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THE PROBLEM OF CRACK OPENING WIDTH AND STIFFNESS OF REINFORCED CONCRETE STRUCTURES, BUILDINGS AND CONSTRUCTIONS

Vladimir I. Kolchunov

Research Institute of Building Physics of Russian Academy of Architecture and Construction Sciences, Moscow, RUSSIA
Southwestern State University, Kursk, RUSSIA

Abstract. The article defines the main results for the development of reinforced concrete mechanics. In the isotropic medium between the cracks is used "first object - flows-blocks", "second object - main cracks" and the effect of reinforced concrete, the physical essence of which is the non-uniformity of concrete and continuous reinforcement. Reactions arise in the concrete for deformation of the reinforcement from the bonding of the compressed concrete in the tensile region. The average resistance of the tensile concrete and the "average total force of the working reinforcement," the third object, are transmitted through the effect of reinforced concrete and the "dowel" effect. The crack opening widths are the relative mutual displacements of reinforcement and concrete, determined from the boundary conditions and the Thomas-Author hypothesis. A new classification of cracks has been developed: regular cracks (anisotropic medium of reinforced concrete) and main cracks based on the effect of reinforced concrete (origins - concentrations) and maximum opening in the closed equations of mechanics of reinforced concrete from the Lagrange function. The author has proposed hypotheses, theorems of linear and angular deformations, functionals for deplanation of cross section of reinforced concrete element from elastic-plastic stage, jumps - cracks and stiffness matrix in a single compound strip which allow to reduce the order of differential equations. The resistance design model method for reinforced concrete mechanics is used for the rod, wall, and slab of the "envelope" of cracks. Hybrid from Lira (finite element method of reinforced concrete from anisotropy) developed in the form of two finite element effect of reinforced concrete of "flat and spatial cantilever" for external and internal displacements. The general principle from Loleith to the "opening - closing" of cracks, the stiffness of the mechanics of reinforced concrete is obtained in the form of the method of the computational model of resistance.

Keywords: reinforced concrete effect, crack classification, source-concentrations, single stripes, resistance models, crack opening-closing

ПРОБЛЕМА ШИРИНЫ РАСКРЫТИЯ ТРЕЩИН И ЖЕСТКОСТИ ЖЕЛЕЗОБЕТОННЫХ КОНСТРУКЦИЙ, ЗДАНИЙ И СООРУЖЕНИЙ

Вл.И. Колчунов

Научно-исследовательский институт строительной физики РААСН, г. Москва, РОССИЯ
Юго-Западный государственный университет, г. Курск, РОССИЯ

Аннотация. В статье определены основные результаты для развития механики железобетона. В изотропной среде между трещинами используется «первый объект – потоки-блоки», «второй объект - магистральные трещины» и эффект железобетона, физическая суть которого заключается в несплошности бетона и сплошной арматуре. В бетоне возникают реакции для деформации арматуры от сцепления сжатого бетона в растянутой области. Среднее сопротивления растянутого бетона и «средне суммарное усилие рабочей арматуры», - третий объект, - передаются через эффект железобетона и «нагельный» эффект (главный вектор в трещине). При этом ширина раскрытия трещин - относительные взаимные смещения арматуры и бетона, определяемые из граничных условий и гипотезы Томаса – автора. Разработана новая классификация трещин: регулярные трещины (анизотропная среда железобетона) и магистральные трещины на основе эффекта железобетона (истоки - концентрации) и максимальной раскрытия в замкнутых уравнениях механики железобетона из функции Лагранжа. Автором предложены гипотезы, теоремы линейных и угловых деформаций, функционалы для депланации поперечного сечения железобетонного элемента из упругопластической стадии, скачки - трещины и матрица жесткости в единичной составной полоске, позволяющие сократить порядок дифференциальных уравнений. Метод расчетной модели сопротивления для механики железобетона используется для стержня, стены, плиты из «конверта» из спиралеобразной, иксообразной и гармошкообразной трещины. Гибрид из Лира (метод конечных элементов железобетона из анизотропии) разработан в форме эффекта железобетона из двух конечных элементов в виде «плоская и пространственная консоль» для внешних и внутренних перемещений. Общий принцип от Лолейта до «раскрытия – закрытия» трещин, жесткости механики железобетона получен в виде метода расчетной модели сопротивления.

Ключевые слова: эффект железобетона, классификация трещин, истоки-концентрации, единичные полоски, модели сопротивления, раскрытие-закрытие

The mechanics of reinforced concrete is the basis for the safety of the system of buildings and structures under new challenges of man-made natural and terrorist nature. The solutions to these problems are obtained at a new scientific level due to modern technologies of experimental research of structures and convergence of physical phenomena in reinforced concrete on the basis of fracture mechanics.

THE MAIN RESULTS FOR THE ACADEMY'S BUILDING SCIENCES ARE FORM:

I. Development of the mechanics of reinforced concrete, - result I.

1) Let's look at the main premises

● The reinforced concrete environment includes force flows from concrete blocks for isotropic environment between cracks "first object - flows (blocks)" in the local region near the fracture bank in fracture mechanics of reinforced concrete.

● The second object is the main cracks from the fracture mechanics of reinforced concrete and the effect of discontinuity of concrete developed by the author. Its essence is the discontinuity of concrete and solid reinforcement, where there are shear reactions ΔT (deformations between reinforcement and concrete), taking into account the compression force for tensile concrete $\sigma_{bt,c}$, the relative deformations of reinforcement $\varepsilon_S = \varepsilon_{S,j} - \varepsilon_э$ and other parameters to solve the problem of resistance near the reinforcement zone of a reinforced concrete element. Experimental strain diagrams were obtained in experiments of J.M. Nemirovsky, B.Sh. Shamuradov, works of the author [1-4] and others.

● In a reinforced concrete structure, the resistance of the tensile concrete is obtained for a transversal-isotropic material. The force for the tensile concrete in the working reinforcement can be transferred through the general parameter ψ_s (or $\psi_{s,sw}$) by Prof. V.I. Murashev [5]. For the average longitudinal force N_{sm} ($N_{s,m} = \varepsilon_s \cdot \psi_s \cdot E_s \cdot A_s$) and transverse force $Q_{s,m}$ ($Q_{s,m} = \varepsilon_s \cdot \psi_{Q,s} \cdot E_s \cdot A_s$) we can talk about the connection of a special third object - the "total average force $N_{s,m,sum}$ of the working reinforcement" ($N_{s,m,sum} = \sqrt{N_{s,m}^2 + Q_{s,m}^2}$) using the reinforced concrete effect and the dowel forses (Fig. 1). The author has developed a second level building mechanics model for a rebar, crack opening, bank shear and buckling.

● The following results were obtained on the basis of fracture mechanics. The author developed a special dual-console element (DCE) and discovered the effect of its physical essence, which consists in the reaction between the discontinuity of concrete and the continuity of the working reinforcement (Fig. 1).

