ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫНЫҢ
Қ. И. Сәтпаев атындағы Қазақ ұлттық техникалық зерттеу университеті

Х А Б А Р Л А Р Ы

ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Казахский национальный исследовательский
технический университет им. К. И. Сатпаева

N E W S

OF THE ACADEMY OF SCIENCES
OF THE REPUBLIC OF KAZAKHSTAN
Kazakh national research technical university
named after K. I. Satpayev

ГЕОЛОГИЯ ЖӘНЕ ТЕХНИКАЛЫҚ ҒЫЛЫМДАР СЕРИЯСЫ

♦

СЕРИЯ ГЕОЛОГИИ И ТЕХНИЧЕСКИХ НАУК

♦

SERIES OF GEOLOGY AND TECHNICAL SCIENCES

2 (428)

НАУРЫЗ – СӘУІР 2018 ж.
МАРТ – АПРЕЛЬ 2018 г.
MARCH – APRIL 2018

ЖУРНАЛ 1940 ЖЫЛДАН ШЫҒА БАСТАҒАН
ЖУРНАЛ ИЗДАЕТСЯ С 1940 г.
THE JOURNAL WAS FOUNDED IN 1940.

ЖЫЛЫНА 6 РЕТ ШЫҒАДЫ
ВЫХОДИТ 6 РАЗ В ГОД
PUBLISHED 6 TIMES A YEAR

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Қазақстан Республикасы Ұлттық ғылым академиясы "ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы" ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

«ҚР ҰҒА Хабарлары. Геология мен техникалық ғылымдар сериясы».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Меншіктенуші: «Қазақстан Республикасының Ұлттық ғылым академиясы» РҚБ (Алматы қ.).
Қазақстан республикасының Мәдениет пен ақпарат министрлігінің Ақпарат және мұрағат комитетінде 30.04.2010 ж. берілген **№10892-Ж** мерзімдік басылым тіркеуіне қойылу туралы куәлік.

Мерзімділігі: жылына 6 рет.
Тиражы: 300 дана.

Редакцияның мекенжайы: 050010, Алматы қ., Шевченко көш., 28, 219 бөл., 220, тел.: 272-13-19, 272-13-18, http://nauka-nanrk.kz /geology-technical.kz

Редакцияның мекенжайы: Қазақстан, 050010, Алматы қ., Қабанбай батыра көш., 69а.
Қ. И. Сәтбаев атындағы геология ғылымдар институты, 334 бөлме. Тел.: 291-59-38.

Типографияның мекенжайы: «Аруна» ЖК, Алматы қ., Муратбаева көш., 75.

«Известия НАН РК. Серия геологии и технических наук».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Собственник: Республиканское общественное объединение «Национальная академия наук Республики Казахстан (г. Алматы)

Свидетельство о постановке на учет периодического печатного издания в Комитете информации и архивов Министерства культуры и информации Республики Казахстан **№10892-Ж,** выданное 30.04.2010 г.

Периодичность: 6 раз в год
Тираж: 300 экземпляров

Адрес редакции: 050010, г. Алматы, ул. Шевченко, 28, ком. 219, 220, тел.: 272-13-19, 272-13-18, http://nauka-nanrk.kz /geology-technical.kz

Адрес редакции: Казахстан, 050010, г. Алматы, ул. Кабанбай батыра, 69а.
Институт геологических наук им. К. И. Сатпаева, комната 334. Тел.: 291-59-38.

Адрес типографии: ИП «Аруна», г. Алматы, ул. Муратбаева, 75

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Owner: RPA "National Academy of Sciences of the Republic of Kazakhstan" (Almaty)
The certificate of registration of a periodic printed publication in the Committee of information and archives of the Ministry of culture and information of the Republic of Kazakhstan N 10892-Ж, issued 30.04.2010

Periodicity: 6 times a year
Circulation: 300 copies

Editorial address: 28, Shevchenko str., of. 219, 220, Almaty, 050010, tel. 272-13-19, 272-13-18,
http://nauka-nanrk.kz/geology-technical.kz

Editorial address: Institute of Geological Sciences named after K.I. Satpayev
69a, Kabanbai batyr str., of. 334, Almaty, 050010, Kazakhstan, tel.: 291-59-38.

