)-\frac{1}{2}\arcsin\left(\frac{5}{3}-\frac{2}{3}\frac{k^2}{t^2}\right)-2\theta=C_2\left(u\right)\end{aligned}\right\}, \quad (6)$$

where γ is the angle value between characteristics and the greater principal normal stress direction at the point under consideration

$$\gamma = arctg\sqrt{\frac{3t-\left(2T_0-p\right)}{3t+\left(2T_0-p\right)}}. \quad (7)$$

The characteristic fields consist of the following areas:

a) the simplest stress state fields are located at the free faces. In such areas, the characteristic lines grid is formed by parallel straight two families lines;

b) centered characteristic fields formed by a radial lines ray and concentric curves;

c) uniform stress state, under which the lines family consists of straight lines.

The solutions were obtained using the arrangement of the plasticity zones and the calculation apparatus proposed in [10] for wedges with uniformly compressive N_c distributed normal σ_n and tangent τ_n components. The strength condition (1) is interpreted in the first approximation as a condition of plasticity.

The plasticity zones are located at the lateral face, formed by an inclined crack, and the wedge truncated face (Fig. 2).

The characteristic fields are continuous. In the triangular region *ABO*, axial compression along free linear boundaries is realized. The *OBC* region is a centered characteristics field.

The problem solution is to determine the ultimate load, the resultant forces N_c and V_c, and the plastic zones dimensions depending on the loading angle ψ, the wedge angle α, and the strength characteristics f_c, f_{ct}. Using the loading conditions for the wedge $tg\psi = V_c / N_c$ and z = const, the functions t and ψ are obtained in the *OCO'* region, which then determine the limiting values σ_n , τ_n, V_c, N_c.

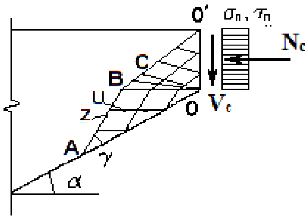


Fig. 2: The plasticity regions location scheme for wedges

The concrete wedge strength problem solution is also obtained using the virtual velocities principle [26, 29].

The concrete wedges strength experimental study has been conducted in Poltava national technical Yuriy Kondratyuk university [10, 30]. Load on the wedge top was transmitted through mutually perpendicular steel shoe plates (Fig. 3). One of them could be moved relatively to the other, so that the force N was applied in the wedge upper edge middle. The samples were tested with a wedge angle from 15 to 45° and loading angle from 0 to α+10° with gradation usually through 5°. The concrete class varied over a wide range. In the interval $\psi = \alpha + 5^{\circ}$, significant concrete plastic deformations fixed by tensoresistors preceded the destruction. At small loading angles $\psi < \alpha / 2$, the wedges strength does not depend on the angle α, for large ψ – it significantly changes.

The plastic regions shape and dimensions observed in experiments with the wedges tip failure correspond to those adopted in the design scheme (Fig. 3).

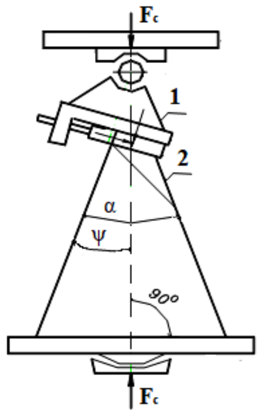


Fig. 3: Scheme for testing concrete wedges: 1 – loading device; 2 – testing sample

To take into account the other strength determining factors influence, an experimental studies results analysis has been carried out [9, 10].

On the compressive zone strength problem analysis and solution results basis, an engineering method is given for calculating reinforced concrete elements along an inclined crack on the V and M joint action is proposed using the scheme given in Fig. 1.

In the general case, they are given by an inclined sections series with different values c (Fig. 4).