● Using the pliability of structural mechanics, a canonical system of equations is derived from classical methods (method of forces, method of displacements, mixed method, finite element method) (Fig. 1):

$$\zeta_{cu} = \lim_{\delta A \to 0}\left(\frac{\delta W - \delta V}{\delta A}\right) = C_I \cdot \Delta T \frac{\partial \Delta T}{\partial h_{crc}} - C_{II} P_1 \cdot \frac{\partial P_1}{\partial h_{crc}} - C_{III} P_2 \cdot \frac{\partial P_2}{\partial h_{crc}} - C_0 M_{con} \cdot \frac{\partial M_{con}}{\partial h_{crc}}; \qquad (1)$$

Here δV is the decrease of the body's potential energy when the crack advances by a small increment δa; δW is the additional work performed on the body when the crack advances by a small increment δa.

$$\left.\begin{aligned} &X_1\delta_{11} + X_2\delta_{12} + X_3\delta_{13} + \Delta_{1p} - (-\Delta_3 + \Delta_2) + \Delta_2 + h_{crc} \cdot (\phi_1 + \Delta\phi) = 0;\\ &X_1\delta_{21} + X_2\delta_{22} + X_3\delta_{23} + \Delta_{2p} - (\Delta_6 + \Delta_2) + \Delta_2 + (h_{crc} - t_b) \cdot (\phi_1 + \Delta\phi) = 0;\\ &X_1\delta_{31} + X_2\delta_{32} + X_3\delta_{33} + \Delta_{3p} + (\phi_2 - \Delta\phi) + (\phi_1 + \Delta\phi) = 0;\\ &X_4\delta_{44} = 1 \cdot (-\Delta\Gamma_1) - 1 \cdot \Delta_2 + (x_{crc} - h_{b,1}) \cdot \Delta\phi . \end{aligned}\right\} \qquad (2)$$

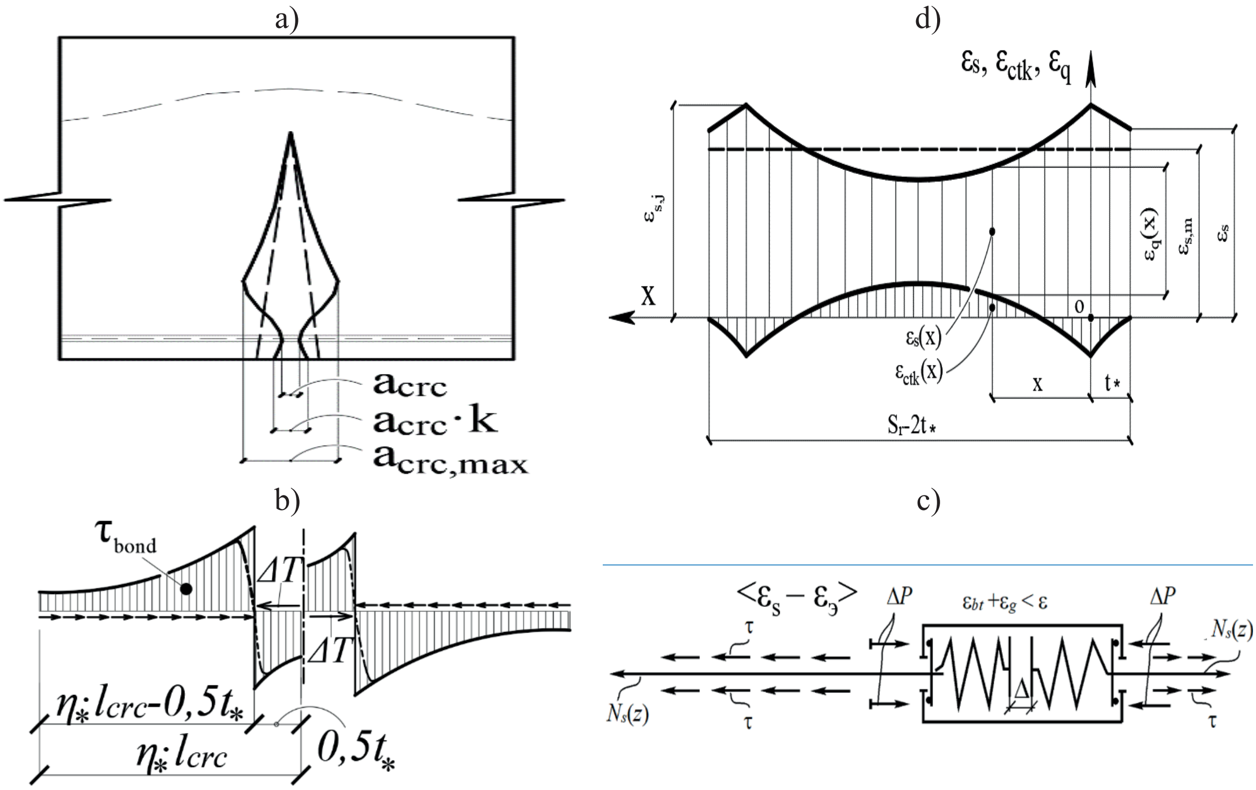


Figure 1. Effect of reinforced concrete: the shape of the crack from triangle to ellipsoid (a); the response from the continuous concrete and continuous reinforcement (b); the mechanical model (c); the relative deformations of the reinforcement and the stretched concrete (d)

Prof. V.I. Murashev has developed formulas for transverse cracks and stiffness, distance between cracks l_{crc}, resistance coefficient of tensile concrete ψ_s and crack opening width a_{crc}. This was later developed to the effect of discontinuity in concrete (Fig. 1 and Fig. 2a). The crack opening width is determined using the Thomas-author hypothesis, and the relative mutual displacements of the reinforcement and concrete are determined from the dependence:

$$\varepsilon_g(x) = \varepsilon_s(x) - \varepsilon_{bt}(x). \qquad (3)$$

$\varepsilon_s(x)$ - relative deformations of reinforcement; $\varepsilon_{bt}(x)$- relative deformations of concrete in section x.
The definition problem is reduced to finding the relative deformations of concrete from dependence (3) and the equilibrium of the reinforcing bar.

$$\frac{d\varepsilon_g(x)}{dx} + B\varepsilon_g(x) = 0. \qquad (4)$$

The solution of the homogeneous first-order differential equation has the form:

$$\varepsilon_g(x) = C \cdot e^{-Bx}. \qquad (5)$$

The integration constant C is found from the boundary condition, according to which at $x = 0,\ \varepsilon_{bt,c}(x) = -\sigma_{bt,c} / (\nu_b E_b)$:

$$C = \frac{B_3}{B} + \frac{1}{B(1-K)}\left(-\frac{\sigma_{bt,c}}{\nu_b E_b}\right). \qquad (6)$$