Address of printing house: ST "Aruna", 75, Muratbayev str, Almaty

N E W S
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224-5278
Volume 2, Number 428 (2018), 55 – 62

UDC 624.044.3:539.42:691.32

O. Dovzhenko, V. Pogrebnyi, I. Yurko

Poltava National Technical Yuri Kondratyuk University, Ukraine.
E-mail: o.o.dovzhenko@gmail.com, V.V.Pohribnyi@gmail.com, ilona.yurko@gmail.com

SHEAR FAILURE FORM REALIZATION IN CONCRETE

Abstract. The shear is considered as concrete and reinforced concrete elements failure form, which differ significantly in constructive solutions, load transfer schemes and stress-strain state on shear surface. Conditions and criterion for shear failure form realization in concrete are formulated. As conditions, it is assumed that plastic deformation is localized in thin layers on failure surface and that shear stresses τ_n are reached $\sqrt{2/3}$ from their maximum value. Criterion for shear realization in structurally inhomogeneous materials with different resistance to compression and tension is simultaneous limit state existence over entire shear surface. To determine shear realization boundary in concrete, concrete plate destruction process under axial compression is analyzed. «Shear – tear» failure transition region existence is substantiated. Lower concrete destruction boundary by shearing is located in mixed region stresses close to axial compression, and upper boundary is in uneven biaxial compression zone. Kinematic concrete elements destruction mechanism under shear is considered as limit macroscopic structure. Rigid-plastic body concept is used. Plastic deformation is thought to be concentrated in thin layers on fracture surface, and adjacent areas are considered as hard disks. Sufficiently general technique for calculating strength based on mathematical plasticity theory apparatus, variational method with virtual velocities principle application, discontinuous solutions, and upper ultimate load magnitude estimate is proposed. Externally brittle destruction character cannot serve as obstacle to plasticity theory application. As plastic potential, concrete strength condition in revolution paraboloid form is adopted, which has fairly simple notation in tensor form and experimental confirmation. Strength problems solution is to write down virtual velocity principle functional for corresponding kinematic fracture mechanism. Functional is investigated for an extremum, which is equivalent to boundary value problem solution. Stationary state achievement by functional corresponds to plastic deformation power minimum. As an example, solution is given to strength problem of bent fixed from one end concrete (reinforced concrete) plate, simulating keyed joints. Realized kinematic mechanism under shear opens fracture surface direction variation possibility by creating lateral compression, which practical interest is.

Key words: concrete, shear failure form, conditions, criterion, realization mechanism, calculation methods.

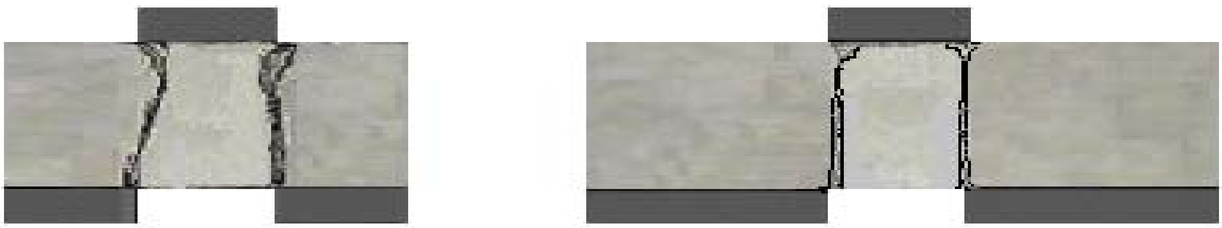
Introduction. Concrete and reinforced concrete elements working on shearing forces perception are widely used in practice, that predetermines necessary for their further study. They differ significantly in constructive solutions, load transfer schemes, and in shear zone stress-strain state specificity. At the present time, there is no sufficiently general method for calculating strength of such elements, makes it possible to take into account their features and determining factors influence. Its creation on basis of single theoretical basis is an actual task.

Work aim is to determine conditions, criterion and mechanism for realization shear in concrete to develop a general calculation technique based on deformed solid mechanics.

