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The modeling method of discrete cracks and rigidity in reinforced concrete

V.I. Kolchunov*, A.I. Dem'yanov,
Southwest State University, Kursk, Russia.
** E-mail: vlik52@mail.ru*

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Abstract. Cracks can be quite critical for the safety of architectural structures so their investigation is crucial. Excessive crack opening in reinforced concrete structures leads to corrosion of the reinforcement, which significantly reduces their serviceability. An extraordinary problem on the width of crack opening was considered for RC (reinforced concrete) elements under the affects of bending and torsion. Its solution was proposed on the basis of RC theory involving the hypotheses of fracture mechanics. The initial hypotheses about the formation and disclosure of spatial cracks for multilayer RC structures were formulated. These proposals allowed assessing the resistance of concrete in tension and the distance between the cracks, as well as the width of its disclosure. Hence, specific features of a double-cantilever element adjacent to spatial cracks were investigated with both mathematical calculations and experimental studies. The results demonstrated that developed new technique can be used for estimating the width of the spatial cracks for RC elements under the affects of bending and torsion.

1. *Introduction*

Excessive crack opening in reinforced concrete structures leads to corrosion of the reinforcement, which significantly reduces their serviceability. In addition, the resulting cracks significantly reduce the stiffness of reinforced concrete structures [1–8]. Nevertheless, despite the obvious and urgent need, a calculation model for a satisfactory assessment of the width of crack opening in reinforced concrete has not yet been developed [9–22], it is not very significant for the experiment and in some cases reaches more than 100%. Thus, this task is extraordinary. In this case, parameters, such as the distance between the cracks and resistance of the concrete in tension between the cracks, currently are not amenable to theoretical description. So the first of them changes discretely as the load increases, an extraordinary change of the second clearly requires the opening of some unknown up to the present time to a wide range of domestic and foreign researchers of the effect arising in the process of resistance to reinforced concrete.

The processes of the development and opening of cracks in elements of reinforced concrete structures are a rather complicated phenomenon, for the phenomenological description of which it is necessary to involve a number of hypotheses about the joint work of two materials. Its analysis becomes more complicated by the fact that the main hypothesis of the mechanics of a solid deformable body (the continuity hypothesis) is not applicable here – the integrity is broken with the formation of macro cracks. The use of simplified approaches is also impossible here, since the inaccuracy allowed in this case exceeds the value of the characteristic a_{crc}, measured in experiments using a microscope.

The problem is further complicated by the fact that along with regular cracks in reinforced concrete there are discrete cracks with different criteria for their formation and development [2, 4, 18–21]. Here, the main role is played by the concentration of deformations in places of abrupt changes in geometric dimensions, zones of concentration of force and deformation loading, inter-media concentration. However, to this day, a technique for modeling discrete cracks, including the use of modern computer systems known in the world, has not been developed. Therefore, to date, the task has not been satisfactorily solved.

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2. Methods

In order to fill the existing gap in reinforced concrete, the following is the essence of the proposed method for calculating the crack opening width taking into account the effect of discontinuity, incompatibility of deformations of concrete and reinforcement in conditions of complex torsional resistance with bending. At the same time, it was experimentally revealed that the crack has a complex profile, and not a triangular one, as it happens in the kinematic scheme of deformation. The laws of crack formation have been studied (it has been established that there are several of these levels, not just one, as is customary in the theory of V.I. Murashev). introduced a new classification of basic spatial cracks.

It should be noted that the designated research occurs Dilemm 1-alignment values experienced and theoretical parameters. It is important to emphasize the fact that in the development of methods and testing, as a rule, the installation of electrical strain gauges is performed before loading the reinforced concrete structure. In this case, already at the initial loading steps, the formed cracks intersect most of the installed electrical strain gauges and, thus, destroy them. With the advent of the relatively new glue «Cyacrine», the installation of electrical strain gauges can be performed after the formation of macrocracks, in which case it work until the stage of destruction. In this case, the possibility of their installation directly on the banks of the crack appears. The «trap» scheme is also new, which allows to obtain of information about the deformed state of concrete in the vicinity of the crack tip [5–9].