The distance between cracks is determined from the ratio:

$$l_{crc} = \frac{2\left(\ln B_4 - Bt_*\right)}{-B}. \qquad (7)$$

The coefficient that takes into account the uneven distribution of the relative strains of the tensile reinforcement between the cracks:

$$\psi_S = \frac{2 \cdot K \cdot B_3}{\varepsilon_S \cdot l_{crc} \cdot B} \cdot \left[1 - e^{-B\cdot\left(0.5l_{crc} - t_*\right)}\right] + \frac{2}{\varepsilon_S \cdot l_{crc}}\left(\varepsilon_S + \frac{\Delta T}{E_S A_S} - K \cdot B_3\right) \cdot \left(0,5l_{crc} - t_*\right) + \\ + \frac{\delta Q \cdot K}{\varepsilon_S \cdot l_{crc} \cdot B \cdot t_*}\left(0,5l_{crc} - t_*\right)^2 + \frac{2 \cdot \varepsilon_S \cdot E_S \cdot A_S + \Delta T}{\varepsilon_S \cdot l_{crc} \cdot E_S \cdot A_S} \cdot t_*; \qquad (8)$$

and the crack opening width has the form:

$$a_{crc} = -\frac{2\Delta T}{G} + \frac{2}{B}\left(\frac{q_{sw}S}{A_{sw}E_{sw}} + B_{a,1}\right)\left(1 - e^{\ln B_4}\right) - \frac{2B_2}{B}\ln B_4 = \\ = -\frac{2\Delta T}{G} - \frac{2B_{a,2}}{B} - \frac{2B_2}{B}\ln\left(1 + \frac{B_{a,2} \cdot A_{sw}E_{sw}}{q_{sw}S + B_{a,1}A_{sw}E_{sw}}\right); \qquad (9)$$

Here in equations (7)-(9): $B = \frac{S \cdot G}{A_{sw}E_{sw}K}$; $B_{a,1} = \frac{\Delta T}{E_{sw}A_{sw}} - \frac{\sigma_{bt,c}}{\nu_b E_b} - B_2$; $\frac{1}{K} = 1 + \frac{A_s E_s}{\omega_{bt}(x)A_{bt}(x)E_b \cdot \nu_{bt}(x)} = 1 + \delta\frac{\mu_s \cdot n\left(h_0 + x \cdot (\gamma - 1)\right)}{0.32 \cdot h_0 \cdot (\gamma - \xi)(\gamma + 0.03\xi)}$; $B_2 = \frac{\delta Q}{t\,B}$; $B_3 = \varepsilon_s + \frac{\Delta T}{E_s A_s} - \frac{\sigma_{bt,s}}{\nu_b E_b} - B_2$; $B_4 = 1 + \frac{\sigma_{bt,c}}{(K-1)B_{3,*}\nu_b E_b} + \frac{\varepsilon_{bt,u}}{B_{3,*}(K-1)}$.

The new level of fracturing corresponds to the fulfillment of the following inequality:

$$l_{crc,i} \le \eta_* \cdot l_{crc,i-1}. \qquad (10)$$

Cracking continues up to the moment of fracture. There are several levels of cracking:

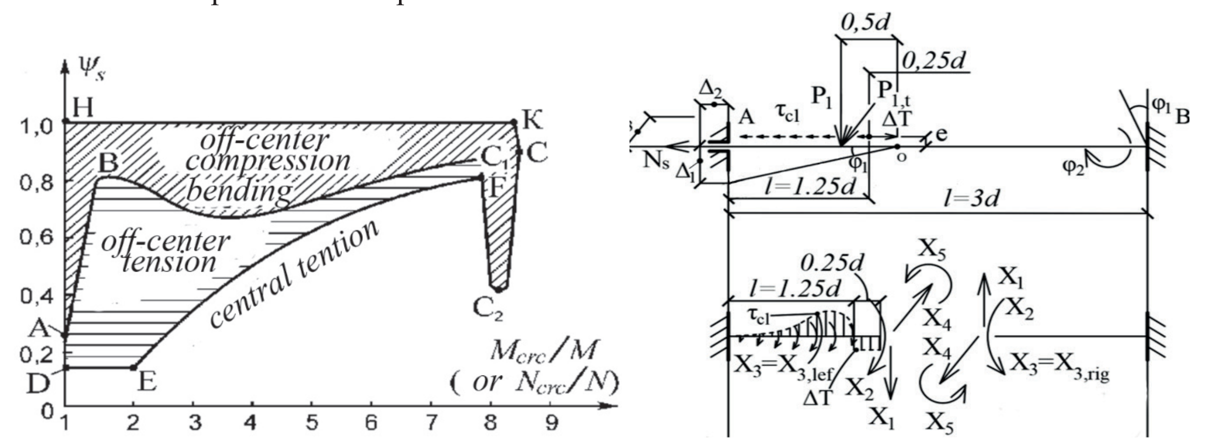
$$\left.\begin{array}{l} l_{crc} > l_{crc,1} - \text{no cracks;} \\ l_{crc,1} \geq l_{crc} \geq l_{crc,2} - \text{first level;} \\ l_{crc,2} \geq l_{crc} \geq l_{crc,3} - \text{second level;} \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ l_{crc} \geq 6t_{*} \end{array}\right\} . \quad (11)$$

● The dowel effect of the author of the second level model [9,10] is developed for a beam with two pinched ends at turns of the pinched ends as well as crack opening $\Delta_{crc,s}$, shifting of the crack-track banks Δ_{crc} and concrete buckling. The longitudinal axis of the reinforcing bar has a sinusoidal shape when displaced with a maximum amplitude of $0.5\Delta_1$, from the longitudinal force $N_s(x)$ and eccentricities in the vertical and horizontal directions (Fig. 2).

The unknowns X_2, X_3, $X_{3,t}$, X_4, X_5 are found from the calculation of statically indeterminate systems by the method of forces from coupled systems of equations (systems (12) and (13)):

$$\left.\begin{array}{l} X_1\delta_{11} + X_3\delta_{13} + \Delta_{1,P} = 0 \\ X_1\delta_{31} + X_3\delta_{33} + \Delta_{3,P} = 0 \end{array}\right\} ; \quad (12)$$

$$\left.\begin{array}{l} X_{3,t}\delta_{43t} + X_4\delta_{44} + \Delta_{4,P} = 0 \\ X_{3,t}\delta_{53t} + X_5\delta_{55} + \Delta_{5,P} = 0 \end{array}\right\} . \quad (13)$$



a) b)

Figure 2 - The nature of the coefficient change under various influences (a), the calculation scheme of the dowel effect (b)

After solving the coupled system, the values are obtained:

$$X_4 = X_3 \cdot \frac{E(\lambda)I_z}{G(\lambda)I_{tor}} \cdot \eta \cdot 0,25 \cdot N_{s,1} -$$
$$-(0.25 \cdot d \cdot P_{1,t} + 0.16 \cdot \frac{\Delta_3}{d} \cdot \left(N_{s,1} + N_{s,2}\right)$$
$$-0.44 \cdot \frac{\Delta_3}{d^3} \cdot E(\lambda)I_z + 0.59 \cdot \frac{\varphi_2}{d^2} \cdot E(\lambda)I_z); \quad (14)$$

$$X_5 = X_3 \cdot \eta \cdot N_{s,1} \cdot e - 0.17 \cdot d \cdot P_{1,t}. \quad (15)$$

Here $X_{3,t}$ are the torsional forces $P_{1,t}$ in Fig. 1 and Fig. 2 b, c).