Research methods. The aim is achieved by analyzing shear phenomenon in concrete [1-4]. Fracture character and shear zone stress-strain state are considered. To solve deformable solid mechanics equations [5-7], which in general is complicated problem, simplifications number have been introduced [8, 9]. The shear strength is evaluated using the variational method [10], virtual velocities principle and discontinuous solution [8, 9], which allow us to obtain result corresponding to plastic deformation power minimum quite easily [8-11].

Results. *Concrete fracture forms.* Realizable in elastic-plastic materials, among which is concrete, fracture forms reflect macromechanical bodies behavior in limit state and exert determining influence on ultimate load magnitude [12]. They differ significantly and as destruction mechanisms components require use different theories, concepts and approaches to solving strength problems. Tearing, element parts move in direction perpendicular to destruction surface, remaining slightly deformed. For crushing plastic deformation zonal placement in destruction area is typically. Bodies behavior in shearing form has its own peculiarities, having investigated which it is possible to formulate conditions, determine mechanism and its realization boundaries, and develop calculation technique that takes into account shear specificity.

The shear as fracture form is characterized by one-part movement of element along other and for plastic bodies is an extension of observed visually directed intense deformation in shear zone (slip) [8, 11]. Plastic concrete properties are limited and depend on stress element state [12]. In biaxial compression, they are crucial, in mixed conditions stress states their influence is significantly reduced, and plasticity regions dimensions' decrease. Externally brittle avalanche shear fracture in a number of cases visually practically does not differ from fracture by tear (figure 1). At the same time, concrete intensity deformation that is fixed in experiments near fracture surface during shear and tear is fundamentally different.



a b

Figure 1 – Concrete beam fracture by shear (a) and tear (b)

Shear failure form boundaries. Shear boundary location depends on material's resistance to axial compression and tension, as well as its structural features.

Studies results analysis [1-4, 11, 13] indicates that shear occurs in plane-stressed concrete elements in biaxial uneven compression, uniaxial compression, and mixed stresses close to axial compression. For purpose of a shear phenomenon detailed study, it is advisable to consider elements behavior at boundary of its realization in transition area «shear – tear», where when comparing two forms, their differences and characteristic features are more clearly visible. The transition area includes destruction under uniaxial compression (figure 2, a, b), choice is also justified for investigation by presence experimental numerous materials [11, 13-15].

а б в

Figure 2 – Concrete destruction prisms by tear (a) and shear (b), plastic deformation localization on shear surface (c)

As is known, the shear failure form area is determined by real existence slip planes [8, 16]. For plastic materials, its boundaries are located in biaxial intervals compression and tension [8]. However, for concrete indicated area is not so wide.

Transition failure area «tear – shear». When concrete element is uniaxial compressed, its case fracture substantially depends on cement stone elastic crystalline and plastic gel ratio components. As first increases, concrete strength increases, and deformability decreases. In direction perpendicular to compression, structural tensile stresses arise around pores and voids, which concentration leads to microcracks appearance already at initial loading stages. At stresses exceeding their lower limit formation, microcracks develop moderately.

With achievement of crack formation upper boundary (boundary between moderate stage and intensive stage of cracks growth), process is undamped and breaks from tear [14, 15]. With gel (plastic) predominance component, bodies fracture mainly occurs by shear. Development possibility and plastic deformation localization is determined by difference between upper and lower microcracks formation boundaries. With increasing this difference, material plastic properties increase, shear failure form probability increases. In the case zones extension insignificant, local stresses decrease, plastic deformation concentration in thin layers on fracture surface occurs (Fig. 2, c) and shear is realized [11, 13].

Thus, under uniaxial compression, there is transition area of «shear – tear» failure. Tearing, there is great behavior instability and an increase in elements strength scatter. In this case, average maximum load value corresponds to load at shear. That is, strength evaluation based on shear failure form under uniaxial compression and throughout transition region is preferable.

Conditions for realization shear. One of mandatory conditions for shear realization in elastic-plastic materials is plastic deformation localization in thin layers on slip surfaces, which determines bodies destruction mechanism.

As plasticity condition, it is recommended to use Balandin-Geniev strength condition [16] (figure 3), which has satisfactory convergence with experimental data and simple record in tensor form.

