CEB
27 th PLENARY SESSION
PARIS SEPTEMBER 1990

COMITÉ EURO-INTERNATIONAL DU BÉTON
CONTRIBUTION OF THE POLISH NATIONAL GROUP

Zbigniew PAJĄK [1)]

PUNCHING SHEAR RESEARCH OF REINFORCED CONCRETE PLATES IN POLAND

Beginning with the late forties of our century numerous investigations of models representing the connection of column with flat floor or base slab have been made in the world, mainly in the United States, Sweden, Federal Republic of Germany, England, Canada, Australia,the Soviet Union. As a result of an analysis of these investigations, many empirical and semi-empirical formulas for the determination of load carring capacity have been proposed [23,39,53]. Some of them are now found in the code rules [48,49,52]. A concise review of the problem of punching has been published in the materials of ACI [53] and CEB [39]. In home literature, an extensive summary of the state of art in this field is included in [2,8,16]. In a general case, in the regions of connections of flat slabs with columns, a twofold mechanism of failure is possible:through flexure or through punching shearing . Flexural strength, both for simple models and whole structures, can now be relatively accurately determined e.g., on the basis of the yield line theory. Some solutions of the problem of flexural strength in the region of internal columns and edge columns have been presented in [2,8]. In the case of failure through punching, depending on the way of load application symmetrical, asymmetrical two patterns of failure, shown in Fig.1, are possible.

1. Home experimental research

In Poland, the first experiments on punching shear of reinforced concrete plates were made in the years 1964–71 [1,26,42] in connection with the implementation of the "jack up" and "lift slab" technology. Further research was done in two centers - the Technical University of

1) Doctor Eng. Silesian Technical University
ul.Pstrowskiego 5, 44–100 Gliwice, Poland

a) b)

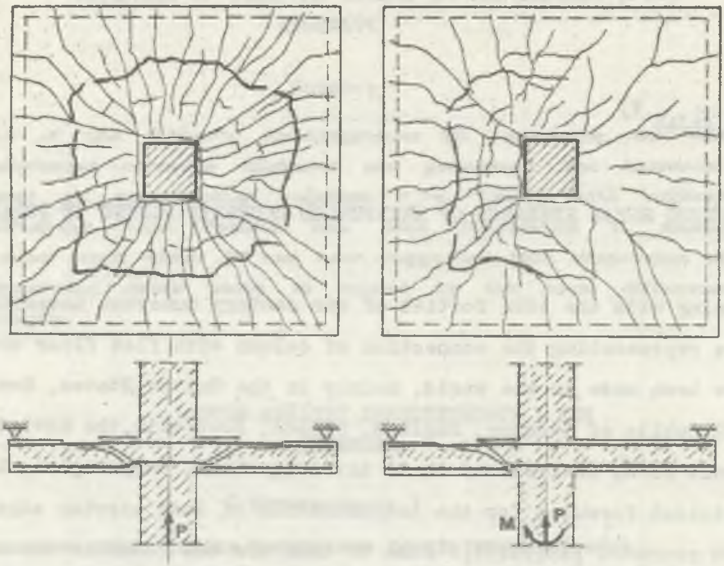


Fig.1 Crack pattern at punching shear: a) symmetrical load,
b) non-symmetrical load

Łódź, and the Silesian Technical University. Up till now, test results of 179 reinforced concrete models of slabs and columns connections have been published (Table 1). All the tests were made on simple models of slabs, mostly in prototype scale, simple-supported along the perimeter and loaded through a column by a axial or eccentric punching force. The size of the assumed, square or rectangular, model slabs reflected the line of contra flexure round the columns in a multi-area floor of the slab-structure.

The most important problems of the research were:

- behaviour at eccentric and axial loading of model slabs with an internal column with various types of connections: monolythic [9], precast/in-situ (prefabricated column, covered with in-situ concrete plate) [23, 26, 43], precast (prefabricated column and plate, mortar-filled joint) [25, 26, 47];