The main vector u of forces in the reinforcement is characterized by two values u_{gi}, υ_{gi} and is related to the normal stresses $\sigma_{s,i}$ of the reinforcement in the cracks and the tangential stresses $\tau_{s,i}$. (Fig. 3).

The relationships between υ_{gi} and angle β from the experiments are of the form:

$$\upsilon_{gi} = k_{\sup} \cdot R_{\sup} = k_{\sup}(Q_s + N_s \cdot tg\beta + P_i)\zeta; \quad (16)$$

Here are the rod yield functions for the distance l_{crc} (using the area and perimeter of the rod) at some small segment u_{gi} and υ_{gi}, ζ is coefficient for the generalized reaction $R_{\sup}$

The components of the main vector along some orthogonal directions are related to each other:

$$0.5 \cdot a_{crc} = u_{gz} \cdot \cos\alpha + u_{gx} \cdot \sin\alpha \quad (i \neq x, z); \quad (17)$$

$$u_{gz} = \frac{0.5 \cdot a_{crc} - u_{gx} \cdot \sin\alpha}{\cos\alpha}; \quad (18)$$

$$\upsilon_{gi} = u_{gy} \cdot \cos\beta_i - u_{gx} \cdot \sin\beta_i; \quad (19)$$

$$\upsilon_{gi} = u_{gz} \cdot \cos\beta_i - u_{gx} \cdot \sin\beta_i; \quad (20)$$

Then (Fig. 3) we get:

$$\cos\beta = 0,5A_\beta \pm \sqrt{(0,5A_\beta)^2 - B_\beta}; \quad (21)$$

Here $A_\beta = \dfrac{2 \cdot \upsilon_{gi} \cdot u_{gz}}{\left(u_{gx}^{\;2} + u_{gz}^{\;2}\right)}$; $B_\beta = \dfrac{\upsilon_{gi}^{\;2} - u_{gx}^{\;2}}{\left(u_{gx}^{\;2} + u_{gz}^{\;2}\right)}$.

After that we get the dependence

$$u_{gi} = u_{gx} \cdot \cos\beta_i + u_{gy} \cdot \sin\beta_i. \quad (22)$$

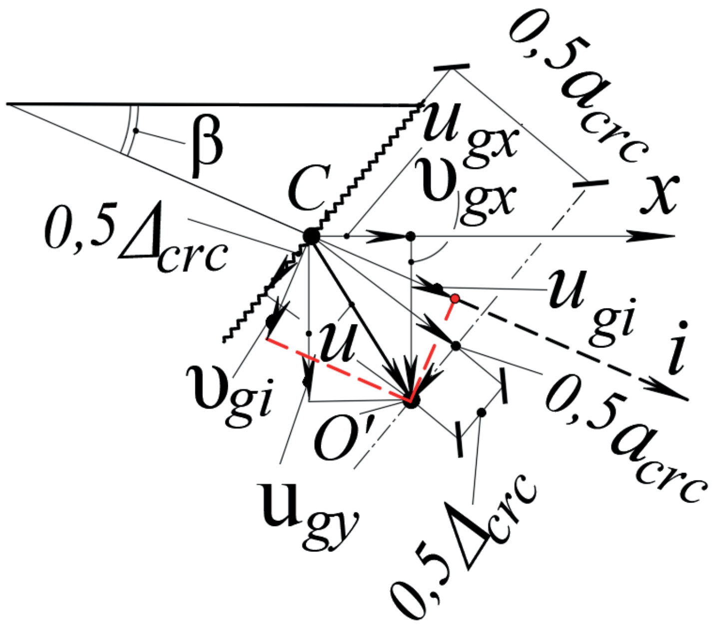


Figure 3. Connected displacements of reinforcing bars u_{gi} and υ_{gi} (for crumpled concrete) in the crack with crack bank opening a_{crc} and shear Δ_{crc}, taking into account the main vector u and the angle β of forces in the reinforcement crossing the crack

2) The classification of trunk cracks has the form (Fig. 4):

- regular cracks Prof. N.I. Karpenko [19] (anisotropic medium of reinforced concrete and finite element method, no effect of reinforced concrete, no width of "opening - closing");
- main cracks of the author (Fig. 4) based on the effect of disruption of the continuity of reinforced concrete.

Basic cracks (geometric force and inter-medium concentrations for the augmented and internal displacements Δ_1, Δ_2, φ_1, φ_2, $\Delta\varphi_{crc}$.