Strength testing is performed by condition

$$H \le (\alpha_{c,s} + \alpha_{sw}) f_{ct} bd. \quad (8)$$

Parameter H is equal to $H = q = kF$, where k – coefficient that connects force effects: concentrated and uniformly distributed load.
The parameter $\alpha_{c,s}$ expresses the relative load perceived by the concrete and the element longitudinal reinforcement, and is equal to

$$\alpha_{c,s} = \frac{\bar{\varphi}_{c1}\xi\zeta\varphi_f + \left[\alpha_{crc}(1-\xi) + \bar{\varphi}_{st}\frac{\sqrt{c_s}}{d}\right]\left(\zeta + \varphi_{c2}\frac{c_o}{d}\right)}{\bar{t}}, \quad (9)$$

where: $\bar{\varphi}_{c1} = \frac{f_{cd}}{f_{ctd}} \frac{V_c}{f_{cd}bx - N_c}$; (10)

$$\alpha_{crc} = \frac{F_{crc}}{f_{ctd} b l_{crc}}; \quad (11)$$

$$\varphi_{st} = \frac{V_s}{f_{ctd} b \sqrt{c_s}}; \quad (12)$$

$\bar{\varphi}_{c2}$ – coefficient depending on the concrete type and class.
$\bar{\varphi}_{c1}$, α_{crc}, φ_{st}, $\bar{\varphi}_{c2}$ are determined by the Table 1;

$$\xi = \frac{x}{d} = \frac{\sqrt{\rho_f E_s / E_c}}{2.5\frac{c_o}{d}\left(1 - 0.22\sqrt{\varphi_n}\right) - 1}; \quad (13)$$

$\frac{c_o}{d}$ is determined by the formulas:
- under the concentrated load action

$$\frac{c_o}{d} = 0,5\left(\frac{c}{d} + n\right), \quad (14)$$

- under the uniformly distributed load action

$$\frac{c_o}{d} = 0.5\left(\frac{l_{elm}}{2d} + n\right), \quad (15)$$

$$n = \frac{1 + 0.35\varphi_n}{1 + \bar{c}/d + \rho_f E_s / E_c}; \quad (16)$$

where $\rho_f = \frac{A_s}{bd}$, φ_n – coefficient that takes into account the concrete compressive force influence P in pre-stressed structures, and is equal

$$\varphi_n = \frac{P}{f_{ctd} bd\left(1 + \rho_f E_s / E_c\right)}, \quad (17)$$

but no more than 5; φ_f – coefficient that takes into account the flange work in the compressed zone; $\varphi_f = 1$ – for the element rectangular section, $\varphi_f = b_{eff} / b$ – for a T-section with a flange in a compressed zone, but no more than 3;

$$\zeta = \frac{z}{d} = 1 - 0.5\xi; \quad (18)$$

$$\bar{t} = \zeta f_q + \bar{\varphi}_{c2} f_m, \quad (19)$$

where f_q and f_m – inclined section projection functions on the longitudinal axis c, which for the loading main cases are given in Table 2.
Parameter α_{sw} expresses the relative load perceived by the stirrups clamps, is equal to

$$\alpha_{sw} = \frac{f_{ywd} A_{sw}\left(\zeta + 0.5\bar{\varphi}_{c2}\frac{c_o}{d}\right)\frac{c_o}{d}}{f_{ctd} b s t}. \quad (20)$$

The c value when the concentrated force F acts upon an element is taken equal to the distance from the "incoming" face (the "incoming" is the face on which only the transverse force acts) to this force application point.
The $\frac{c}{d}$ value while acting the uniformly distributed load q on the element is equal to

$$\frac{c}{d} = \frac{c_o}{d} + 0.25\frac{l_{clt}}{d} - 0.5n. \quad (21)$$

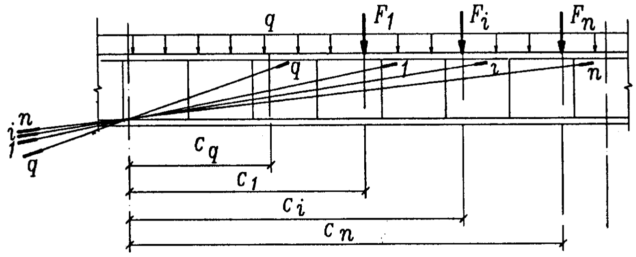


Fig. 4: The calculated inclined sections location with the projections c_1, c_i, c_n and c_q on the element longitudinal axis in the loading general case by concentrated forces F_1, F, F_n and a uniformly distributed load q