Table 1

Tests of model slabs in Poland

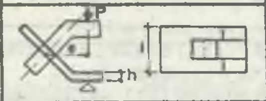
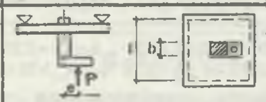
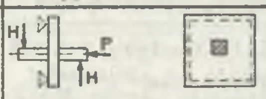
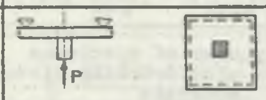
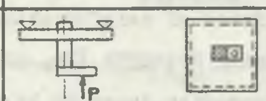
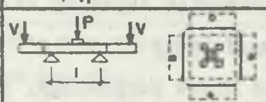
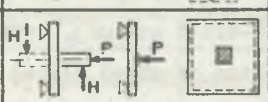
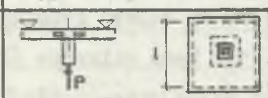
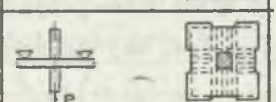
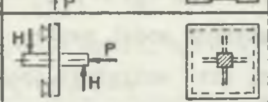
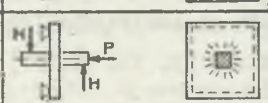
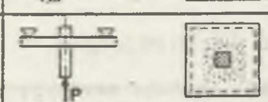
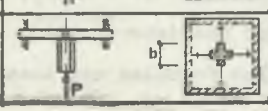
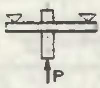
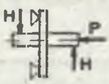
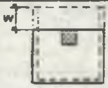
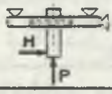
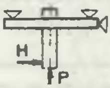
No	reference year	Scheme of the test	n	remarks , dimensions
1	[26] 1964		3	h = 0,1; l = 0,6 ; b = 0,2 ; e = 0,43 [m]
2	[42] 1971		15	h = 0,16;(0,24);(0,28); l = 17 ; b = 0,45; e=0÷0,75[m] ϱ = 0,3÷1,29 % ; f_{cu} = 11÷30 [MPa] light-weight concrete
3	[9] 1974		4	h = 0,15 ; l = 1,7 ; b = 0,45 ; e = 0÷0,75 [m] ϱ = 0,5÷1,5 % ; f_{cu} = 28÷32 [MPa]
4	[25] 1975		10	h = 0,1 ; l = 0,94 ; b = 0,2 [m] ; ϱ = 0,98 % f_{cu} = 20÷34 [MPa]
5	[23] 1976		30	h = 0,16 (0,24) ; l = 1,7 ; b = 0,45 ; e = 0÷0,75 [m] ϱ = 0,35÷1,29 % ; f_{cu} = 12÷30 [MPa] lightweight concrete
6	[35] 1977		6	h = 0,26 ; l = 1,0 ; b = 0,24 [m] ; ϱ = 1,35 % f_{cu} = 21÷28 [MPa]
7	[43] 1978		8	h = 0,16 ; l = 1,7 ; b = 0,25 ; e = 0÷0,25 [m] ; ϱ = 1,0 % f_{cu} = 12÷23 [MPa]
8	[38] 1979 [37] 1989		6	h = 0,22 (26) ; l = 2,25 ; b = 0,4 [m] ; ϱ = 0,4÷1,0 % f_{cu} = 20÷35 [MPa] steel collars
9	[13] 1979		4	h = 0,16 ; l = 1,7 ; b = 0,25 [m] ; ϱ = 0,94 % f_{cu} = 30÷37 [MPa] two-way prestresed slabs
10	[12,13,14] 1980		12	h = 0,16 ; l = 1,7 ; b = 0,25 ; e = 0÷0,25 [m] ϱ = 0,5 (1,0) % ; f_{cu} = 14÷19 [MPa] shearheads
11	[10,11] 1981 [27] 1984		19	h = 0,16 ; l = 1,7 ; b = 0,25 ; e = 0÷0,25 [m] ϱ = 1,0 (1,5) % ; f_{cu} = 12÷25 [MPa] shear reinforcement
12	[45] 1984		6	h = 0,16 ; l = 17 ; b = 0,25 [m] ; ϱ = 1,0 (1,25) % f_{cu} = 19÷27 [MPa] steel fiber reinforced concrete
13	[3] 1985		6	h = 0,18 ; l = 1,8 ; b = 0,45 [m] ; f_{cu} = 42÷53 [MPa] press moulded lightweight concrete