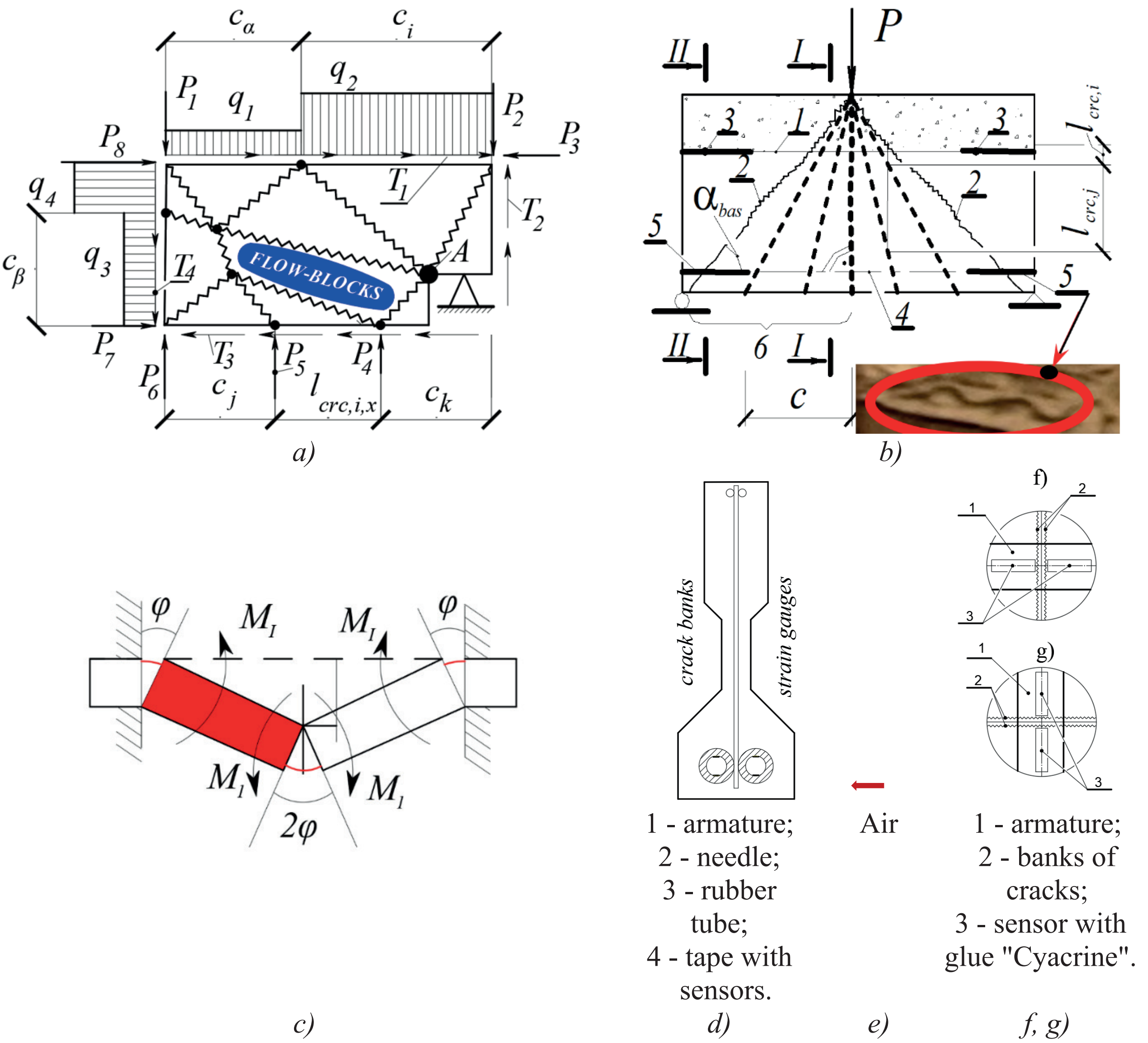


Figure 4. Classification of trunk cracks: a - calculation model of resistance 4 for a wall with trunk oblique cracks; b - baseline crack origins - concentrations: geometric, force concentrations for external and internal displacements Δ_1, Δ_2, φ_1, φ_2, $\Delta\varphi_{crc}$); c - computational model of resistance 4a - slab with trunk cracks; d - shape of cross-section for types of cracks and technology of experiments for punches in the reinforcement (e), gauges with glue "Zyakrin" for the banks of cracks (f, g)

The general model is proposed for the analysis of systems partitioning into physical and computational models of resistance of reinforced concrete (RRC) in cracks rod for RRC 1 - 3, flat cracks RRC4, 4 * and spatial RRC5, 5 * for system "opening-closing" width.

Here types I-III of area cracks M >Mcrc, Mt < Mt,crc and Q ≥ Qcrc; M < Mcrc, Mt > Mt,crc or Mt < Mt,crc, Q > Qcrc; type IV - crack development from fracture mechanics; type V - cracks from compressed concrete ε_3 (top) and ε_1 (wall); type VI - cracks from anchoring

The Lagrange function is constructed for the maximum crack opening width in the closed equations of reinforced concrete mechanics

(Fig. 4) $F_i = f\left(q_{sw}, x_B, \sigma_s, x, \sigma_c, \sigma_{s,1}, \sigma_{c,1}, C_2, \lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6, \lambda_7\right)$:

$$\left.\begin{array}{l} \dfrac{\partial f}{\partial x_1} + \lambda_1 \dfrac{\partial \theta_1}{\partial x_1} + \lambda_2 \dfrac{\partial \theta_2}{\partial x_1} + \ldots + \lambda_m \dfrac{\partial \theta_m}{\partial x_1} = 0; \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ \dfrac{\partial f}{\partial x_n} + \lambda_1 \dfrac{\partial \theta_1}{\partial x_n} + \lambda_2 \dfrac{\partial \theta_2}{\partial x_n} + \ldots + \lambda_m \dfrac{\partial \theta_m}{\partial x_n} = 0. \end{array}\right\} \quad (23)$$

3) The author proposed new hypotheses and theorems:

- The first one is about the distribution of relative linear deformations $\varepsilon_{x,b}$ and $\varepsilon_{x,s}$ using a special geometric volumetric figure for the deplanation of the cross-section of a reinforced concree element from elastic-plastic stages I-III and in jumps - cracks [14-18];

The second hypothesis on the distribution of relative angular deformations of concrete and reinforcement ($\gamma_{sum,b}$ and $\gamma_{sum,s}$) using a special geometric volume figure for the deplanation of the cross-section of a reinforced concrete element from elastic-plastic stages I-III, in jumps - cracks and theorems 1-3 [14-18];

4) Analytical functionals first - fourth are developed when solving the system of proposed complex functions from the grids method families in the compressed and stretched zones with the help of small squares. Linear and angular deformations are determined at all stages I-III for a complex-stressed reinforced concrete element and in the jumps-cracks. The first functional $f_{5,*}(y,z)$ is a function of two functions along the y-axis and z-axis; the second functional $f_{***}(x,z,y)$ is a function of three functions along the x-axis, z-axis, and y-axis. The bending and torsional moments are determined using the third uncertain function $f_{\varepsilon,\text{int,vol}}(x,y,z)$ (a special function of subtraction from the triangle in the calculated cross sections of the element when it is approximated by rectangles), and the torsional moments are determined using the fourth uncertain function $f_{5,\,**,\,\iint}\,(z,y)$.

5) Stiffness due to intersecting cracks for a unit strip uses the hypothesis, which allowed for reinforced concrete to reduce the differential equations of composite structures by an order of magnitude A.R. Rzhanitsyn [11, 18]. The stiffness matrix is constructed for rectangular cross-sections using small squares for physical characteristics: static equations (equilibria), geometric equations (deformations), and physical equations (Fig. 5).

$$\left.\begin{array}{l} \dfrac{T_1'}{\xi_{m,1}} - \Delta_{11}T_1 - \Delta_{12}T_1 - \ldots - \Delta_{in}T_n = \Delta_{10}; \\ \dfrac{T_2'}{\xi_{m,2}} - \Delta_{21}T_1 - \Delta_{22}T_2 - \ldots - \Delta_{2n}T_n = \Delta_{20}; \\ \dfrac{T_n'}{\xi_{m,n}} - \Delta_{ni}T_i - \Delta_{n2}T_2 - \ldots - \Delta_{nn}T_n = \Delta_{n0}. \end{array}\right\} \quad (24)$$

$$\Delta = -\frac{N_{0.1}}{(E_{b,1}A_{b,1})_{ekv}} + \frac{N_{0.2}}{(E_{b,2}A_{b,2})_{ekv}} - \frac{f(x_{crc})}{r_y}; \quad (25)$$

$$\lambda = \sqrt{\xi\gamma} = \sqrt{\xi\left[\frac{1}{(E_{b,1}A_{b,1})_{ekv}} + \frac{1}{(E_{b,2}A_{b,2})_{ekv}} + \frac{f^2(x_{crc})}{M \times r_y}\right]}; \quad (26)$$

Here T_1, T_2, T_n - shear forces accumulated along the length of the rod to the section; $\xi_{m,1}$, $\xi_{m,2}$, $\xi_{m,n}$ - modulus in a single shear band of the joint; Δ - displacements along a given direction; - difference of average relative linear and angular deformations in the joint point; ε_{qm}, $\gamma_{b,m}$ - equivalent stiffness; $f(x_{crc})$ - function of height of concrete compressed zone, averaged between cracks; $1/r_y = \chi$ - curvature of reinforced concrete composite rod.

