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THE GENERALIZED ENGINEERING METHOD S CALCULATION OF SUBSIDIARY AREAS OF REINFORCED CONCRETE BEAM CONSTRUCTIONS

Submitted are the main results of experiments dealing with the study of strength properties of the support areas of common, whole, pre-stressed, eccentrically tensioned and compressed reinforced concrete beams. New destruction patterns-of support- areas of said- structuresvare identified and their dependence on-the appropriate relationship of the studied factors was established. A new general engineering method to calculate the strength of support areas of such elements which is based upon a selection and sequential analysis of possible destruction patterns was developed.

Keywords: *reinforced concrete beams, support areas, strain-stress behaviour, strength.*

Introduction. Resistance of reinforced concrete elements to a joint action of axial and transversal forces and bending and torsion forces remains one of the most important and underexplored problem both in the reinforced concrete theory and in practical design. Therefore, systemic experimental and theoretical research aimed at improvement of the existing and development of modern computational models of support areas in reinforced concrete elements is of essential importance.

Analysis of prior research. The priority research areas and recent publications on said topic concern development of the normative framework in the sphere of structural design and implementation of the strain method for computation of their load-bearing capacity. At that, while numerous works of domestic and foreign researchers deal with a study of the load-bearing capacity of normal shears, the load-bearing capacity of inclined shears of said elements remains understudied. Alongside with that, destruction of reinforced concrete structures due to inclined shears is very unsafe and, therefore, extremely undesirable.

Dismissal of the so-called analogue methods when calculating strength, including the frame strength, of inclined shears, which main deficiency is a distinction of the adopted computation models from actual conditions at site, and which are present in the effective European standard EC-2 [1], has brought domestic standards in this sphere to a leading edge of science in the second half of the 20* century.. However, along with that, as it was relevantly emphasized by V.V. Tur and A.A. Kondratchyk [2], an insufficiently substantiated reduction of strength margin in support areas and negligence of a number of design and external factors resulted in a considerable reduction of reliability of the computation in accordance with SNiP 2.03.01-84* [3]. The authors consider [2] that the maximum accuracy and reliability can be achieved by the use of computational formula found in Norwegian standards NS 3473E which are based on the postulates of the modified "contracted fields" and the Canadian standards CSA 23 which are based on the general theory of shear computation. Reliability evaluations of the EC-2 computational formulas has shown that they occupy a certain intermediate position between American standards of ACI Code 318 and Norwegian standards NS 3473E.

Taking into consideration the above, the authors (O.S. Zalesov, O.I. Zvezdov, T.A. Mykhamediyev, Ye.A. Chystyakov et al.) revised the standards of SNiP 2.03.01-84* that were introduced in Russia as of 2003 [4] and 2004 [5] and assert that the existing methods to calculate strength of inclined shears of reinforced concrete elements under the action of transversal and axial forces, bending and torsion torques have not yet achieved such level that they can be accepted as normative methods because of the absence of a systemic approach and due account of the influence of a whole series of a number of factors, including the complex stress-strain condition of the elements. Therefore, the new Russian standards [4, 5] adopted a simplified scheme for calculating the support area of the reinforced concrete spans so as to make an additional safety margin.

In this context the works of A.M. Bambura, O.B. Golyshev, O.I. Davydenko et al. [6, 7, 8, 9, 10] have the advantage as they allow of a satisfactory determination of the strength of inclined shears of common and pre-stressed bar elements by means of the deformation method using the strength values of normal shears.

Practical designers also make use of the method developed by L.O. Doroshkevych, B.G. Demchyny, S.B. Maksymovych, B.Yu. Maksymovych [11, 12] which links the strength calculation of inclined and normal shears. At that, the authors consider [11, 12] that the calculation of the transverse rods is similar for the beams, short cantilevers and plates, and is performed based on so-called "pushing".

However, the nature of the stress-strain behaviour, the performance and destruction of the spanned reinforced concrete elements that experience not only transversal but also axial compressing or tension forces, which are applied eccentrically, and bending and torsion torques differ considerably from those described in the works [1... 12].

Objective and tasks of the studies. This paper is aimed at presenting a general characteristic of the proposed engineering method for calculating strength of support areas of plate stress elements of span elements. The tasks of the studies are to disclose the features of deformation, origination of cracks and destruction of reinforced concrete elements characterized by complex stress-strain behaviour of plate stress support areas, determination of mechanisms and description of new destruction patterns of these areas depending on correlation of the studied factors.