Table 1. continuation

14	[47] 1985			6	$h=0.16$; $l=1.8$; $b=0.25$ [m] ; $\varrho=1.0$ (1,25) % $f_{cu}=23\div34$ [MPa]
15	[46] 1980			14	$h=0.16$; $l=1.7$; $b=0.25$; $e=0\div0.75$ [m] $\varrho=1.0$ % ; $f_{cu}=12\div20$ [MPa] $w=0$;(0.16);(0.82) [m] , edge connections
16	[36] 1980			6	$h=0.175$, $l=2.25\times1.75$; $b=0.3\times0.35$ [m] $e=0\div0.75$ [m] ; $\varrho=0.75$ % ; $f_{cu}=15\div37$ [MPa] shearheads , edge connections
17	[32,33] 1982			24	$h=0.2$; $l=2.25$; $b=0.4$; $e=0\div0.25$ [m] $\varrho=0.9\div1.3$ % ; $f_{cu}=21\div44$ [MPa] large holes
			total n = 179		

n - number of specimens
f_{cu} - cube crushing strength of concrete
ϱ - ratio of reinforcement

- effect of lightweight concrete on punching strength [23, 42] ;
- effect of slab reinforcement ratio on carrying capacity at punching [9, 23], and the effect of slab prestress [13];
- effect on the load carrying cpacity and crack morphology, of the connection shape (one-sided column, two-sided column), method of load transfer (axial, eccentric, through column or steel plate) [43];
- effect of shear reinforcement in the form of closed stirrups, bent-up-bars, "segments of I sections", [10, 11], beam stirrups [27], shear-heads [12, 14, 36], and also reinforced steel fibre [45];
- behaviour at punching of edge connections [44, 46] and connections with large holes [32, 33, 36].

Apart from complex research including numerous model series, also a number of separate investigations dealing with untypical cases of punching shear and connected with attenpts at implementation of the specific design solutions have been realized [3, 35, 36, 37].

2. Analytical methods

On the basis of the investigations made in this country, many empirical and semi-empirical formulas for the determination of punching strength (Table 2) have been proposed. The formulas are mostly a

Table 2

Equations for punching resistance

Method No	reference	Equations for punching resistance (m, MPa, MN)	No eq.	notes and limitations
		$P_u = P_0 \left(1 + \frac{e P_0}{M_0}\right)^{-1}$; for methods No 1÷4 : $M_0 = \frac{J P_0}{\gamma d u c}$	(1) (2)	expresion(1) for methods No 1÷6
1	[9]	$P_0 = 0{,}33 \sqrt{f_{cc}}\, u\, d$ $\gamma = (4758 \varrho^2 - 133{,}87 \varrho + 1{,}55)\left(1 + 1{,}5 \sqrt{b_2 + d / b_1 + d}\right)^{-1}$	(3) (4)	
2	[15]	$P_0 = 0{,}465 \sqrt{f_{cc}}\, u\, d$ $\gamma = 0{,}85 \left(\frac{e}{b_1 + d}\right)^{0{,}42} \cdot \left(1 + 1{,}5 \sqrt{b_2 + d / b_1 + d}\right)^{-1}$	(5) (6)	u-for edge connections according to [15] $0{,}33 < \frac{e}{b_1 + d} < 2{,}51$
3	[23]	$P_0 = \frac{1{,}63 P'(1 - 0{,}075\, b/d) + (P_w - 0{,}43 P')}{1 + 0{,}5 P'/P_y}$ $\gamma = \left(1 + 2{,}126 \sqrt{b_2 + d_2 / b_1 + d_1}\right)^{-1}$; $P' = 0{,}23 k_1 \sqrt[3]{f_c^2}\, u\, d$	(7) (8) (9)	$k_1 = 1{,}0$ normal concrete ; $k_1 = 0{,}722$ lightweight concrete $P_w - 0{,}43 P' > 0$
4 [1)]	[41]	without shear reinf.: $P_0 = k_1 k_2 f_{ctd} u\, d$ with shear reinf.: $P_0 = \Sigma A_{sw} f_{yw} \sin\alpha \leq 1{,}4\, k_1 k_2 f_{ctd} u\, d$	(10) (11)	$k_1 = 1{,}0$ normal concrete $k_1 < 1{,}0$ lightweight concrete $k_2 = 0{,}5 + b_2/b_1 \leq 1$, $b_2 < b_1$ $\gamma = \left(1 + 1{,}5 \sqrt{b_2 + d / b_1 + d}\right)^{-1}$ (12)
5	[44]	$P_0 = k_2 u\, d\, (0{,}22 + 0{,}058 \varrho f_y) \sqrt{f_{cc}}$ $M_0 = m(2b_1 + b_2 + \alpha_u d) k_2$; $\alpha_u = 15{,}3 / \left(\frac{e_1 - e_2}{b_1}\right)^{1/3} \leq 18{,}5$	(13) (14) (15)	$k_2 = 0{,}6 + 0{,}4\, b_2/b_1$; $b_2 < b_1$; k_2-according to [44] $(0{,}22 + 0{,}058\, \varrho_1 f_y) \leq 0{,}523$
6	[34]	$P_0 = 0{,}3 \sqrt{f_{cu}}\, u\, d + 0{,}53 \frac{\Phi}{s} u_d$ $M_0 = 1{,}78 \sqrt{f_{cu}}\, n\, d\, (b_1 - d/3) + (m^t + m^b)(b_2 + 6d)$	(16) (17)	$\Phi/s \leq 0{,}25$; Φ/s in [MN/m]
7	[11]	$\left(\frac{P_u - P_w}{P_c}\right)^2 + k \frac{P_u e}{M_u} \leq 1$; $k = 1 - 0{,}5\, e/b_1 \geq 0{,}3$ $P_0 = P_c + P_w = 0{,}3 \sqrt{f_{cc}}\, u_\alpha d + \beta A_{sw} f_y \sin\alpha$ $M_u = 0{,}3 \sqrt{f_{cc}}\, J / c$	(18) (19) (20) (21)	$\beta = 0{,}6$ - stirrups $\beta = 0{,}55$ - bent up bars additional restricts for u_α in [11]
8 [1)]	[54]	P_0 - according to (10) and (11) for $k_1 = k_2 = 1$	(22)	slabs and footings axially loaded with normal concrete
9	[29]	$P_0 = P_c + P_w$; P_c -according to (13) ; $P_w = \eta \frac{\Sigma M_y}{l_s - 0{,}5b}$ $\eta = 0{,}05 + 0{,}365 \left(\frac{l_s - 0{,}5b}{h_s} - 2{,}3\right)$	(23) (24)	slab-column connections with shearheads axially loaded