II. RESISTANCE CALCULATION MODEL METHOD FOR STRUCTURAL MECHANICS, - RESULT II.

Calculated models of resistance (Fig. 5) fully meet the modern trend of deformation models of the theory of reinforced concrete, denoted today by the conceptual hierarchy (section - element - system) for the following levels: rod, flat and volumetric.

The analysis of the first model is performed. This is the rod with main normal cracks for the analytical fracture mechanics functional. The analysis of the second model for trunk oblique cracks is also performed using closed equations, which are included in the Lagrange function to determine the dangerous crack.

The third model of resistance has diagonal and other cracks for pliable units, as opposed to rigid units from structural mechanics (Fig. 5). Model 4 is a wall with trunk oblique cracks as well as diagonal (seismic) cracks, and 4a is a slab with trunk cracks (Fig. 4c and Fig. 5). Model 5 uses volumetric spatial blocks in torsion with bending. 5a are volumetric spatial blocks under the action of torsion with bending and shear force.

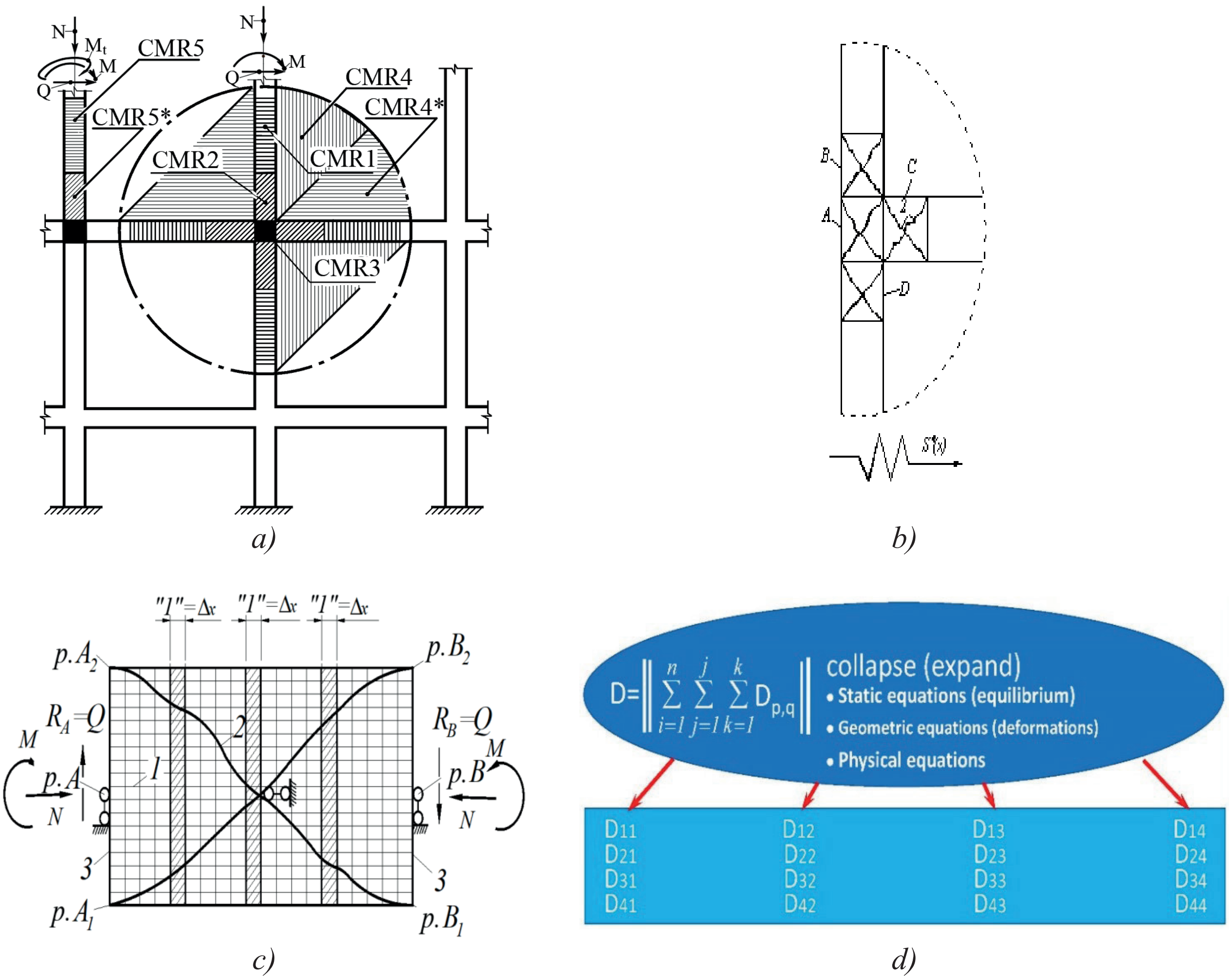


Figure 5. Calculation models of resistance (CMR) of buildings and structures (a) and stiffness for intersecting cracks of reinforced concrete for a single strip of composite rods (b, c), stiffness matrix scheme (d)

In the spatial design model of resistance in bending with torsion, two-console elements in models A and B [6], as well as a universal dual console element in reinforced concrete [8, 15] are used.

Applying the method of initial parameters [7 9] for a compressed-curved axis in the form of a spline is a general solution of the differential equation for displacements, - external (a_{crc} and $\delta(\Delta_{crc})$, φ_i, Θ_i) and internal (jump-crack: Δ_1, Δ_2, φ_1, φ_2, $\Delta\varphi_{crc}$). The construction mechanics classification for active or passive parameters is used for equal [7]

$$\frac{d^4 y}{dx^4} = 0. \qquad (27)$$

The general solution of equation (27) is expressed as a linear combination of the four functions:

$$y(x) = C_1 \cdot K_1(\beta x) + C_2 \cdot K_2(\beta x) + \\ + C_3 \cdot K_3(\beta x) + C_4 \cdot K_4(\beta x), \qquad (28)$$

where $\beta = \sqrt[4]{a}$; $K_1(x) = \frac{1}{2}(\text{ch}\, x + \cos x)$, $K_2(x) = \frac{1}{2}(\text{sh}\, x + \sin x)$, $K_3(x) = \frac{1}{2}(\text{ch}\, x - \cos x)$, $K_4(x) = \frac{1}{2}(\text{sh}\, x - \sin x)$ or we can use the Krylov-Vlasov functions: Φ_1(x)=chx · cosx; Φ_2(x)= = shx · sinx; Φ_3(x)=shx · cosx; Φ_4(x)=chx · sinx.