To be fair, it should be noted that, as applied to integral parameters, for example, deflections, the theory of reinforced concrete using the model of averaged section gives quite satisfactory results when comparing experimental and theoretical values. However, considering such a differential parameter as the width of crack opening, this is not observed, the differences can reach 400 % or more.

At first glance, it would seem, everything is clear and simple – the width of the a_{crc} crack opening determines the difference between the deformations of reinforcement and concrete in the area between the cracks:

$$a_{crc} = (\varepsilon_{S,m} - \varepsilon_{bt,m}) \cdot l_{crc} \approx \varepsilon_S \cdot \psi_S \cdot l_{crc}. \quad (1)$$

However, the parameters included in this formula l_{crc} (the distance between the cracks) and ψ_s (the factor of accounting for the work of stretched concrete between the cracks) turned out to be very problematic in their experimental determination.

When solving the designated problem occurs Dilemm 2: either to re-develop the mechanics of reinforced concrete, which will take more than one decade, or rely on the existing provisions of fracture mechanics, which has been developing for a whole century and is studying the stress-strain state in the vicinity of cracks. It is clear that the second way is much more logical. here fore, today, the main focus of scientific research by the authors was to develop two-console elements of fracture mechanics in relation to reinforced concrete, including a crack, so that later using them to build models of reinforced concrete deformation based on hypotheses and fine tools of fracture mechanics.

Discovery of the discontinuity effect [5-9] allowed to reach a completely different level of development of two-console elements for reinforced concrete [2, 4, 6, 7]. The laws of crack formation were studied (it was established that there are several of these levels, and not one, as is customary in the theory of V.I. Murashev [6]). It was established experimentally that the crack has a complex profile, and not a triangular one, as it happens in the kinematic deformation scheme; studied the patterns of deformation in the layers adjacent to the seam between the concrete.

Continuing these studies [1, 4–6], we will proceed from the functional of fracture mechanics, which relates the rate of energy ζ_{bu} release during the formation of new specific surfaces of a spatial crack in the pre-fracture zone:

$$\zeta_{bu} = \lim_{\delta A \to 0} \left(\frac{\delta W - \delta V}{\delta A} \right) = \frac{dW}{dA} - \frac{dV}{dA}. \quad (2)$$

where δV is decrease in the potential energy of the body during crack propagation by a small increment δA;

δW is additional work done on the body as the crack advances by a small increment δA.

At the same time, the reduction of the potential energy of the body during crack propagation and the additional work accomplished in this case can be expressed through the flexibility of the crack faces by cutting out the double-cantilever element (DCE) including the crack. This approach allows preserving the physical meaning of the dependencies obtained, unlike using the Gursa function with complex numbers [3, 4, 6, 7].

Below are the main provisions on the development of a universal double-cantilever element, suitable also for solving the problem of resistance of reinforced concrete structures in torsion with bending.

First, if the DCE is allocated for a long double-cantilever element (completely including the entire crack), the crack length is determined from the condition of fracture mechanics:

$$\frac{d\zeta_{bu}}{dh_{crc}} = 0. \tag{3}$$

For a short DCE, the length is known structural considerations (it stands out at half the length of the zone adjacent to the crack located between the working reinforcing bars. In this case, the condition $\frac{\partial\zeta_{bu}}{\partial h_{crc}} = 0$ (of which is the length of the crack) is replaced by the condition for finding the projection of the spatial crack C, using Lagrange function and multipliers λ_1 for many variables. Then, from the condition of extremum of a function of several variables $F_{1,2} = f\left(q_{sw}, x_B, \sigma_s, x, \sigma_b, \sigma_{s,I}, \sigma_{b,1}, C_2, \ldots \lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6, \lambda_7, \ldots\right)$, and the equalities resulting from it to zero of the corresponding partial derivatives:

$$\left.\begin{array}{l}
\frac{\partial f}{\partial x_1} + \lambda_1 \frac{\partial \varphi_1}{\partial x_1} + \lambda_2 \frac{\partial \varphi_2}{\partial x_1} + \ldots + \lambda_m \frac{\partial \varphi_m}{\partial x_1} = 0 \\
\frac{\partial f}{\partial x_2} + \lambda_1 \frac{\partial \varphi_1}{\partial x_2} + \lambda_2 \frac{\partial \varphi_2}{\partial x_2} + \ldots + \lambda_m \frac{\partial \varphi_m}{\partial x_2} = 0 \\
\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
\frac{\partial f}{\partial x_n} + \lambda_1 \frac{\partial \varphi_1}{\partial x_n} + \lambda_2 \frac{\partial \varphi_2}{\partial x_n} + \ldots + \lambda_m \frac{\partial \varphi_m}{\partial x_n} = 0
\end{array}\right\} \tag{4}$$

the projection of the spatial crack C is found and the region of the cutted DCE is specified.

Secondly, the efforts in the sections, passing at a distance t and *Δb* for a double-cantilever element from a crack, it is necessary to associate with the desired parameters of the mode of deformation of the reinforced concrete element.

Thirdly, we should not forget about the virtual movements of the dedicated DCE consoles when the neutral axis of the reinforced concrete element is rotated and the angles of rotation of the working reinforcing bar caused by arcing, i.e., the clamping of the consoles on both sides of the DCE may not be completely rigid in some cases.

Thus, the selection of DCE for reinforced concrete (which is transformational between the dependencies of fracture mechanics and the theory of reinforced concrete) is a very important, but not an easy task. It should be linked not only with the task of determining the stress-strain state of the cross section of a reinforced concrete element, but also with the task of distributing adhesion between reinforcement and concrete, since the appearance of a crack in a solid body can be viewed as a certain deformation effect, which is reflected in the adhesion characteristics of reinforcement and concrete in zones adjacent to the crack.

3. Results and Discussion

With respect to the double-cantilever element, which is under the influence of a number of efforts, (ΔT, P_1, P_2, q, M_{con}), the functional of fracture mechanics (2) takes the form:

$$\zeta_{bu} = \frac{1}{3} \cdot \sum_{i=1}^{n} \left(\frac{P_i^2 \cdot \delta C_i}{\delta A} - C_i P_i \frac{\delta P_i}{\delta A} \right). \tag{5}$$

Displacements in any sections are determined by building mechanics methods.

Performing term-by-term differentiation, after algebraic transformations, we obtain the dependence connecting the tangential force ΔT arising in the immediate vicinity of the crack with the length of its development h_{crc} through the concrete constant ζ_{bu}.

Such a relationship allows us to find the tangential stresses in the zone directly adjacent to the crack. It is here, as shown by experimental and numerical studies, that a sharp perturbation of shear stresses occurs, accompanied by their abrupt increase and change of sign. At the same time, the sign and the normal stresses in the concrete change (from the tensile it turns into compressive), which is also confirmed experimentally [4, 7, 8].

In the case of using a short double-cantilever unit, when h_{crc} is known, the parameters $X_1 = \Delta T$, $X_2 = P_{bt,c}, \dots, X_n$ can be determined using conventional methods of structural mechanics [4, 7, 8].

A new classification of discrete basic spatial cracks in reinforced concrete structures (including compound ones) is given in [4]. It distinguishes between geometric, force (deformation), inter-media concentration for basic discrete cracks, and a method is proposed for finding adjacent cracks. Additionally, the cracks are divided into three types depending on the conditions of their formation and the intersection of the working reinforcement during their development.

The method of calculating reinforced concrete composite structures for the formation, development and disclosure of spatial cracks (with the ability to estimate the resistance of stretched concrete between cracks, the width of their disclosure and the distance between them) is based on the following working premises:

- for medium deformations of concrete and reinforcement, the hypothesis of flat sections is considered to be valid (in the case of a composite structure, within each of the rods included in the composite rod); stresses in concrete and reinforcement are determined using three- and bilinear bond diagrams σ–ε, respectively;

- the formation of spatial cracks occurs after the main deformations of the elongation of concrete reach their limiting values $\varepsilon_{bt,u}$; in the process of loading several levels of crack formation are distinguished; the distance between the cracks of the next level is within the distance between the cracks of the previous level, dividing it through the parameter η;

- introduced a classification of discrete basic spatial cracks in reinforced concrete (including composite) structures;