1) equations for designing

List of denotations to the formulas from Table 2:

A_{sw} - total section area, respectively for shear reinforcement with stirrups, bent-up-bars

b_1, b_2 - length of the sides of a rectangular column, respectively in the directions 1 and 2

c - distance from the column centre to the farthest point of the control perimeter

d, d_1, d_2 - effetive depth of the slab, and respectively for the rectangular-to-each-other directions 1 and 2

e - eccentricity of the punching force to the centre of cricital section constituting a geometric sum of static and geomertic eccentricity e_g

f_{cu}, f_c, f_{cc} - mean values of the compressive strength of concrete determined respectively on cubes 15x15x15 cm, cylinders 16 and h = 16 cm, and cylinders 15x30 cm

f_{ctd} - design tensile strength of the concrete according to PC [54]

f_{yw} - design strength of the steel of reinforcement with stirrups or bent-up-bars according to PC [54]

f_y - mean value of reinforcement yield stress of steel

h_s - depth of the shear-head section

I - polar moment of inertia of the critical section to the axis passing through its centre of gravity in the direction perpendicular to the moment plane

l_s - length of the arm of the shear-head

m, m^t, m^b - moment resistance per unit width of the tensioned reinforcement and the corresponding one for the top and bottom reinforcement

M_o - ultimate value of unbalanced moment for pure moment loading (P=0)

M_y - total plastic moment of the arms of the shearhead

n - number of the lateral planes of the column transferring the torsion moment

P_o - ultimate value of punching shear force for pure punching (M=0)

P_u - ultimate punching shear strength at eccentric load

P_c, P_w - shear forces transferred respectively by concrete and shear reinforcement

P_y - flexural strength determined according to yield line theory

s - axial spacing of the slab reinforcement bar

u - perimeter of the critical section at the distance 0,5 h_o from the sides of the column