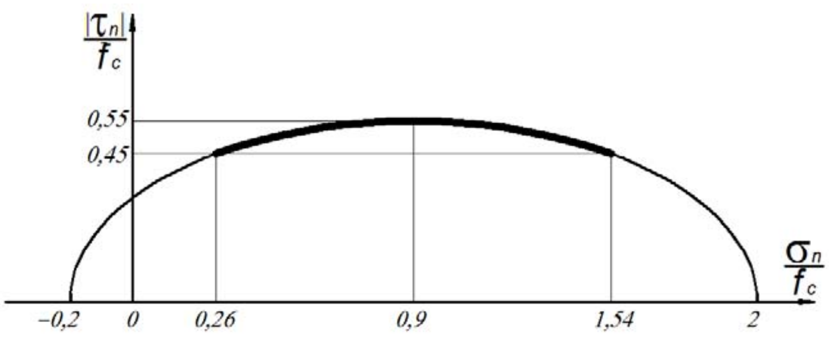


Figure 3 – Concrete strength condition at resistances ratio tension and compression

f_{ct} / f_c=0,1: ▬▬ – shear realization interval

Interval for concrete shear failure form realization is proposed to be points limited in which tangent angles ψ values to envelope of Mohr's circles (figure 3) correspond to their values for axial compression and tension of plastic materials. Specified limit defines ultimate stress level at shear areas.

Rigid-plastic body concept was adopted (figure 4).

Destruction mechanism and criterion for its use. To use plasticity theory, it is important to consider features of deformed solid development process limit state. This process leads to macroscopic structure formation, so-called kinematic mechanism, which development is due to body limit state attainment in the most stressed and deformed region (fracture area) where large irreversible deformations are localized, due to which parts separated by fracture surface mutual motion acquire possibility [10-12]. With plastic kinematic mechanism, deformation process proceeds gradually. Its characteristic feature is simultaneity of limit state existence over whole failure area, which is impossible with brittle kinematic mechanism with dominant stress level in tension zone and tear crack formation This plastic kinematic mechanism behavior is due to sufficient deformed solid plastic deformations resource, that elastic-plastic or rigid-plastic body diagram with limited plasticity interval can be used.

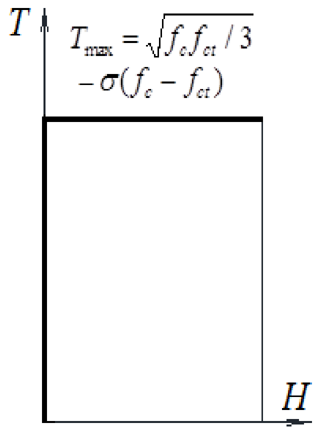


Figure 4 – Diagram «Tangential stresses intensity T – shear strain velocity intensity H » for concrete

For inhomogeneous stresses states, fracture surface consists of shear and tear areas. It is quite difficult to determine tear or shear form predominance quite difficult. There is need for qualitative criterion for using plasticity theory. Following criterion formulation of its applicability is proposed: existence of plasticity (strength) condition over whole concrete limit state area which completely intersects body, which development is necessary to make it mechanism. Limit state simultaneity in tension and compression zones is attained at stage preceding shear when compression stresses level outstrips tension stress level. At same time, externally brittle fracture nature is not an obstacle to shear realization and plasticity theory applicability.

Shear strength calculation. A sufficiently general and exact calculation theory should explain physical essence of known phenomenon wide range, predict new dependencies and properties, and describe with necessary accuracy processes parameters ratio.

In Poltava National Technical Yuri Kondratyuk University developed technique for calculating strength based on concrete ideal plasticity theory [12, 16], supplemented by its limitations applicability, considering elements failure stage, design schemes that clearly demonstrate fracture mechanism kinematics, and using the variational method of determining ultimate load.

Particular element ultimate load calculation is related to its assignment kinematic destruction mechanism and virtual velocity principle functional recording [9, 10, 12].