Study methodology. In order to achieve the set objective, a special methodology of performing systemic field and numerical tests was developed and accomplished in six series with common, pre-stressed, whole, eccentrically tensioned and compressed reinforced concrete spans with due account of continuous loading and use of a special laboratory equipment. All indicated tests were made at three levels according to almost D-optimum plans of Hartley Ha5 type.

The studied elements presented hinge-propped one- and two-span beams of square and T-shaped shears having 200 mm height and the span lengths equalling $9h_0$. They were reinforced with two plane frames. The lower and the upper axial rods were adopted to be of A500C class while the transversal rods were taken to belong to Bp-I class.

To prepare the test specimens - beams - a heavy-weight concrete of classes CI2/15, C20/25 and G30/35 was used and contained granite macadam and quartz sand with the use of a common 400 grade Portland cement without additives.

In calculation deformation models use was made of the averaged approximate diagrams illustrating deformation of concrete prisms DP NDIBK with descending branches, known idealized two-line and more complex shape diagrams illustrating deformation of reinforcement steel as well as diverse phenomenological criteria of concrete and reinforced concrete strength.

For creating various kinds of deformation and testing the specimens - beams - special multipurpose power benches were designed and manufactured.

Deformations of concrete and reinforcement of specimens in the course of the tests were measured with the aid of strain gauges and the results of measurement were checked by clock-type indicators.

Results of the study. Disclosed in the course of the tests were peculiar features of deformation, cracking and destruction of the reinforced concrete spans under complex stress-strain behaviour of support areas; a systemic influence of the design features and external factors upon their load-bearing capacity was determined; the mechanism and new destruction patterns of these areas were revealed; adequate mathematical models of strength, crack resistance, deformability and other parameters of the load-bearing capacity of the studied elements were found out.

Depending on the correlation of the design features and external factors, a destruction of the support areas of plane-stressed spanned reinforced concrete elements can occur according to one of the patterns presented in Fig. 1:

– according to pattern $A\text{-}1/N_b$, or $A\text{-}2/N_н$ destruction occurs according to **normal** shears due to **yield** of, accordingly, the upper or the lower axial reinforcement in case its quantity is insufficient or if the axial tension force is excessive;

– according to pattern *B/M* destruction occurs according to **inclined** shear under the dominant action of the **bending torque** and minimum (to 1%) and insufficient (to 0,3%) quantity of the transverse reinforcement;

– according to pattern *C/V* destruction occurs according to **inclined** shear under the dominant action of the **transverse force** from the shear (slide) or due to breaking of concrete within the compressed zone with average (>1,5%) and great quantity of axial reinforcement;

– according to pattern *D//CM,* i.e., destruction occurs according to the **inclined compressed strip** between the concentrated force.and the support in the eccentrically compressed and pre-stressed elements with the shear span *a<2ho;*

– according to pattern *F/V* destruction occurs due to **pushing above the middle support** in kind of an upturned trapezoid with a possible formation of "plastic hinges" above the middle support and in the spans, as well as due to re-distribution of external forces.

Engineering methods to calculate strength of support areas of plane-stressed rod-type reinforced concrete elements [13] can be combined in a single *general engineering method* which means that with the aid of improved non-linear rough or improved general deformation models or the finite element method [14] it is possible to simulate the stress-strain behaviour of a spanned structure, determine the load-bearing capacities of individual normal (sometimes according to MCE and inclined) shears and, through them, the strength of support areas and inclined shears inclusively. This procedure can be simplified. Knowing the correlation between the design factors and the external influence factors, it is required to analyse, step-by-step the most probable destruction patterns (Fig.l) of the support areas of the structure, determine the destructive forces and adopt their minimum load-bearing capacity as the basis.