- the connection between the adhesion stress τ and relative conditional mutual displacement of the two concrete $\varepsilon_{q,b}$ and concrete and reinforcement $\varepsilon_g(x)$ is taken in the form: $\tau(x) = G(\lambda)\varepsilon_g(x)$, where $G(\lambda)$ – equivalent modulus of deformation of adhesion between concrete (or reinforcement and concrete)

- additional deformation effect in the crack and change of its profile are considered, which are associated with the violation of material integrity;

- crack opening is the accumulation of relative conditional mutual displacements of reinforcement and concrete in areas located on both sides of the crack, taking into account the features caused by the effect of discontinuity (Figure 1), – the upgraded Thomas hypothesis;

- takes into account distortion of normals to the cross section of concrete element in a location with a crack depending on the distance from the contact surface with reinforcement to the surface of the structure.

From Figure 1 it follows that the relative mutual displacements of reinforcement and concrete are determined from the dependence:

$$\varepsilon_g(y) = \varepsilon_s(y) - \varepsilon_{bt}(y), \tag{6}$$

where $\varepsilon_s(y)$ and $\varepsilon_{bt}(y)$ are relative deformations of reinforcement and relative deformations of concrete in section x, respectively.

Then, after differentiation, the solution of a nonhomogeneous differential equation of the first order is:

$$\varepsilon_g(y) = \left(\varepsilon_{sw} + \frac{\Delta T}{E_{sw}A_{sw}} - \frac{\sigma_{bt,c}}{\nu_b E_b} - \frac{D_{14}}{D_{13} \cdot B}\right) e^{-\mathrm{B}y} - \frac{D_{14}}{D_{13} \cdot B}. \tag{7}$$

The distance between the cracks l_{crc} is determined using the second prerequisite:

$$l_{crc} = \frac{2(\ln B_4 - Bt_*)}{-B}. \tag{8}$$

Variables $D_{i,j}$, B, B', B'_4, entering into formulas (7) and (8), are functions of boundary deformations of concrete elongation, parameters that take into account the effect of concrete discontinuity (ΔT, $P_{bt,c}$), geometric characteristics and characteristics of reinforcement and concrete adhesion [4];

The emergence of a new level of cracking corresponds to the fulfillment of inequality:

$$l_{crc,i} \le \eta l_{crc,i-1}, \tag{9}$$

where η – the ratio of the distances between the cracks when it is divided at the subsequent level. Having the parameters $\varepsilon_g(y)$ and $\varepsilon_{bt}(y)$ it is easy to write the parameter $\varepsilon_s(y)$.

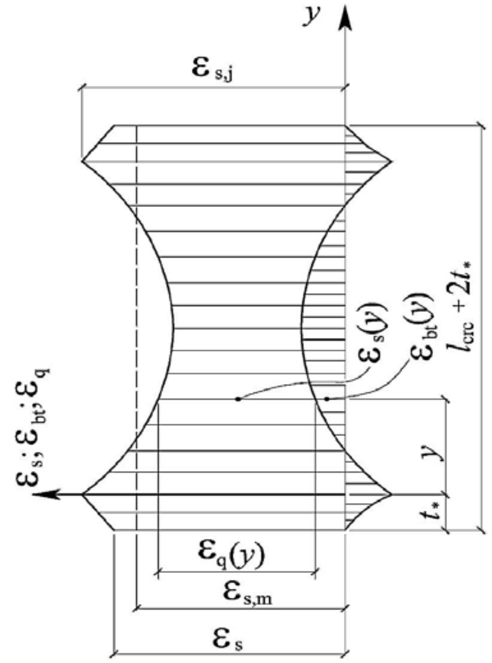

Figure 1. Diagrams of concrete deformations $\varepsilon_{bt}(y)$, reinforce $\varepsilon_s(y)$ and their relative mutual displacements $\varepsilon_g(y)$ in the area between spatial cracks in reinforced concrete structures in torsion with bending