u_d - perimeter at the distance h_o from the sides of the column

α - angle of the bending up of bars

ϕ - diameter of the tensioned reinforcement bars of the slab

ρ - slab reinforcement ratio

γ, β, η, k, k_1, k_2, k_z - coefficients

specification, modification or expansion of the already-known methods of foreign researchers. In [9] is presented a suggestion of specifying more closely the coeffcient γ in the method of ACI code [49] by relating its value to the reinforcement ratio of the slab - formula (4). Coefficient γ determines the part of the moment transferred through shearing at punching. The verification of modified-in-this-way method of ACI code carried out in [23] has shown that it gives a better conformity with the test results (159 models) than the code method. A somewhat different form of the coefficient γ has been given in [15], and checked on models of edge connections. The method based on an analysis of shear stresses in the critical section 0,5 h_o distant from the sides of the column has been presented in [23, 24] - formulas (1, 7, 8, 9). The load carrying capacity at symmetrical punching is calculated here from the modified Moe's formula (31). To calculate the load carrying capacity of the internal connections with shear reinforcement in the form of steel shearheads - formulas (12, 23, 24) Herzog's approach [18], as well as Corley and Hawkins method were used [5]. Herzog's approach was also used for edge connections [44] - formulas (13, 14, 15). Some expressions, based also on the analysis of the state of failure, which make it possible to take into account, among others, the influence of large holes in the column head region, are given in [33, 34] - formulas (1, 16, 17). The function of M and P interaction in the form of a parabole was used for an analysis of the strength of the connections shear reinforcement [11] - formulas (18 ÷ 21).
However, in [28] Kanoh's and Yozhizaki's beam analogy method [21] was adapted to calculate strength capacity of such connections.

In Polish recommendations [41] for the designing of slab-column structures, a universal and repeatedly verified American code [48] was adapted as it permits taking into consideration, in a relatively simple way, a great number of possible designing situations: internal and edge connection, shear reinforcement, eccentricity of the punching force, holes in column head region, proportions of the column sides dimensions, and shear-heads. A disadvantage of this method is in not including the tensile reinforcement ratio of the slab, the effect of this factor being many times confirmed in the investigations. The methods described above were analyzed by the authors with the test results of their own and of others. The synthetic results of these analyses are included in Table 3. The most extensively verified with the test results (159 models) were the methods [9] and [23] and also, indirectly, method [41].

Table 3

Veryfication of analytical formulas acc.to Table 2 with the test results

Method acc.to No Table 2	No 1	No 2	No 3	No 5	No 6	No 7	No 8		No 9
Reference	[23]	[15]	[23]	[44]	[33]	[11]	Fig. 2	Fig. 3	[29]
Number of models	159 (109)[1]	6	159 (109)	37	71	16	86	21	12
$\left(\frac{P_{obs}}{P_{cal}}\right)_{mean}$	1,307 (1,200)	0,978	1,121 (0,973)	1,014	1,008	0,994	1,128	1,127	0,965
Coefficient of var. ν [%]	25,89 (21,80)	5,76	31,54 (15,23)	7,50	10,51	13,90	13,27	24,00	3,21

[1] In parentheses, the values for prototype scale models only.

3. Punching shear in the light of code PN-84/B-03264 and CEB recommendations

The problem of punching shear in the Polish code was limited, to column footings only. The latest version of the code from 1984 [54] permits the use of equations (10, 11, 22) also for the purpose of checking the load carrying capacity of the slab elements, but only those axially loaded. Eccentric load may be considered, in a much simplified way, only for column footings. It should be noted that the state of axial punching in slab-column structures practically does not occur on account of horizontal loading or nonuniform distribution of vertical loads in the particuler floor fields. Moreover, the code approach does not include the effect of the ratio of the sides of the transverse section of the column which factor is essential for the rectangular columns - the corresponding coefficient is used e.g., in ACI code and following it - recommendations [41] and the recommendations of CEB. In Fig.2 is presented a confrontation of the code expression - formula (22) after assuming the mean values of the tensile strength of concrete (f_{ct}) with 68 results of various investigations of home and foreing authors, depending on the compressive strength of concrete f_{cu}. On the other hand, Fig.3 shows similar checking of the load carrying capacity of shear-reinforced elements in the column head region - here, obtained are higher values of the coefficient of variation ν of the ratios P_{obs}/P_{cal}.