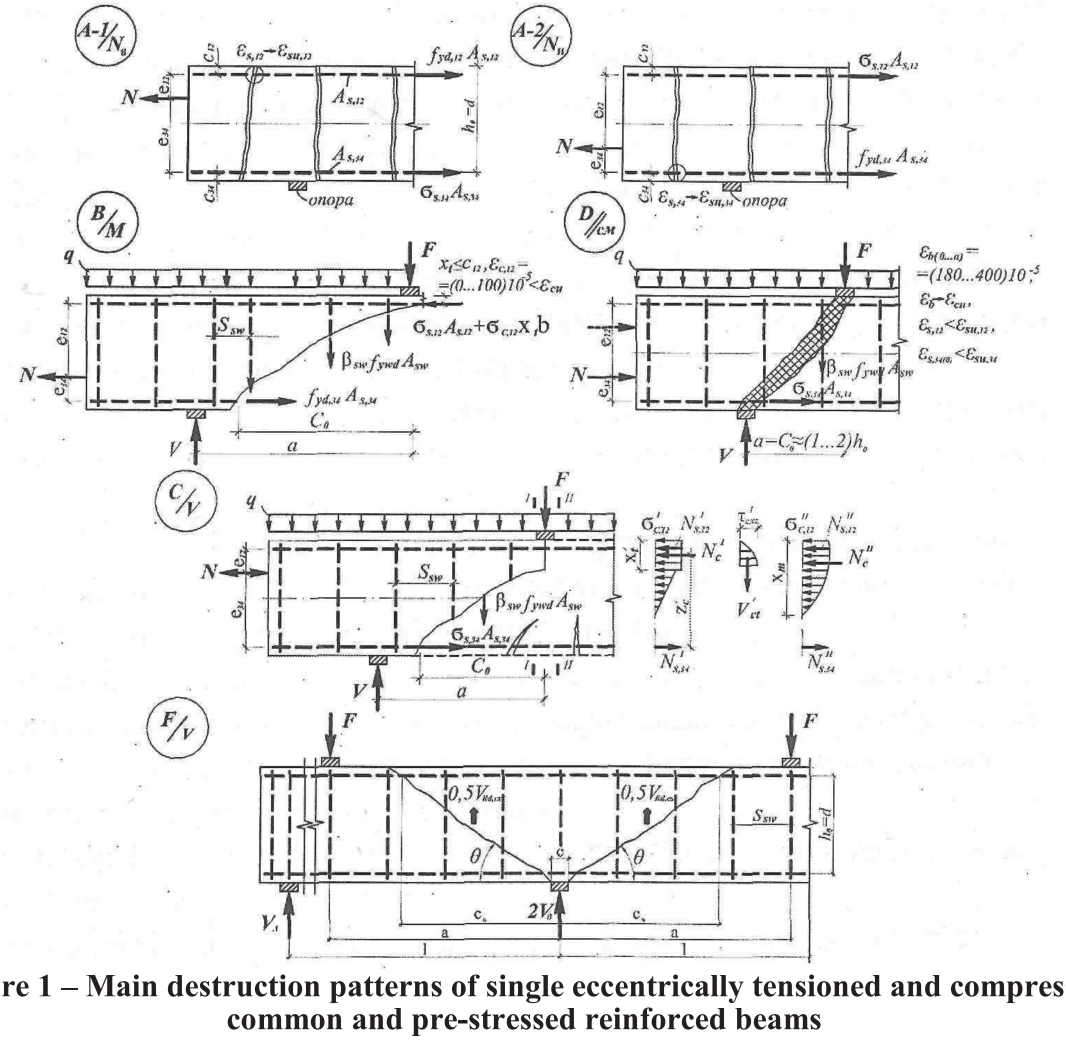

Figure 1 – Main destruction patterns of single eccentrically tensioned and compressed common and pre-stressed reinforced beams

Thus, in the eccentrically tensioned specimens with relatively small eccentricity the nature of normal crack formation (along the entire shear) and their opening prove that the so-called 2nd pattern takes place. This being the case, the strength conditions for the destruction patterns *A-1/N$_e$, A-1/N$_H$* look like:

$$N \leq f_{yd,12} A_{S,12} (h_0 - c_{12}) / e_{34}; \tag{1}$$

$$N \leq f_{yd,34} A_{S,34} (h_0 - c_{12}) / e_{12}, \tag{2}$$

and allow of selecting the required quantity of axial reinforcement in the support or of determining the acceptable value of *N.*