Integration $\varepsilon_s(y)$ within the distance between the cracks l_{crc} allows to obtain the value of the coefficient of the work of the stretched concrete ψ_s by the formula:

$$\psi_S = \frac{2\cdot K\cdot B_3}{\varepsilon_S\cdot l_{crc}\cdot B}\cdot\left[1-e^{-B\cdot(0.5l_{crc}-t_*)}\right]+\frac{2}{\varepsilon_S\cdot l_{crc}}\left(\varepsilon_S+\frac{\Delta T}{E_S A_S}-K\cdot B_3\right)\cdot\left(0,5l_{crc}-t_*\right)+$$
$$+\frac{\delta Q\cdot K}{\varepsilon_S\cdot l_{crc}\cdot B\cdot t_*}\left(0,5l_{crc}-t_*\right)^2+\frac{2\cdot\varepsilon_S\cdot E_S\cdot A_S+\Delta T}{\varepsilon_S\cdot l_{crc}\cdot E_S\cdot A_S}\cdot t_*. \tag{10}$$

Thereafter, in accordance with the sixth prerequisite, the task, by definition a_{crc}, is reduced to finding the relative mutual displacements $\varepsilon_g(y)$ of reinforcement and concrete in different areas between cracks:

$$a_{crc} = 2\int_0^{t_*}\varepsilon_g(y_1)dy_1+\int_{t_*}^{\eta\cdot l_{crc}}\varepsilon_g(y)dy+\int_{\eta\cdot l_{crc}}^{l_{crc}-t_*}\varepsilon_g(y)dy. \tag{11}$$

After integration and algebraic transformations, we obtain:

$$\lambda_3 = -\frac{k_1}{(k_2-1)C_2^{\,2}-C_2}. \tag{12}$$

When performing practical calculations, one should take into account distortion of normals to the cross section of concrete element depending on the distance of the reinforcement surface to the concrete surface. For this purpose, a cantilever design scheme is used to determine the movements of the crack faces, selected in the zone of the protective layer [6, 7]. Displacements in the zone of the protective layer $y_{pr,1}$ are determined using the method of initial parameters.

In turn, the processing of such data allows to obtain the following dependence:

$$2f_R = \frac{2\cdot 0,0163\cdot 100\cdot\sigma_S\cdot\left(1-e^{-0,516\cdot r}\right)\cdot 10}{100\cdot R_S}. \tag{13}$$

Here the values σs and Rs are accepted in kN/cm^2, and value f_R in mm.

The ratio of the calculated displacement in the zone of the protective layer $y_{pr,1}$ to the experimental displacements in the zone f_R under consideration shows that if the value of the protective layer differs from the baseline (assumed to be equal to the diameter of the working reinforcement), then before accumulating a sufficient amount of experimental data and carrying out a comparative analysis, it is accepted to include the coefficient $k_{r,dep}$:

$$k_{r,dep} = \frac{y_{\text{pr},1}}{f_R}. \quad (14)$$

Taking into account the noted, the width of the crack opening at the level of the protective layer will be found by the formula:

$$a_{crc,tot} = a_{crc,S} + 2 \cdot \frac{y_{\text{pr},1}}{k_{r,dep}}. \quad (15)$$

Here $a_{crc,s}$ is determined by the formulas obtained with the base value of the protective layer.

The solution of an extraordinary problem of the width of crack opening in reinforced concrete at the modern level of evolution of the theory of reinforced concrete with the involvement of fracture mechanics hypotheses is proposed. Simplified dependences are constructed for the energy functional and the specifics and features of the construction of the double-cantilever element of fracture mechanics in the zones adjacent to spatial cracks are considered, taking into account the discontinuity effect. The dual console element is a link and serves as a transformational element between the dependencies of fracture mechanics and the equations of the theory of reinforced concrete. The developed method makes it possible to estimate the resistances of reinforced concrete structures under various force and deformation effects, including torsion with bending.

4. Conclusions

1. As a result of scientific research, it has been established that the main hypothesis of the mechanics of a solid deformable body (continuity hypothesis) is not applicable when evaluating the resistance of reinforced concrete structures – continuity is broken with the formation of macro-cracks. The use of simplified approaches is also impossible here, since the error allowed in this case exceeds the value of the most sought a_{crc}, characteristic measured in experiments with a microscope. Therefore, to date, the task has not been satisfactorily solved.