Wherein:

$$H = qd = k_1F_1 = k_iF_i = k_nF_n;\; f_{qq} = \frac{V_q}{H},\; f_{q1} = \frac{V_1}{H},\; f_{qi} = \frac{V_i}{H},\; f_{qn} = \frac{V_n}{H};$$

$$f_{mq} = \frac{M_q}{Hd},\; f_{m1} = \frac{M_1}{Hd},\; f_{mi} = \frac{M_i}{Hd},\; f_{mn} = \frac{M_n}{Hd},$$

where V_q, V_1, V_i, V_n, and M_q, M_1, M_i, M_n – transverse forces and bending moments from an external load located on one side of the cross-section *q - q*, *1 - 1*, *i - i*, *n – n* respectively.
The clamps cross-section area in one plane is determined by the formula:

$$A_{sw} = \frac{(H - \alpha_{c,s} f_{ctd} bd)st}{f_{ywd}(\zeta + 0.5\bar{\varphi}_{c2} c_o / d)c_o}. \quad (22)$$

For elements reinforced with bends, formulas (20) and (22) are written in the form:

$$\alpha_{sw} = \frac{f_{ywd} A_{sw} \bar{n}\left(\zeta \sin\beta + 0.5\bar{\varphi}_{c2}\bar{m}\frac{c_o}{d}\right)\frac{c_o}{d}}{f_{ctd} b s t}, \quad (23)$$

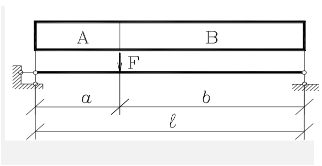
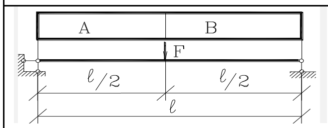
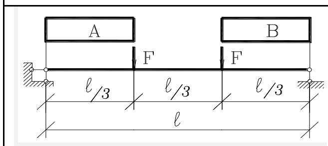
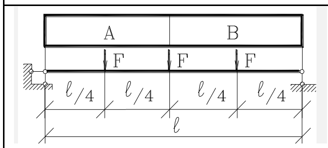
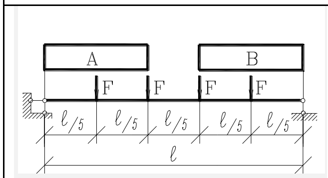
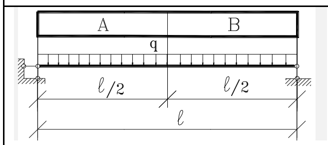
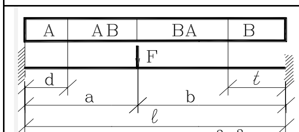
$$A_{sw} = \frac{\left(H - \alpha_{b,s} f_{ctd} bd\right) st}{f_{swd}\bar{n}\left(\zeta \sin\beta + 0.5\bar{\varphi}_{c2}\bar{m}\frac{c_o}{d}\right)c_o}, \quad (24)$$

where: $\bar{n} = \sin\beta + \cos\beta tg\alpha$; $\bar{m} = \sin\beta - \cos\beta tg\alpha$, where angles α and β – see Fig. 1.