The method of initial parameters for displacements allows us to obtain expressions for deformations and rotation angles under the action of bending moment and shear force on the deformable base:

$$y_i = \varphi_1 L \frac{i-1}{n} - \frac{L^2}{n^2}\left(\frac{(3i-4)\chi_1 + \chi_i}{6} \sum_{j=2}^{i-1} (i-j)\chi_j\right) + \delta_i. \quad (29)$$

$$\varphi_i = \varphi_1 - M_1 \frac{L}{n} \times \left(\frac{\chi_1 + \chi_i}{2} + \sum_{j=2}^{i-1} \chi_j\right) + \Theta_i. \quad (30)$$

$$\chi(z) = \chi_i + \left(\frac{\chi_{i+1} - \chi_i}{2}(z - b_i)\right) \qquad (31)$$

$$R_i = k_i y_i a. \qquad (32)$$

Here R_i, k_i and y_i are the force, stiffness and displacement, respectively, in the i-th bond of the base.

The bending moment is described by the following relationship:

$$M_i = M_1 + Q_1 L \frac{i-1}{n} + \left(\frac{L}{n}\right)^2 \sum_{j=1}^{i-1} (i-j) y_j k_j - q_l \bar{M}_{0i}, \quad (33)$$

where M_1 is the moment in the console at i = 1; M_i - the moment in the i-th cross-section from a given unit vector of external forces.

We obtain a system of n equations (2≤ k ≤ n + 1) in the form of the method of initial parameters:

$$\Phi_k\left[y_1, \varphi_1, M_1, Q_1, M_{n+1}, y_i, q_l(q_d)\right] = 0.$$

Here $q_l(q_d)$ is the modulus of the force (deformation) impact vector,

Experimental studies are important (about a hundred experiments of the author) for full-scale structures, buildings and constructions. New technologies are used: glue "Cyacrine" (Cyanocrylate), sensors to measure 80% of the destructive load, punches for the inside of the working reinforcement, installation for displacements.

III. HYBRID calculations in the software package by means two elements in the form of "flat and spatial console", - RESULT III for internal and external displacements $S_i, \Delta_1, \Delta_2, \Delta_3, \delta\Delta_{crc}, \varphi_1, \varphi_2, \varphi_{crc}$.

IV. GENERAL PRINCIPLE - from the works of A.F. Loleit to the "opening - closing" of cracks in the working reinforcement and stiffness of reinforced concrete structures, buildings and structures taking into account the development of mechanics of reinforced concrete, - RESULT IV. There is also an economical expenditure of material (steel) in beams (ξ=0.3-0.4; μ=1%-2%); in slabs (ξ=0.10-0.15; μ=0.3%-0.6%) and in columns (ξ=0.4; μ= up to 3.0%)). The calculation must take into account that if a_m > a_R , then:

- 1) increase the cross-section of the elements and the shape of the cross-section;
- 2) increase the class of concrete to B100;
- 3) introduce reinforcement of compressed concrete;
- 4) use a diagram of materials (steel);
- 5) consider the criteria of fragmentation of the compressed concrete (ultimate deformations $\varepsilon_{b,u}$, as well as in the violation of the force equilibrium and $\varepsilon_{3,ult,t}$, ε_1 - top and , - wall), the development of cracks $d\zeta_{bu} / dh_{crc} = 0$ from fracture mechanics, and cracks from the anchoring ($l_x / l_{an} = m_{a33}$) for tensile working reinforcement.

6) consider the main (basic and adjacent) cracks for levels, stiffness and "opening-closing" of the crack using design models of resistance of reinforced concrete (rod 1-3, flat-tensioned 4 and 4*, spatial 5 and 5*.

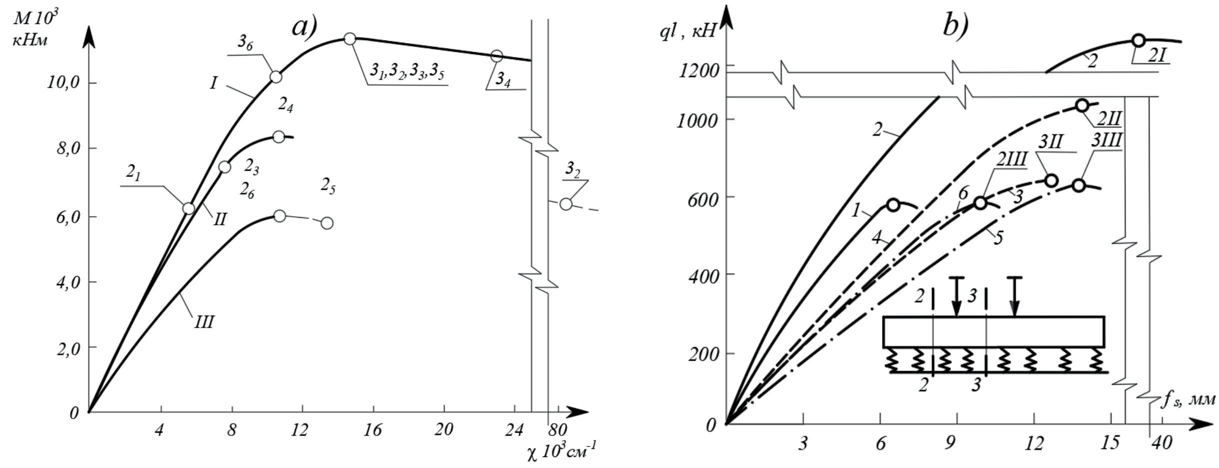


Figure 6. Diagrams of M-χ (a) and ql-fs dependences (b): I, II, III - M-χ dependences for clean zone, transverse bending zone in the absence of inclined cracks and transverse bending zone in the presence of inclined cracks, respectively; 1, 2, 3, 4, 5, 6 - ql-fs dependences at s = 3 and dependences I in section 2; at s = 2 and dependence I in section 2; at s = 3 and dependence II in section 2; at s = 2 and dependence II in section 2; at s = 3 and dependence III in section 2; at s = 2 and dependence III in section 2, respectively