When an element is destructed according to pattern *B/M,* the strength condition of the support area in relation to the centre of gravity of the upper (erection) reinforcement will be:

$$M \leq M_S + M_{S,W} = M_{S,N} + M_{S,F} + M_{SW,F} \tag{3}$$

which can also be represented as:

$$M \leq Va + Ne_{12} - f_{yd,34} A_{s,34} z_s - q_{sw} c_0^2 / 2 \tag{4}$$

Considering that $N_S = N_{S,N} + N_{S,F}$, the additional axial force $N_{S,N}$ and the normal stress $\sigma_{s,34,N}$ *y* Pf fe working reinforcement caused by the axial tension force can be determined according to the deformation model through $\varepsilon_{S,N}$ and the force $N_{S,F}$ caused by the transverse force *Fby* means of the expression:

$$N_{S,F} = N_S - N_{S,N} = f_{yd,34} A_{s,34} - \sigma_{s,34,N} \cdot A_{s,34} = (f_{yd,34} - \sigma_{s,34,N}) A_{s,34} \tag{5}$$

In practical calculations it is recommended that the relative length of the horizontal projection of an unsafe inclined crack c_0 is determined with the aid of empirical dependencies obtained through the appropriate mathematical models c_0/h_0 for the conducted test series which have been published earlier by the authors:

$$c_0 = f\left[a / h_0, c, \rho_w, \rho f_{\text{П}}, \rho, f_{\text{В}}, Np / (f_{ck} b h_0), p / (f_{ck} b h_0)\right] \tag{6}$$

In order to predict strength of the inclined shear of a reinforced concrete span which can be destructed according to pattern *C/V,* the following prerequisites have been adopted: a) the strength of inclined shears is determined through the strength of normal shears that can be found by means of the deformation or conventional methods; b) the actual normal shear of the element is replaced with the calculated one with the average deformations of the compressed concrete and tensioned reinforcement; c) the stress (deformation) in the reinforcement are determined with the aid of the deformation method in its non-linear variation; the actual curvilinear stress diagram in the concrete of the compressed zone can be replaced, when calculating the strength, with the rectangular diagram above the apex of the unsafe inclined crack, and with the triangular diagram - under it; d) possible forces in the apex of the unsafe inclined crack are not taken into account as the width of inclined cracks in non-overreinforced elements considerably exceeded possible shearing deformations; e) the calculation begins with a determination of the bearing capacity of the normal shear of the element under the concentrated force (in the shear span end) with due account of a possible increase (decrease) of the concrete strength in the compressed zone in its complex stressed condition and upon achievement by the maximum tangent stress of 50% value of the prism (characteristic f_Ck when determining the destructive V_u or the calculated f_{Cd} when determining the calculated *V*) strength of concrete.

The unknown internal forces, the height of the compressed zone of concrete and other performance parameters of the support area of the reinforced concrete element span at its destruction according to pattern C/Fare determined as follows:

$$\pm N = N_{ct}^I + N_{S,12}^I - N_{S,34}^I; \tag{7}$$

$$V_I = V_{ct}^I + V_{sw} + V_s; \tag{8}$$

$$M_I = M_{II} = M_{U,M+V} = M_{U,M} = N^I_{ct}(h_0 - 0,5X_t) + \\ + N^I_{S,12}(h_0 - c_{12}) + V_S \cdot C_0 + V_{SW} \cdot C_0/2, \tag{9}$$

where
$$N^I_{ct} = \sigma^I_{c,12} \cdot A^I_{ct}; \tag{10}$$

$$V^I_{ct} = (2/3)V_{Rd} \cdot A^I_{ct}; \tag{11}$$

$$V_{sw} = q_{sw} \cdot C_0 = \beta_{sw} \cdot f_{ywd} \cdot A_{sw} \cdot C_0/S_{sw}; \tag{12}$$

$$V_I = M_I/a = M_{U,M+V}/a, \tag{13}$$

where A^I_{ct} - is a part of the shear *I-I* of height X $_t$;

$\beta_{sw} = \sigma_{swz}/f_{ywk}$ – a coefficient characterizing a normal stress level in the transverse reinforcement.

The average values equal $\beta_{sw} = 0.8$ for the common eccentrically tensioned and pre-stressed beams, and $\beta_{sw} = 0.6$ for the whole beams;

$$M_{u0} = M_{u,M+V}(1 - C_0/a) - N^I_{S,12}(h_0 - c_{12}) + 0,5q_{sw} \cdot C_0^2; \tag{14}$$

$$0,5\sigma^I_{c,12} \cdot b \cdot X_t^2 + \left[(2/3)V_{Rd} \cdot C_0 - \sigma^I_{c,12}h_0\right]b \cdot X_t + M_{u0} = 0 \tag{15}$$

where $B_1 = 0,5\sigma^I_{c,12} \cdot b;$ $\quad B_2 = +\left|(2/3)V_{Rd} \cdot C_0 - \sigma^I_{c,12}h_0\right| \cdot b$ $\quad B_3 = M_{u0}$

$$V_s = V_I - (2/3)V_{Rd} \cdot b \cdot X_t - q_{sw} \cdot C_0 \le [\hat{V}_s] \tag{16}$$

where $[\hat{V}_s] \le 0,05V_I = 0,05M_I/a$ for the common single-span, whole, eccentrically tensioned and compressed beams;