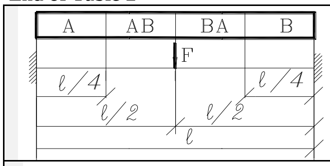
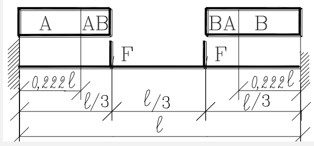
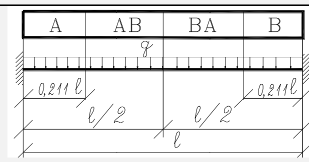
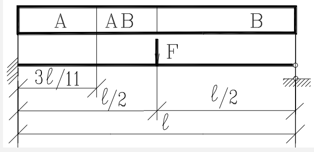
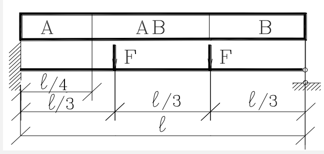
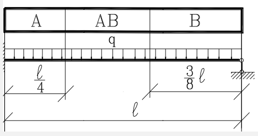
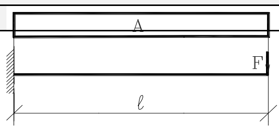
Table 1: Inclined section strength characteristic

Characteristics designation	Strength characteristics at concrete class									
	C12/15	C16/20	C20/25	C25/30	C30/35	C32/40	C35/45	C40/50	C45/55	C50/60
$\bar{\varphi}_{c1}$	10					9.5		9		8.5
$\bar{\varphi}_{c2}$	0.75			0.7		0.6		0.5	0.45	0,4
α_{crc}	0.2									
φ_{st}	11					10.5	10	9.5	9	8.5

Table 2: The inclined section projection functions under various loading schemes

Loading scheme and calculated elements	Inclined section projection functions: fq	fm
	Element A	
	$\frac{b}{l}$	$\frac{b}{l}\frac{c}{d}$
	Element B	
	$\frac{a}{l}$	$\frac{a}{l}\frac{c}{d}$
	Elements A, B	
	$\frac{1}{2}$	$\frac{1}{2}\frac{c}{d}$
	Elements A, B	
	1	$\frac{c}{d}$
	Elements A, B	
	at $c \le l/4$: $\frac{3}{2}$; at $c > l/4$: $\frac{1}{2}$	at $c \le l/4$: $\frac{3}{2}\frac{c}{d}$; at $c > l/4$: $\frac{2c+l}{4d}$
	Elements A, B	
	at $c \le l/5$: 2; at $c > l/5$: 1	at $c \le l/5$: $2\frac{c}{d}$; at $c > l/5$: $\frac{c+l/5}{d}$
	Elements A, B	
	$\frac{l/2-c}{d}$	$\frac{c(l-c)}{2d^2}$
 $d=a(1-b/l)/(3-b^2/l^2)$	Elements A, AB	
	$\frac{b^2}{l^3}(l+2a)$	$\frac{b^2(l+2a)}{l^3}\frac{c}{d}$
	Elements BA, B	
	$\frac{a^2(l+2b)}{l^3}$	$\frac{a^2(l+2b)}{l^3}\frac{c}{d}$

End of Table 2

Loading scheme and calculated elements	fq	fm
	Elements A, AB, BA, B	
	$\frac{1}{2}$	$\frac{1}{2}\frac{c}{d}$
	Elements A, AB, BA, B	
	1	$\frac{c}{d}$
	Elements A, B	
	$\frac{0.5l/\sqrt{3}+c}{d}$	$\frac{c\left(l/\sqrt{3}+c\right)}{d^2}$
	Elements AB, BA	
	$\frac{0,5l/\sqrt{3}-c}{d}$	$\frac{c\left(l/\sqrt{3}-c\right)}{d^2}$
	Elements A, AB	
	$\frac{11}{16}$	$\frac{11}{16}\frac{c}{d}$
	Element B	
	$\frac{5}{16}$	$\frac{5}{16}$
	Element A	
	$\frac{4}{3}$	$\frac{4}{3}\frac{c}{d}$
	Element AB	
	at $c \le l/12$: $\frac{4}{3}$; at $c > l/12$: $\frac{1}{3}$	at $c \le l/12$: $\frac{4}{3}\frac{c}{d}$; at $c > l/12$: $\frac{c+l/4}{3d}$
	Element B	
	$\frac{2}{3}$	$\frac{2}{3}\frac{c}{d}$
	Element A	
	$\frac{\frac{3}{8}l+c}{d}$	$\frac{c\left(\frac{3}{4}l+c\right)}{2d^2}$
	Elements AB, B	
	$\frac{\frac{3}{8}l-c}{d}$	$\frac{c\left(\frac{3}{4}l-c\right)}{2d^2}$
	Element A	