2. When conducting research, there are several designated priority dilemms, Dilemm 1-alignment values experienced and theoretical parameters. Dilemm 2: either to re-develop the mechanics of reinforced concrete, which will take more than one decade, or rely on the existing provisions of fracture mechanics, which has been developing for a whole century and is studying the stress-strain state in the vicinity of cracks. It is important to emphasize the fact that in the development of methods and testing, as a rule, the installation of electrical strain gauges is performed before loading the reinforced concrete structure. In this case, already at the initial loading steps, the formed cracks intersect most of the installed electrical strain gauges and, thus, destroy them. With the advent of the relatively new glue "Cyacrine", the installation of electrical strain gauges can be performed after the formation of macrocracks, in which case it works until the stage of destruction. In this case, the possibility of their installation directly on the banks of the crack appears. The «trap» scheme is also new, which allows to obtain of information about the deformed state of concrete in the vicinity of the crack tip

3. It has been established that, as applied to integral parameters for assessing the strength and deflection of reinforced concrete spatial structures, the use of the average section model yields quite satisfactory results when comparing experimental and theoretical values. However, considering such a differential parameter as the width of crack opening, this is not observed, the differences can reach 400 % or more.

4. The discovery of the discontinuity effect allowed us to reach a completely different level of development of double-cantilever elements for reinforced concrete. It was experimentally revealed that the crack has a complex profile, and not a triangular one, as it happens in the kinematic deformation scheme. The laws of crack formation have been studied (it has been established that there are several levels, not one, as is customary in the theory of V.I. Murashev).

5. It has been established that the decrease in the potential energy of the body during the crack propagation and the additional work accomplished in this case can be expressed in terms of the flexibility of the crack faces by cutting out the double-cantilever element (DCE), including the crack. In this case, displacements in any sections are determined by methods of structural mechanics.

This approach allows us to preserve the physical meaning of the dependencies obtained, in contrast to the use of the Goursat function with complex numbers.

6. As applied to a cut-out double-cantilever element under the influence of a number of forces ΔT, P_1, P_2 , q, M_{con} , etc.), the functional of fracture mechanics takes on the form suitable for solving the problem of resistance of reinforced concrete structures under torsion with bending. A number of dependencies follow from it, including the connecting tangential force ΔT arising in the immediate vicinity of a crack with the length of its development through a concrete constant ζ_{bu} .

7. Isolation of DCE for reinforced concrete (which is transformational between the dependencies of fracture mechanics and the theory of reinforced concrete) is a very important but difficult task.

First, it must be linked not only with the task of determining the stress-strain state of the cross section of a reinforced concrete element, but also with the task of distributing adhesion between the reinforcement and the concrete, since the appearance of a crack in a solid body can be viewed as a certain deformation effect affecting the features adhesion of reinforcement and concrete in areas adjacent to the crack. It is also important to determine the length of the crack h_{crc}.

Secondly, the efforts in sections that pass at a distance of t и Δb for the double-cantilever element from the crack must be associated with the desired parameters of the stress-strain state of the reinforced concrete element.

Thirdly, we should not forget about the virtual movements of the dedicated DCE consoles when the neutral axis of the reinforced concrete element is rotated and the angles of rotation of the working reinforcing bar caused by arcing, i.e., the clamping of the consoles on both sides of the DCE may not be completely rigid in some cases.

8. Finding the projection of a spatial crack C is advisable to perform using the Lagrange function and multipliers for many variables. Then, from the condition of extremum of a function of several variables $F_{1,2} = f\left(q_{sw}, x_B, \sigma_s, x, \sigma_b, \sigma_{s,I}, \sigma_{b,1}, C_2, \ldots \lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6, \lambda_7, \ldots\right)$, and the equalities resulting from it to zero of the corresponding partial derivatives, the projection of the spatial crack C is sought and the region of the cut DCE specified.

9. The initial hypotheses to calculating reinforced concrete structures, including multilayer, to the formation, development and disclosure of spatial cracks are formulated. These proposals allow to assess the resistance of concrete in tension and the distance between the cracks, the width of its disclosure. This takes into account the additional deformation effect in the crack and the change in its profile associated with the violation of the material continuity. It also takes into account t distortion of normals to the cross section of concrete element in a location with a crack, that depends on the distance from the contact surface with the reinforcement to the external surface of the structure.