The functional for triaxial stress states has form

$$I = \int_{S_l'} m\left[B^2 + 0,25\left(\Delta V_t' / \Delta V_n'\right)^2 \right]\Delta V_n' dS - \int_{S_f} f_i V_i' dS, \tag{1}$$

where $m = f_c - f_{ct}$; $B^2 = \left(1+\chi/\left(1-\chi\right)^2\right)/3$; $\chi = f_{ct} / f_c$, f_i, V_i' – given forces on body surface S_f and kinematic possible velocities; S_l' – fracture surface; $\Delta V_n'$, $\Delta V_t'$ – breaks (jumps) of normal and tangent to surface S_l' components velocity.

For plane stress states, first term of expression (1) is written:

$$I_l = \int_{S_l'} m\left[2B\left(1+0,25\left(\Delta V_t' / \Delta V_n'\right)^2\right)^{0,5} - 1\right]\Delta V_n' dS\,. \tag{2}$$

On real stress state functional I is zero. Limit load value is found from plastic deformation minimum condition power by varying geometrical surface parameters S_l and disks velocities ratio.

As an example, let us consider bent plate strength problem clamped at one end, which simulates keys work in elements joints [4, 18-20]. The kinematic plate fracture scheme is shown in figure 5. The unknown parameters of this problem are limit load q_u, slope angles α of platform AB and β of platform BC to vertical (where ABC – fracture surface), disks velocities ratio $k = V_x / V_y = tg(\psi + \beta)$ I and II (figure 5).

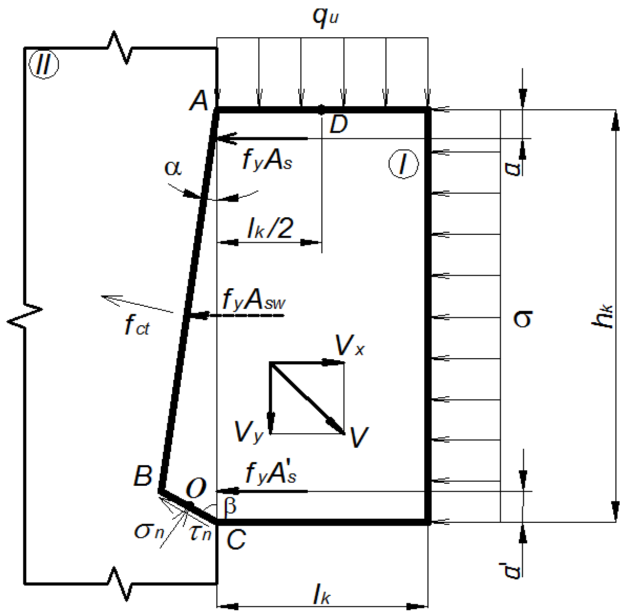


Figure 5 – Kinematic possible concrete destruction scheme (reinforce concrete) plate, pinched from one end

Compression σ is taken into account as an external load uniformly distributed over plate height, and reinforcement effect in reinforced concrete element is by applying compressive external force in reinforcement (A_s, A_{sw}, A_s') level [21].

The formula for determining maximum load is written in form:

$$q_u = \left(\begin{array}{l} m\left[2B\sqrt{(k-tg\beta)^2+0,25(ktg\beta+1)^2}+k+tg\beta\right] \\ \times\dfrac{tg\alpha}{tg\alpha+tg\beta}+f_{ct}(k+tg\alpha)\dfrac{tg\beta}{tg\alpha+tg\beta}+k\sigma \end{array} \right)\frac{h_k}{l_k}. \qquad (3)$$

Additional conditions are used in moment form equations applied to key part cut off by surface of velocity discontinuity *ABC*. In this case points *B*, *O*, *D* are offered as moment points.

Conclusion. Thus, shear failure form in elastic-plastic materials, to which concrete relates, is characterized by concentration of directional plastic deformation in thin layers on slip surface. Neighboring regions in limit state remain slightly deformed and are considered as rigid.

Stressed states interval for which shear is typical as concrete fracture form is narrowed in comparison with shear realization area in plastic materials. Shear occurs at tangent angles values to envelope of Mohr's circles $-\arcsin 1/3 \le \psi \le \arcsin 1/3$ and the tangential stresses level on the slip surface $\sqrt{2/3} \le \tau_n/\tau_{\max} \le 1$. At the same time, lower concrete destruction limit by shear is located in mixed area stresses states, close to axial compression, and upper one in zone of uneven biaxial compression. As a criterion for shear realization, limit state achievement (strength condition) is considered, even for a moment, over entire area that completely intersects body.