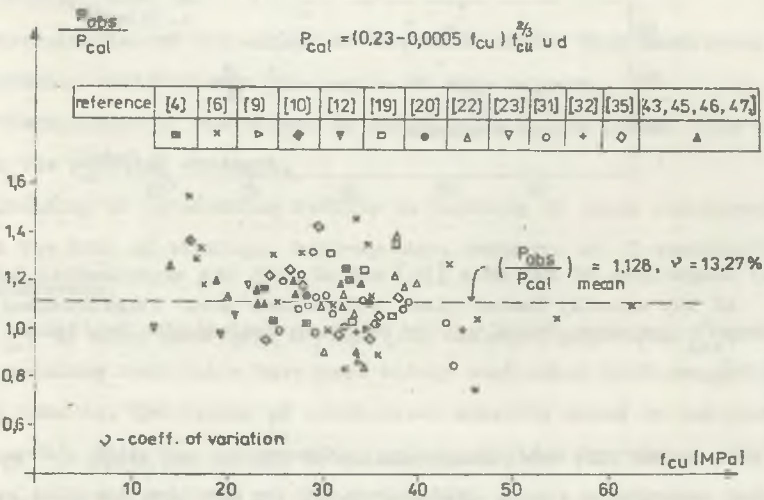


Fig.2 Comparison of the code PN-84/B-03264 [54] method with the experimental data of the axially loaded plate-models without shear reinforcement. Note: 1) P_{cal} according formula (10) computed for mean value of $f_{ct} = (0,23 - 0,0005\ f_{cu})\ f_{cu}^{2/3}$; 2) for lightweigth concrete used factor $k_1 = 0,75$

The obtained values of static measures correspond to the values obtained according to other code methods [2]. The recommendations of CEB FIP Model Code, 1990 on the punching of reinforced concrete slabs were not conclusively explicit in the first edition from Dubrownik [51]. Work is being continued in Committee IV and is based on the elaborations of CEB from 1978 [50] and 1985 [39]. For 86 models of reinforced concrete slabs, analyzed in Fig.2 at average concrete strength values, the mean value P_{obs}/P_{cal} = 1,297 was obtained according to CEB approach given in [50] with the coefficient of variation ν = 12,12%.

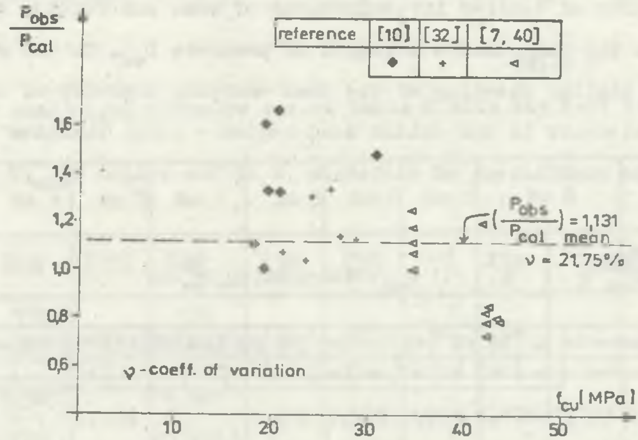


Fig.3 Comparison of the code [54] method with the experimental data of the axially loaded plate models with shear reinforcement; P_{cal} according formulas (10) and (11) for mean value of f_{ct}, f_{yw}

Hence, it results that the recommendation of CEB in the field of symmetrical punching are more cautious (about 15% in relation to the mean values) than the recommendation of the Polish code. The Rules of CEB permit, however, a better consideration, in the calculations of the load carrying capacity, of the effect of the slab depth, dimensions and proportions of the sides of the transverse section of the column, with due consideration to the effect of the slab reinforcement ratio and to other aspect of punching like; prestress, eccentricity of the punching force and holes. They also make possible taking into account the shear reinforcement in the punching region to a higher degree than Polish recommendations [41]. According to CEB [50] the strength of the column region with shear reinforcement is 1,6 of the strength of the not-reinforced region, while Polish code takes into consideration only a possibility of 40% increase of load carrying capacity (formula 11).

4. Recapitulation

In Poland, 179 models of slabs have been tested for punching. Eccentric load occurred in 88 cases, however, in available literature descriptions of tests of about 300 elements have been found.

Significant achievements of the investigations compiled in Table 2 are:

- a better distinction of the behaviour of reinforced concrete slabs made of lightweight and normal concrete at non-symmetrical coses of punching,
- determination of the effect of the reach of the slab cantilever on the punching resistance in the region of edge columns,
- determination of the effect of large holes in the column head region on the punching strength,
- obtaining of interesting results on punching of shear reinforced slabs in the form of stirrups, bent-up-bars, segments of I sections and shearheads.

The analytical expressions proposed by the Polish authors, determining the punching resistance have been widely confronted with own and foreign test results. The values of statistical measures based on analyses are comparable with the corresponding values obtained by other authors which is an indirect evidence of the credibility of the experiments made in this country. The specification presented in [9, 14, 15, 23, 28, 29, 44], and modifications [5, 18, 21, 31, 48] of methods led to a better conformance of the results of tests and calculations.