	1	$\frac{c}{d}$

Conclusions

A methodology is proposed for calculating the beam reinforced concrete structures bearing capacity for the transverse forces and bending moments joint action.
On the plasticity theory basis, the truncated concrete wedge strength problem solved as a compressed concrete zone model over a dangerous inclined crack. The dependence between the transverse and longitudinal forces on the face of wedge truncation is identified. Along with the forces perceived by the compressed zone and the transverse reinforcement, the engagement in the inclined crack and the longitudinal reinforcement work as nagel are taken into account.

References

[1] Grandić D, Šćulac P, Štimac Grandić I (2015), Shear resistance of reinforced concrete beams in dependence on concrete strength incompressive struts. *Tehnicki Vjesnik*, Vol. 22(4), pp. 925-934, https://doi.org/10.17559/TV-20140708125658

[2] Latha MS, Revanasiddappa M, Naveen Kumar BM (2018), Influence of stirrup spacing on shear, resistance and deformation of reinforced concrete beam. *International Journal of Engineering & Technology*, Vol. 7(1), pp. 126-134, http://dx.doi.org/10.14419/ijet.v7i1.9013

[3] Michael P Collins, Evan C Bentz, Edward G Sherwood, Liping Xi (2007), An adequate theory for the shear reinforced concrete structure. *Proceedings of the Morley Symposium on Concrete Plasticity and its Application*, pp. 75-94, http://dx.doi.org/10.1680/macr.2008.60.9.635

[4] Gurley CR (2008), Plastic Shear Strength of Continuous Reinforced Beams, *NZSEE Conference*, Paper Number 19, available online: https://www.nzsee.org.nz/db/2008/Paper19.pdf

[5] Mitrofanov VP (2000), Optimization strength theory of reinforced concrete bar elements and structures with practical aspects of its use. *Bygningsstatiske Meddelelser*, Vol. 71, No 4, pp. 73-125.

[6] ACI 318M-95 (1996), *Building Code Requirements for Structural Concrete and Commentary*, United States, ACI, 369 p.

[7] Concrete Structures Euro – Design Hand back. Design of Concrete Structures to ENV 1992 (1995), Berlin, 308 p.

[8] Borishanskiy MS (1964), Calculation of reinforced concrete elements under the action of transverse forces [Raschet zhelezobetonnyih elementov pri deystvii poperechnyih sil]. *Calculation and design of elements of reinforced concrete structures [Raschet i konstruirovanie elementov zhelezobetonnyih konstruktsiy]*, Moscow, Russia, pp. 122-143. (In Russian).

[9] Klimov YuA (1999) To calculate the strength of reinforced concrete elements in inclined sections [Do rozrakhunku mitsnosti zalizobetonnykh elementiv v pokhylykh pererizakh]. *Taurian scientific bulletin [Tavriiskyi naukovyi visnyk]*, Kherson, Ukraine, Vol. II, pp. 11-17. (In Ukrainian).

[10] Mitrofanov VP (1982) Stress – strain state, strength and cracking of reinforced concrete elements in transverse bending [Napryazhenno-deformirovannoe sostoyanie, prochnost i treschinoobrazovanie zhelezobetonnyih elementov pri poperechnom izgibe], Ph.D thesis in Engineering science, Moscow, Russia, 41 p. (In Russian).