CONCLUSION

1. The development of the mechanics of reinforced concrete and the basic prerequisites, - result I:

● The environment of reinforced concrete includes the force flows of solid deformable body mechanics of concrete blocks for isotropic medium between cracks, - " first object - flows (blocks). "Second object, - trunk cracks" using the functional, two-concrete element and the effect of reinforced concrete. The physical essence is the discontinuity of concrete and solid reinforcement, where there are reactions between the reinforcement and concrete in the form of relative deformations of the reinforcement $\varepsilon_S = \varepsilon_{S,j} - \varepsilon_э$, adhesion ΔT, the stress $\sigma_{bt,c}$ of compressed concrete, the pliability of structural mechanics and other parameters. The resistance of the tensile concrete in the transversal-isotropic medium is transferred to the working reinforcement through the general parameter (ψ_s or $\psi_{s,sw}$ by Prof. V.I. Murashev. The average longitudinal force N_{sm} and transverse force $Q_{s,m}$ are related using a special third object, the "total average force of the working reinforcement". Models of the second level of structural mechanics have been developed for a rebar with two pinched ends at cantilever rotations as well as crack opening $a_{crc,s}$, shear of crack banks Δ_{crc}. The longitudinal axis of the rebar is sinusoidal when moved with a maximum amplitude of $0.5a_{crc}$ and $0.5\Delta_{crc}$. The unknown X_2, X_3, $X_{3,t}$, X_4, X_5 quantities are determined from the calculation of statically indeterminate systems by the method of forces from coupled systems of equations. The main vector of reinforcement displacement in the crack is characterized by two values ugi, υgi in orthogonal directions and the angle β . Distances between cracks l_{crc}, resistance parameter of tensile concrete ψ_s and crack opening width a_{crc} use the effect of discontinuity of concrete from Thomas-author hypothesis, where the relative mutual displacements of reinforcement and concrete are found from the equilibrium of the cut reinforcement bar and the homogeneous differential equation with boundary conditions. The perimeter, diameter and area of the reinforcement, B_i, $1/K$, ΔT, $\sigma_{bt,c}$, modulus of elasticity and shear of concrete, reinforcement factor, boundary linear deformations of concrete, several levels, etc. are used for this purpose.

● Classification of main cracks has the form:

- regular cracks of Prof. N.I. Karpenko (anisotropic medium of reinforced concrete, without the effect of reinforced concrete and the width of "opening - closing");
- the author's main cracks on the basis of the effect of reinforced concrete discontinuity;
- base cracks for geometric (undercutting), force and inter-medium concentration, as well as external and internal displacements.

Consider the first - third types of cracks for the bending moment, torsional moment and shear force area. The fourth type is obtained in the development of cracks from the fracture mechanics condition $d\zeta_{bu} / dh_{crc} = 0$, the fifth type - cracks from compressed concrete, the sixth type - cracks from anchoring ($l_x / l_{an} = m_{az3}$).

The calculated models of resistance of reinforced concrete for their analysis of rod, plane and spatial cracks have been developed. The Lagrange function $F_i = f\left(q_{sw}, x_B, \sigma_s, x, \sigma_c, \sigma_{s,1}, \sigma_{c,1}, C_2, \lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6, \lambda_7\right)$ is used for the maximum crack opening width in the closed equations of reinforced concrete mechanics.

The author proposed new hypotheses and theorems:

The first of these is about the distribution of linear deformations and for the deplanation of the cross-section of a reinforced concrete element.

The second hypothesis about the distribution of total relative deformations of concrete and reinforcement shear ($\gamma_{sum,b}$ and $\gamma_{sum,s}$) for the deplanation of the cross-section of a reinforced concrete element.

● Analytical functionals are developed when solving the system of the proposed complex functions from the families of the mesh method in the compressed and stretched zones using small squares. The first functional $f_{5,*}(y,z)$ is a function of two functions along the y-axis and z-axis. The second functional $f_{***}(x,z,y)$ is a function of three functions on the x-axis, z-axis, and y-axis. The bending and torsional moments are determined using the third undefined functional $f_{\varepsilon,\mathrm{int,vol}}(x,y,z)$ as well as the fourth undefined functional $f_{5,**,\iint}(z,y)$.

● Stiffness hypothesis allowed for reinforced concrete by an order of magnitude reduced differential equations of composite structures by A.R. Rzhanitsyn. The stiffness matrix of rectangular cross-sections uses static equations (equilibria), geometric equations (deformations) and physical equations.

2. The method of computational model of resistance for structural mechanics, - result II:

● Analysis of the first model (rod with main normal cracks) and the second model (main inclined cracks between the links of reinforcement and concrete blocks) was performed. The third model of resistance has diagonal and other cracks for pliable units as opposed to rigid units from structural mechanics. The fourth model is a wall with mainline oblique cracks, and model 4a is a slab with mainline "envelope" cracks. Model 5 (5a under the action of torsion with bending and transverse force) uses volumetric spatial blocks.

● The general solution of the Krylov-Vlasov function equation is a system of a linear combination of four functions, for the general solution of a differential equation.

● The basic solutions in the boundary parameters for compressed-bent and stretched-bent prismatic rods (frames with rigid units) are defined by means of active and passive parameters.

● Applying the initial parameter method for a compressed-curved axis is a general solution of the differential equation for external (a_{crc}, φ_i, Θ_i) and internal (Δ_1, Δ_2, φ_1, φ_2, $\Delta\varphi_{crc}$) displacements.

● The method of initial parameters for displacements allows us to obtain, in the i-th cross section, the deformations and angles of rotation under the action of bending moment and transverse force on the deformable base from a given unit module of the force vector ql (deformation qd) impact of external forces in the form of an equation $\Phi_k\left[y_1, \varphi_1, M_1, Q_1, M_{n+1}, y_i, q_l(q_d)\right]=0$.

● Experimental research for structures, buildings and constructions is important. New technologies are used: glue "Cyacrine" (cyanocrylate), sensors, punches for the inside of the working armature, installation for determining displacements.

3. Hybrid calculations in the software package and by means of the finite element method, - result III for internal and external displacements $S_i, \Delta_1, \Delta_2, \Delta_3, \delta\Delta_{crc}, \varphi_1, \varphi_2, \varphi_{crc}$

4. The general principle from A.F. Loleit's works to "opening - closing" of cracks in working reinforcement and stiffness of reinforced concrete structures taking into account development of mechanics of reinforced concrete (MRMS method), - result IV. The economical consumption of material (steel) in beams (ξ=0,3-0,4; μ=1%-2%), in slabs (ξ=0,10-0,15; μ=0,3%-0,6%), in columns (ξ=0,4; μ= up to 3,0%) is obtained. If $a_m > a_R$, then increase the cross-section of elements $b\,x\,h_0$ and the form of cross-section; increase the class of concrete from B to B100; introduce reinforcement of compressed concrete A_s'.

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Kolchunov Vladimir Ivanovich, Southwestern state university, Kursk, Russia, corresponding member of the Russian Academy of Architecture and Construction Sciences, doctor of Technical Sciences, Professor of the Department of Unique Buildings and Structures. E-mail: vlik52@mail.ru

Колчунов Владимир Иванович, ФГБОУ ВО «Юго-Западный государственный университет», г. Курск, Россия, член-корреспондент РААСН, доктор технических наук, профессор кафедры уникальных зданий и сооружений. E-mail: vlik52@mail.ru