$[\hat{V}_s] = f[a/h_0, \; b_f/b, \; h_f h_0, \; \rho_w, \; p/(f_{ck}bh_0)]$ for the pre-stressed T-shaped reinforced concrete elements is proposed to be determined with the aid of the appropriate mathematical model.

Verification:
$$N_s = \sigma^I_{c,12}A^I_{ct} + \sigma^I_{s,12}A_{s,12} \pm N \tag{17}$$

with the condition that remains:

$$N_s \le N_{s,1} = \gamma_{s6} f_{yd,34} A_{s,34}. \tag{18}$$

In case the condition (18) is not observed, the calculation pattern *C/V* should be replaced with the simpler *B/M,* however $V_s = 0$; $V'_{ct} = 0$ should remain, and for it

$$M \le M_s + M_{sw} = f_{yd,34}A_{s,34}(h_0 - c_{12}) + q_{sw}c_0^2/2 = M_I = V_I a. \tag{19}$$

Taking into account the actual stressed state and the domestically adopted dialectic singularity of approaches to calculating the load-bearing capacity of reinforced concrete elements that are destructed according to the inclined compressed strip (pattern *Д//str.),* it is expedient to adopt the condition of strength of the inclined compressed strip in its conventional expression:

$$V \le \varphi^*_{c_I} f_{cd} bh_0, \tag{20}$$

where $\varphi_{cI}{}^*$ – a coefficient that, as distinct from the old domestic and new Russian and Belarus standards, has a variable value and integrally accounts for the existing factors. It can be determined for the common and eccentrically compressed reinforced concrete beams in accordance with the empirical dependence below:

$$\varphi^*_{c_I} = 0,30 - 0,09(c - 25)/10 + 0,01(\rho_w - 0,0035)/0,00145, \tag{21}$$

and for the pre-stressed reinforced concrete elements in accordance with the expression:

$$\varphi_{c_1}^{*} = 0{,}398 - 0{,}008c + 13{,}889\rho_w - 0{,}007\frac{\sigma_{sp} \cdot A_{sp}}{bh_0} \tag{22}$$

Strength conditions of the support areas of the whole reinforced concrete beams which destruction occurs above the middle support according to the pushing pattern *F/V* is as follows:

$$F_B = 2V_B \le F_c + F_{sw} = \alpha_c f_{ctd} U_m h_0 + \beta_w f_{ywd} \sum A_{sw,2C_0}, \tag{23}$$

where F_B – is a value of reaction above the middle support; V_B – calculated values of the transverse forces on the left and right of the support; F_c – shearing force taken up by concrete; F_{sw} – shearing force acting on the transverse reinforcement located on the side planes of the pushing body of an aggregate area $\sum A_{sw,2C_0}$; $\alpha_c = \sigma_c / f_{ctk}$ – a coefficient that characterizes the level of normal to the beam axis stresses in concrete on the sides of the pushing body, and is determined according to the empirical formula: $\alpha_c = f(a/h_0,\ c,\ \rho_w,\ \rho_{fн},\ \rho_{fв})$, α_c=0,60...4,16; $\beta_w = \sigma_{sw} / f_{yk}$ – a coefficient that characterizes the stress level in the transverse reinforcement of the support areas which crosses the side planes of the pushing body and is determined according to the similar empirical relation: β_w=0,15...1,00; U_m – the arithmetic mean of the perimeters of the upper and lower base of the pushing body within the limits of the working height of the shear *ho*.

It is recommended to predict the load bearing capacity of the spanned reinforced elements experiencing a complex stress taking into account their compressed or free torsion in accordance with the non-linear deformation calculation model that was improved by the authors.

Comparative analysis of the test results and the results obtained by calculations in accordance with the proposed engineering methodologies yielding the strength values of the studied elements support areas (Table 1) has proved their satisfactory coincidence (variation coefficient Q<12%).