[11] Pavlikov A, Kosior-Kazberuk M, Harkava O (2018) Experimental testing results of reinforced concrete beams under biaxial bending. *International Journal of Engineering & Technology*, 7 (3.2), pp. 299-305. https://doi.org/10.14419/ijet.v7i3.2.14423

[12] Zalesov AS, Petrosyan AV (1987), Method for calculating the strength of reinforced concrete elements under the joint action of bending moments and transverse forces, taking into account the deformation conditions [Metod rascheta prochnosti zhelezobetonnyih elementov pri sovmestnom deystvii izgibayuschih momentov i poperechnyih sil s uchetom usloviy deformirovaniya]. *Perfection of methods for calculating statically indeterminate reinforced concrete structures [*Sovershenstvovanie metodov rascheta staticheski neopredelimyih zhelezobetonnyih konstruktsiy*]*, Moscow, Russia, pp. 50-55. (In Russian).

[13] Zalesov AS, Klimov YuA (1989), *Strength of reinforced concrete structures under the action of transverse forces [Prochnost zhelezobetonnyih konstruktsiy pri deystvii poperechnyih sil]*, Kiev, Ukraine, 104 p. (In Russian).

[14] Kolchunov VI (1997), To the calculation of crack resistance and strength of core reinforced concrete elements along inclined sections [K raschetu treschinostoykosti i prochnosti sterzhnevyih zhelezobetonnyih elementov po naklonnyim secheniyam]. *Resource-saving constructive-technological solutions of buildings and structures [Resursosberegayuschie konstruktivno-tehnologicheskie resheniya zdaniy i sooruzheniy]*, Belgorod, Russia, Part 6-7, pp. 159–167. (In Russian).

[15] Mitrofanov VP, Kotlyarov VA (1990), General theory of calculating the strength of reinforced concrete elements for inclined and normal cracks [Obschaya teoriya rascheta prochnosti zhelezobetonnyih elementov po naklonnyim i normalnyim treschinam]. *University news. Construction and architecture [Izvestiya vuzov. Stroitelstvo i arhitektura]*, Russia, Vol. 9, pp. 3-9. (In Russian).

[16] Shkurupiy, O, Mytrofanov, P, & Masiuk, V (2018), Calculation of The Stability of the Form of Equilibrium of Discrete Systems. *International Journal of Engineering & Technology*, **7**(3.2), pp: 401-407, http://dx.doi.org/10.14419/ijet.v7i3.2.14561

[17] Geniyev GA, Kissyuk VN & Tyupin GA (1974), *Concrete and reinforced concrete plasticity theory* [*Teoriya plastichnosti betona i zhelezobetona]*, Moscow, Russia, 316 p. (In Russian).

[18] Kachanov LM (1969), *Basic of the plasticity theory [Osnovy teorii plastichnosti]*, Moscow, Russia, 420 p. (2013) Ripol Klassik, 426 p. (In Russian).

[19] Cherepanov GA (1974), *Mechanics of brittle failure [Mehanika hrupkogo razrusheniya]*, Moscow, Russia, 640 p. (In Russian).

[20] Rzhanitsin AR (1986), *Composite rods and plates [Sostavnyie sterzhni i plastinki]*, Moscow, Russia, 315 p. (In Russian).

[21] Nielsen MP & Hoang LC (2011), *Limit Analysis and Concrete Plasticity*, CRC Press, Taylor & Francis Group. 3rd ed., 669 p.

[22] Pavlikov A, Mykytenko S, Hasenko A (2018) Effective structural system for the construction of affordable housing. *International Journal of Engineering & Technology*, 7 (3.2), pp. 291-298. http://dx.doi.org/10.14419/ijet.v7i3.2.14422

[23] Dovzhenko OA, Pohribnyi VV, Karabash LV (2018) Effective Keyed Connections Of Hollow-Core Floor Slabs With Walls In Modern Large-Panel House Building, *Science & Technique*, 17(2), pp. 146-156. (In Russian). https://doi.org/10.21122/2227-1031-2018-17-2-146-156