The tests and analyses of punching carried out in the country referred almost entirely to the static load. The effect of the dynamic load, as well as the phenomena of post punching behaviour have not been analyzed. These problems are particularly essential in the structures designed for the seismically active regions and are discussed i.a., in [7, 17, 39]. A proper construction of reinforcement of the column head region, taking into consideration the post failure phenomena permit suitable protecting of the structure against progressive collapse. As results from [17], the decisive factors here are: shear reinforcement and continuity of the bottom reinforcement of the slab, passing through the column.

Evident here is the lack of critical analyses, both in home literature and foreign one, dealing with a comparison of the test results obtained on simple models with relation to the real structures. It is a common view, partly confirmed in paper [35], that the expected load carrying capacities in the prototype will be higher than those obtained on models. A quantitative consideration of this problem has not been clarified and may be the subject of properly programmed studies. The mechanism of cracking and failure at punching, especially of the symmetrically loaded internal columns is now well identified. However, no universal method has been developed which would be based on a constitutive model, and which would take into account most of the factors affecting the strength capacity with the possible types of geometrical and static asymmetry (edge columns, holes etc.). It seems that such a solution may be found through an analysis of the state of failure, representing best the essence of the phenomena taking place.

There is a need for bringing up-to-date the home code rules on punching shear. The calculational expressions should take into consideration the effect of the reinformcement ratio of the slab, and of the proportion of the column sides on punching strength. These factors are reflected in most of the code recommendations [48, 49, 52].

The Polish code should also be supplemented with suitable recommendations dealing with the effect, on the load carrying capacity, of the eccentric load, prestress, holes, shearheads, etc.

Reference

[1] Ajdukiewicz A., Kliszczewicz A., Kliszczewicz R., Pająk Z., Starosolski W.: Badania doświadczalne żelbetowych ustrojów płytowo-słupowych, (Experimental research on reinforced concrete slab-column structures), Edited by W.Starosolski. Studies on Engineering, No 26, PWN, Warszawa-Łódź, 1988

[2] Ajdukiewicz A., Starosolski W.: Żelbetowe ustroje płytowo-słupowe, (Reinforced, slab-column structures), Arkady, Warszawa, 1981

[3] Badura J.: Badania nośności na ścinanie prefabrykowanych płyt stropowych podpartych w narożach, (Investigations of the shearing strength

of prefabricated floor slabs supported in the corners), Zeszyty Naukowe Politechniki Śląskiej, Budownictwo, No 60, 1985

[4] Corley W.G., Hawkins N.M.: Shearhead reinforcement for slabs. ACI Journal, No 10, 1968

[5] Corley W.G., Hawkins N.M.: Moment transfer to columns in slabs with shear reinforcement. SP-42 Shear in reinforcement concrete, ACI, Detroit, Mich. 1974

[6] Elstner R.C., Hognestad E.: Shearing strength of reinforced concrete slabs. ACI Journal, No 2, 1956

[7] Ghali A., Elmasri M.Z., Dilger W.: Punching of flat plates under static and dynamic horizontal force. ACI Journal, No 10, 1976

[8] Godycki-Ćwirko T.: Mechanika betonu, (The mechanics of concrete), Arkady, Warszawa, 1982

[9] Godycki-Ćwirko T., Dilger H.W., Ghali A.: Behaviour of reinforced concrete slab-column connections subjected to static loadings. Archiwum Inżynierii Lądowej, No 2, 1977

[10] Godycki-Ćwirko T., Kosińska A.: Punch failure of concrete flat plates with shear reinforcement, Archiwum Inżynierii Lądowej, No 3, 1980

[11] Godycki-Ćwirko T., Kosińska A.: Stan graniczny mimośrodowego przebicia złączy płyta-słup ze zbrojeniem poprzecznym, (Ultimate state of the eccentric punching of the slab-column connections with shear reinforcement). Inżynieria i Budownictwo, No 6, 1982

[12] Godycki-Ćwirko T., Kozicki J.: Flat plates with shearhead reinforcement. Archiwum Inżynierii Lądowej, No 4, 1978

[13] Godycki-Ćwirko T., Kozicki J.: Shearing strength of partly prestressed concrete slab-column connections under concentrated loads. The Ninth International Congress of the FIP, Stockholm, June 6÷10, 1982