10. A new classification of discrete basic spatial cracks in reinforced concrete structures (including composite ones) is introduced, in which geometric, force (deformation), inter-media concentrations for basic discrete cracks are distinguished and a technique is proposed for finding adjacent cracks; Additional cracks are divided into three types depending on the conditions of their formation and the intersection of the working reinforcement during their development.

An extraordinary problem on the width of crack opening in reinforced concrete is considered and its solution is proposed at the modern level of evolution of reinforced concrete theory involving the hypotheses of fracture mechanics. Formulated are working prerequisites for building a methodology for calculating reinforced concrete structures, including compound ones, by education, development and disclosure of spatial cracks (with the possibility of estimating the resistance of concrete in tension and the distance between cracks, the width of their opening). This takes into account the additional deformation effect in the crack and the change in its profile associated with the violation of the integrity of the material; It also takes into account distortion of normals to the cross section of concrete element in a location with a crack, depending on the distance from the contact surface with the reinforcement to the surface of the structure.

The discovery of the discontinuity effect made it possible to reach a completely different level of development of double-cantilever elements for reinforced concrete. Specific features and features of the construction of a double-cantilever element of fracture mechanics in the zones adjacent to spatial cracks with regard to the effect of discontinuity are considered.

The dual console element is a link and serves as a transformational element between the dependencies of fracture mechanics and the equations of the theory of reinforced concrete. The developed method makes it possible to estimate the resistances of reinforced concrete structures under various force and deformation effects, including torsion with bending.

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Contacts:

Vladimir Kolchunov, +79103154850; vlik52@mail.ru

Alexey Dem'yanov, +74712222461; speccompany@gmail.com

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Неординарная задача о раскрытии трещин в железобетоне

В.И. Колчунов*, А.И. Демьянов,
Юго-Западный государственный университет, г. Курск, Россия
** E-mail: vlik52@mail.ru*

Ключевые слова: железобетонные конструкции, пространственные трещины, кручение с изгибом, двухконсольная модель, сопротивление растянутого бетона.

Аннотация. Рассмотрена неординарная задача о ширине раскрытия трещин в железобетоне и предложено ее решение на современном уровне эволюции теории железобетона с привлечением гипотез механики разрушения. Сформулированы рабочие предпосылки для построения методики расчета железобетонных конструкций, в том числе составных, по образованию, развитию и раскрытию пространственных трещин (с возможностью оценки сопротивления растянутого бетона и расстояния между трещинами, ширины их раскрытия). При этом учитывается дополнительное деформационное воздействие в трещине и изменение ее профиля, связанные с нарушением сплошности материала; также учитывается депланация бетона в сечении с трещиной в зависимости от расстояния от поверхности контакта с арматурой до поверхности конструкции. Открытие эффекта нарушения сплошности позволило выйти на совершенно иной уровень разработки двухконсольных элементов для железобетона. Тем не менее, до сегодняшнего дня методика моделирования дискретных трещин, в том числе с использованием известных в мире современных вычислительных комплексов не разработана, что не дает возможности эффективного (без излишних запасов) расчета и проектирования железобетонных конструкций в условиях сложного сопротивления – кручения с изгибом с обеспечением необходимой жесткости и антикоррозионной стойкости. Рассмотрены специфика и особенности построения двухконсольного элемента механики разрушения в зонах, прилегающих к пространственным трещинам с учетом эффекта нарушения сплошности. Двухконсольный элемент является связующим звеном и служит в качестве трансформационного элемента между зависимостями механики разрушения и уравнениями теории железобетона. Разработанная методика позволяет оценивать сопротивления железобетонных конструкций в условиях различных силовых и деформационных воздействий, в том числе при кручении с изгибом.

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Контактные данные:

Владимир Иванович Колчунов, +79103154850; эл. почта: vlik52@mail.ru
Алексей Иванович Демьянов, +74712222461; эл. почта: speccompany@gmail.com