[24] Pohribnyi V, Dovzhenko O, Karabash L, Usenko I (2017), The design of concrete elements strength under local compression based on the variational method in the plasticity theory, *Web of Conferences*, Vol. 116, https://doi.org/10.1051/matecconf/20171160201

[25] Dovzhenko O, Pogrebnyi V, Yurko I (2018), Shear Failure Form Realization in concrete, *News NAS RK. Series of geology and technical science*, Vol. 2 (428), pp. 212-219, available online: http://geolog-technical.kz/images/pdf/g20182/55-62.pdf

[26] Pohribnyi V, Dovzhenko O, Maliovana O (2018) The Ideal Plasticity Theory Usage Peculiarities to Concrete and Reinforced Concrete. *International Journal of Engineering & Technology*, Vol. 7(3.2), pp: 19-26, http://dx.doi.org/10.14419/ijet.v7i3.2.14369

[27] Dovzhenko O, Pogrebnyi V, Yurko I, Shostak I (2017), The bearing capacity experimental determination of the keyed joints models in the transport construction. *Web of Conferences*, Vol. 116, https://doi.org/10.1051/matecconf/201711602011

[28] Dovzhenko O, Pohribnyi V, Karabash L (2018) Experimental Study on the Multikeyed Joints of Concrete and Reinforced Concrete Elements, *International Journal of Engineering & Technology*, Vol. 7 (3.2), pp: 354-359, http://dx.doi.org/10.14419/ijet.v7i3.2.14552

[29] Kolmogorov VL (1986), *Metal forming mechanics [Mekhanika obrabotki metallov davleniyem]*, Moskow, Russia, 689 p. (In Russian).

[30] Maliovana OO (2018) Strength of higher strength concrete elements under shear action. *Academic Journal (Industrial Machine Building, Civil Engineering)*, Issue 1 (50), pp. 131-40, available online: https://doi.org/10.26906/znp.2018.50.1068

[31] Pavlikov, A., Kosior-Kazberuk, M., & Harkava, O. (2018). Experimental testing results of reinforced concrete beams under biaxial bending. *International Journal of Engineering and Technology(UAE)*, *7*(3), 299-305. https://doi.org/10.14419/ijet.v7i3.2.14423

[32] Goryk, O. V., Pavlikov, A. M., & Kyrychenko, V. A. (2009). Calculation of statically indeterminate composite beam elements by using refined boundary conditions and with account of their state dia-

grams. Mechanics of Composite Materials, 45(1), 53-58. https://doi.org/10.1007/s11029-009-9058-9
[33] Kochkarev, D., & Galinska, T. (2017). Calculation methodology of reinforced concrete elements based on calculated resistance of reinforced concrete. Paper presented at the MATEC Web of Conferences, , 116 https://doi.org/10.1051/matecconf/201711602020
[34] Piskunov, V. G., Goryk, A. V., & Cherednikov, V. N. (2000). Modeling of transverse shears of piecewise homogeneous composite bars using an iterative process with account of tangential loads. 1. construction of a model.Mechanics of Composite Materials, 36(4), 287-296. https://doi.org/10.1007/BF02262807
[35] Kochkarev, D., Galinska, T., & Azizov T. (2018) Bending deflection reinforced concrete elements determination. Paper presented at the MATEC Web of Conferences, 230 https://doi.org/10.1051/matecconf/201823002012
[36] Kochkarev, D., Galinska, T., & Tkachuk, O. (2018). Normal sections calculation of bending reinforced concrete and fiber concrete element. *International Journal of Engineering and Technology(UAE)*, *7*(3), 176-182. http://dx.doi.org/10.14419/ijet.v7i3.2.14399
[37] Kochkarev, D., & Galinska, T. (2018). Nonlinear Calculations of the Strength of Cross-sections of Bending Reinforced Concrete Elements and Their Practical Realization. Cement Based Materials, 13-30 http://dx.doi.org/10.5772/intechopen.75122