The results of the work are used in practical design of the leading construction companies of Odessa (LLC «Stikon», PSMO «Odesbud», RCC «Ekobud», LLC «Golovbud» etc.) when reinforcing the foundation of the Odessa Academic Opera & Ballet Theatre, renewal of the Cathedral of the Transfiguration of the Saviour in Odessa, new construction and reconstruction of the symbolic for Odessa buildings and facilities as well as in the training courses in Odessa State Academy of Civil Engineering and Architecture (3 candidate theses and i9 masters' diplomas were successfully defended), and are, partially, implemented in the effective national design standards.

Conclusions. 1. Disclosed are peculiar features of the strain-stress behaviour of the studied specimen beams. The dependence of the nature and kind of destruction of these areas on the appropriate relationship of the design and external factors was established for the first time. The known and identified destruction patterns pertaining to the plane-stressed *(A-1/*N_e*, A-2/*N_H*, B/M, C/V, Д//str., F/V,)* and complex-stressed *(E/*T_{Compr}*,E/*T_{free}*)* support areas of spanned reinforced concrete elements have been classified. Peculiar features of the internal force re-distribution in the studied elements were identified which takes place due to non-linear nature of deformation of these materials and formation of the conventional "plastic hinges" in the whole beams. 2. The analysis of calculation methods applicable to strength of the spanned reinforced concrete structure support areas, that are prescribed by the national design standards of the developed countries, and of the methods developed by the authors has proved that the absolute majority of such methods is based upon the partially improved methods, which were applied in old standards at a certain time, and not upon a new general method. In particular, the EC-2 calculation methods and the methods of other foreign countries are based on various conventional schemes and similarities which necessitate an empirical approach and use of the ever increasing number of formulae of the indicated origin.

Table 1 – Results of comparison of the test and calculated values of the destructing transverse loading

Test No	Series I			Series III-A			Series III-B			Series IV			Series V		
	Test value of the destructive transverse force Q»,кН	Calculated value of the destructive transverse force Q_u, кН	Destruction pattern	Test value of the destructive transverse force	Calculated value of the destructive transverse force Q_u, кН	Destruction pattern	Test value of the destructive transverse force	Calculated value of the destructive transverse force Q_u, кН	Destruction pattern	Test value of the destructive transverse force Q»,кН .	Calculated value of the destructive transverse force Q_u, кН	Destruction pattern	Test value of the destructive transverse force Q»,кН	Calculated value of the destructive transverse force Q_u, кН	Destruction pattern
1	63	52	as⊥	63	52	B/M	97	132	*Д//str*	86	73	B/M	189	160	F/V
2	119	106	*Д//str*	119	106	A-1/N_B, B/M	150	132	*Д//str*	93	86	*Д//str*	269	271	F/V
3	118	123	*Д//str*	118	123	C/V	131	93	*	76	78	*Д//str*	206	199	F/V
4	32	27	as⊥	32	27	C/V	60	31	*	64	64	C/V	93	78	F/V
5	146	123	*Д//str*	146	123	B/M '	143	132	*Д//str*	93	86	*Д//str*	366	375	F/V
6	43	61	B/M	43	61	C/V	64	46	*	80	73	B/M	136	147	F/V
7	35	33	as⊥	35	33	B/M	78	31	*	69	77	C/V	93	109	. F/V
8	92	106	*Д//str*	92	106	C/V	139	132	*Д//str*	77	78	*Д//str*	162	167	F/V
9	158	135	*Д//str*	158	135	C/V	162	132	*Д//str*	95	86	*Д//str*	256	254	F/V
10	50	64	B/M	–	–	–	74	132	*Д//str*	81	83	B/M	129	106	F/V
11	34	33	as⊥	–	–	–	53	31	*	64	54	C/V	139	129	F/V
12	93	101	*Д//str*	–	–	–	122	132	*Д//str*	73	78	*Д//str*	233	221	F/V
13	117	135	*Д//str*	–	–	–	156	132	*Д//str*	78	78	*Д//str*	324	314	F/V
14	33	27	as⊥	–	–	–	77	31	*	65	55	C/V	109	147	F/V
15	58	61	B/M	–	–	–	65	132'	*Д//str*	89	83	B/M	135	149	F/V
16	105	101	*Д//str*	–	–	–	126	132	*Д//str*	90	86	*Д//str*	189	196	F/V
17	47	48	B/M	–	–	–	74	39	*	80	70	B/M	128	.127	F/V
18	119	132	*Д//str*	–	–	–	144	132	*Д//str*	83	81	*Д//str*	251	251	F/V
19	76	70	B/M	–	–	–	103	132	*Д//str*	81	82	C/V	182	182	F/V
20	56	70	B/M	–	–	–	94	132	*Д//str*	81	80	C/V	134	134	F/V
21	71	72	B/M	–	–	–	113	132	*Д//str*	82	80	C/V	160	158	F/V
22	67	69	B/M	–	–	–	91	128	*Д//str*	80	80	C/V	156	155	F/V
23	86	91	B/M	–	–	–	106	132	*Д//str*	90	96	C/V	178	178	F/V
24	58	52	B/M	–	–	–	98	132	*Д//str*	70	69	C/V	139	140	F/V
25	71	70	B/M	–	–	–	104	132	*Д//str*	82	92	C/V	190	189	F/V
26	70	70	B/M	–	–	–	100	132	*Д//str*	80	100	C/V	127	125	F/V
27	71	70	B/M	–	–	–	102	132	*Д//str*	81	96	C/V	158	157	F/V
var. coeff.	*v=15,4%*			*v=5,9%*			*v=25,0%*			*v=8,l%*			*v=8,0%*		