To solve concrete and reinforced concrete elements strength problem in shear failure form, mathematical application plasticity theory apparatus is promising. Using the variational method, solutions were obtained for strength problems of elements differing in shape, load transfer circuit, fracture zone stress state, which was confirmed in experiments [1-4, 18-20].

The kinematic mechanism under the shear as a limit macroscopic structure opens fracture surface varying direction possibility for example, by creating lateral reduction. Slip plane orientation makes it possible to change elastic-plastic material plastic layer location, taking into account configuration, size ratio, holes and weakened places presence in bodies, which is of practical interest due to shear cases variety.

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О. А. Довженко, В. В. Погребной, И. А. Юрко

Полтавский национальный технический университет им. Юрия Кондратюка, Украина

РЕАЛИЗАЦИЯ СРЕЗОВОЙ ФОРМЫ РАЗРУШЕНИЯ В БЕТОНЕ

Аннотация. Рассматривается срез как форма разрушения бетонных и железобетонных элементов, существенно различающихся конструктивными решениями, схемами передачи нагрузки и напряженно-деформированным состоянием на поверхности сдвига. Сформулированы условия и критерий реализации срезовой формы разрушения в бетоне. В качестве условий приняты обязательность локализации пластической деформации в тонких слоях на поверхности разрушения и достижение сдвиговыми напряжениями τ_n уровня $\sqrt{2/3}$ от их максимального значения. Критерием реализации среза в структурно-неоднородных материалах з различным сопротивлением сжатию и растяжению является одновременное существование предельного состояния по всей поверхности сдвига. Для определения границы реализации среза в бетоне проанализирован процесс разрушения бетонной пластины при осевом сжатии. Обосновано существование переходной области разрушения «сдвиг-отрыв». Нижняя граница разрушения бетона путем среза расположена в области смешанных напряженных состояний, приближенных к осевому сжатию, а верхняя – в зоне неравномерного двухосного сжатия. Кинематический механизм разрушения бетонных элементов при срезе рассматривается как предельная макроскопическая структура. Используется концепция жестко-пластического тела. Пластическая деформация считается сосредоточенной в тонких слоях на поверхности разрушения, а соседние области рассматриваются как жесткие диски. Предложена достаточно общая методика расчета прочности на основе математического аппарата теории пластичности, вариационного метода с применением принципа виртуальных скоростей, разрывных решений и верхней оценки величины предельной нагрузки. Внешне хрупкий характер разрушения не может служить препятствием применения теории пластичности. В качестве пластического потенциала принято условие прочности бетона в виде параболоида вращения, имеющее достаточно простую запись в тензорной форме и экспериментальное подтверждение. Решение задач прочности сводиться к записи функционала принципа виртуальных скоростей для соответствующего кинематического механизма разрушения. Функционал исследуется на экстремум, что эквивалентно решению краевой задачи. Достижение функционалом стационарного состояния соответствует минимуму мощности пластической деформации. В качестве примера приведено решение задачи прочности изгибаемой защемленной с одного конца бетонной (железобетонной) пластины, моделирующей работу шпонок стыкового соединения. Реализуемый кинематический механизм при срезе открывает возможность варьирования направления поверхности разрушения путем создания бокового обжатия, что представляет практический интерес.

Ключевые слова: бетон, срезовая форма разрушения, условия, критерий, механизм реализации, методика расчета.