* concrete crushing in the simple bending zone

Comparative analysis of the calculated and test values of load bearing capacity of various types support areas in spanned structures that were calculated following the recommendations of various national design standards has proved that, for one part, their coincidence is unsatisfactory on the whole, and, for the other part, that the reliability of proposed formulae is insufficient as the calculated strength for a rather great number of test specimens, particularly of complex stressed, with great shear spans, exceeded considerably their actual bearing capacity. 3. Diverse forms of the complex strain-stress behaviour and of the destruction patterns make it impossible to develop a single simple and, at the same time, universal calculation model applicable to rapid evaluation of support area bearing capacity in various types of spanned structures which can adequately reflect the influence both of design factors and external factors. The proposed new general engineering method to calculate strength of support areas in plane-stressed spanned reinforced concrete structures that is based upon a selection of the most probable destruction patterns depending on the relationship of the studied factors and their sequential analysis with a view of determining the minimum bearing capacity allows of narrowing the existing scatter "corridor" of the test and calculated bearing capacity values of said areas from D=20.. .60% to D=6... 12%.

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УЗАГАЛЬНЕНИЙ ІНЖЕНЕРНИЙ МЕТОД РОЗРАХУНКУ ПРИОПОРНИХ ДІЛЯНОК ЗАЛІЗОБЕТОННИХ БАЛКОВИХ КОНСТРУКЦІЙ

Наведено основні результати експериментальних досліджень міцності приопорних ділянок звичайних, нерозрізних, попередньо напружених, позацентрово розтягнутих та стиснутих залізобетонних балок. Виконано аналіз методів розрахунку міцності приопорних ділянок прольотних залізобетонних конструкцій, розміщених у національних нормах проектування різних країн світу. Розкрито особливості деформування, тріщиноутворення та руйнування прольотних залізобетонних конструкцій із складним напружено-деформованим станом приопорних ділянок. Запропоновано новий загальний інженерний метод розрахунку міцності приопорних ділянок плосконапружених прольотних залізобетонних конструкцій.

***Ключові слова:** залізобетонні балки, при опорні ділянки, напружено-деформований стан, міцність.*

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ОБОБЩЕННЫЙ ИНЖЕНЕРНЫЙ МЕТОД РАСЧЕТА ПРИОПОРНЫХ УЧАСТКОВ ЖЕЛЕЗОБЕТОННЫХ БАЛОЧНЫХ КОНСТРУКЦИЙ

Приводятся основные результаты экспериментальных исследований прочности приопорных участков обычных, неразрезных, предварительно напряженных, внецентренно растянутых и сжатых железобетонных балок. Произведен анализ методов расчета прочности приопорных участков пролетных железобетонных конструкций, заложенных в национальных нормах проектирования развитых стран мира. Раскрыты особенности деформирования, трещинообразования и разрушения пролетных железобетонных конструкций со сложным напряженно-деформированным состоянием приопорных участков. Предложен новый общий инженерный метод расчета прочности приопорных участков плосконапряженных пролетных железобетонных конструкций.

***Ключевые слова:** железобетонные балки, приопорные участки, напряженно-деформированное состояние, прочность.*

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