О. А. Довженко, В. В. Погребной, И. А. Юрко

Юрий Кондратюк атындағы Полтава ұлттық техникалық университеті, Полтава, Украина

БЕТОНДАҒЫ БҰЗЫЛЫСТАРДЫҢ КЕСІНДІ ҚАЛЫПТАРЫН ЖҮЗЕГЕ АСЫРУ

Аннотация.Кесінді ығысу бетіндегі кернеулік түр өзгерту күйі, жүктемені тарату мен, конструктивтік шешімдерімен айрықша ажыратылатын бетонды және темірбетонды элементтерді бұзу қалыптары ретінде қарастырылады. Бетондағы бұзылыстың кесінді пішіндерін жүзеге асыру шарттары мен критерийлері тұжырымдалған. Шарт ретінде пластикалық деформацияның бұзылыс бетінде жұқа қабаттарда орналасу міндеттілігі мен ығысу кернеуімен максималды мәніндегі деңгейге жетуі қабылданған. Сығу мен созуға кедергісі әр түрлі құрылымдық біртекті емес материалдардағы кесіндіні жүзеге асыру критерийі ығысу бетінің барлық бөліктерінде бір уақытта шектік күйінің болуы болып табылады. Бетондағы кесіндіні жүзеге асыру шекарасын анықтау мақсатында осьтік сығу кезіндегі бтондық платинаның бұзылу үрдісі талданған. Бұзылудың «ығысу-жұлу» аралық бөлігінің болуы негізделген. Бетонның кесінді арқылы бұзылуының төменгі шекарасы кернеулі күйі аралас аймақтарда, ал жоғарғысы – біртекті емес екі осьтік сығу аймағында орналасқан. Кесу кезіндегі бетондық элементтердің бұзылуының кинематикалық механизмі шектік макроскопиялық құрылым ретінде қарастырылады. Қатты-пластикалық дене концепциясы пайдаланылады. Пластикалық деформация бұзылу бетінің жұқа қабаттарында жинақталған болып есептелінеді, ал көршілес аймақтар қатты дисктер ретінде қарастырылады. Созылымдылық теориясының математикалық аппараты, виртуалды жылдамдықтар қолданылған вариациялық әдіс, үзіліс шешімдері мен шектік кернеу мәнінің жоғарғы бағасы негізінде беріктікті есептеудің жалпы әдістемесі ұсынылған. Бұзылудың сырттай морт сипаттамасы созылымдылық теориясын қолдануға кедергі бола алмайды. Пластикалық потенциал ретінде тензорлық түрде қарапайым жазбасы мен тәжрибелік дәлелі бар айналу параболоиды түріндегі бетон беріктігі шарты қабылданған. Беріктік мәселелерін шешу бұзылудың сәйкес кинематикалық механизмі үшін виртуалдық жылдамдықтар принципі функционалын жазуға саяды. Функционал экстремумға зерттеледі, бұл шеттік есепті шешуге эквивалентті болып табылады. Функционалдың стационарлы күйге жетуі созылымдылық деформациясы қуатының минимумына сәйкес келеді. Мысал ретінде, түйістірілген қосынды кілтектері жұмысын модельдейтін, бір шетінен қысылған иілгіш бетон (темірбетон) пластинасының беріктігі есебінің шешімі берілген. Кесіндідегі жүзеге асырылатын кинематикалық механизм бүйірлік сығу арқылы бұзылу бетінің бағытын түрлендіру мүмкіндігін береді, бқл тәжрибелік маңызға ие.

Түйін сөздер: бетон, бұзылудың кесінді түрі, шарттары, критерий, жүзеге асыру механизмі, есептеу әдістемесі.

Сведения об авторах:

Довженко Оксана Александровна – кандидат технических наук, профессор кафедры «Железобетонных и каменных конструкций и сопротивления материалов» Полтавского национального технического университета имени Юрия Кондратюка, o.o.dovzhenko@gmail.com

Погребной Владимир Владимирович – кандидат технических наук, старший научный сотрудник, доцент кафедры «Железобетонных и каменных конструкций и сопротивления материалов» Полтавского национального технического университета имени Юрия Кондратюка, V.V.Pohribnyi@gmail.com

Юрко Илона Анатольевна – кандидат технических наук, доцент кафедры «Автомобильных дорог, геодезии, землеустройства и сельских строений» Полтавского национального технического университета имени Юрия Кондратюка, ilona.yurko@gmail.com

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ISSN 2518-170X (Online), ISSN 2224-5278 (Print)

http://geolog-technical.kz/index.php/kz/

Верстка *Д. Н. Калкабековой*

Подписано в печать 02.04.2018.
Формат 70x881/8. Бумага офсетная. Печать – ризограф.
16,9 п.л. Тираж 300. Заказ 2.

Национальная академия наук РК
050010, Алматы, ул. Шевченко 28, т. 272-13-19, 272-13-18