[14] Godycki-Ćwirko T., Kozicki J.: Eccentrically loaded interior slab-column connections with, shearhead reinforcement. Materiaux et Constructions, No 98, 1984

[15] Godycki-Ćwirko T., Urban T.: Prodavlivanie żeleobetonnych bezbałocznych perekritij w zone krajnych kołonn, (Punching of the reinforced concrete flat-slabs in the region of edge columns).Bieton i Żelezobieton, No 4, 1980

[16] Godycki-Ćwirko T., Kozicki J., Urban T.: Morfologia rys krzyżowo zbrojonych bezbelkowych stropów żelbetowych, (The cracking morphology of two-way reinforced concrete flat slab floors), Inżynieria i Budownictwo, No 7-8, 1981

[17] Hawkins N.M., Mitchell D.: Progressive collapse of flat plate structures. ACI Journal, No 7, 1979

[18] Herzog M.: Wichtige Sonderfälle das Durchstanzens von Stahlbeton - und Spannbetonplatten nach Versuchen. Der Bauingenieur, No 9, 1974

[19] Hognestad E., Elstner R.C., Hanson J.A.: Shear strength of reinforced structural lightweight concrete slab. ACI Journal, No 6, 1964

[20] Ivy Ch.B., Ivey D.L., Buth E.: Shear capacity of lightweight concrete flat slabs. ACI Journal, No 6, 1969

[21] Kanoh Y., Yoshizaki S.: Strength of slab-column connections transferring shear and moment. ACI Journal, No 3, 1979

[22] Kinnunen S., Nylander H.: Punching of concrete slabs without shear reinforcement. Transactions of the Royal Institute of Technology, Stockholm, No 158, 1960

[23] Kliszczewicz R.: Nośność żelbetowych połączeń płyty ze słupem na mimośrodowe przebicie, (The strength of reinforced concrete slab-column connections for eccentric punching). Unpublished Ph.D. thesis, Silesian Technical University, Gliwice, 1976

[24] Kliszczewicz R.: Obliczanie żelbetowych połączeń płyty ze słupem przenoszących moment i siłę przebijającą, (Calculations of the reinforced concrete connections of the slab with the column transferring the moment and punching force). Proceedings of XXIII Scientific Conference on "Actual Research Problems in Civil Engineering, Krynica, 1977

[25] Kliszczewicz R., Pająk Z., Starosolski W.: Badania nośności połączenia płyty ze słupem prefabrykowanym przy obciążeniu osiowym, (Investigations of the load carrying capacity of the slab-prefabricated column connection at axial load). Archiwum Inżynierii Lądowej, No 4, 1977

[26] Korpys K.: Sprawozdanie z badań próbnych połączeń stropu i słupa budynku szkieletowego, realizowanego metodą wypychania kondygnacji, (Report on the investigations of experimental connections of the slab and column of a skeleton building realized by means of the storey "jack up" method). Unpublished Technical Report, Silesian Research and Experimental Establishment of Civil Engineering, Katowice, 1964

[27] Kosińska A.: Złącze płyta-słup z belkowym zbrojeniem poprzecznym poddane różnym rodzajom obciążenia, (Slab-column connection with beam shear reinforcement subjected to various kinds of loads). Proceedings of XXX Scientific Conference on "Actual Research Problems in Civil Engineering", Krynica, 1984

[28] Kosińska A.: Metoda analogii belkowej w zastosowaniu do oceny nośności mimośrodowego przebicia płyt, (The beam analogy method as used for the estimation of the eccentric punching strength of slabs). Proceedings of XXXI Scientific Conference on "Actual Research Problems in Civil Engineering", Krynica, 1985

[29] Kozicki J.S., Urban T.T.: Analiz niesuszczej sposobnosti żelezobietonnych pieriekrytij w zonie siprijazenija plity s kołonnoj, (Analysis of the load carrying capacity of the reinforced concrete

slab-floors in the region of slab-column connection. Bieton i Żelezobieton, No 5, 1983
[30] Langohr P.H., Ghali A., Dilger W.H.: Special shear reinforcement for concrete flat plates. ACI Journal, No 3, 1976
[31] Moe J.: Shearing strength of reinforced concrete slabs and footings under concentrated loads. Bulletin D47, Portland Cement Association, Illinois, 1961
[32] Pająk Z.: Badanie wpływu otworów na nośność żelbetowych połączeń płytowo-słupowych, (Investigations on the effect of holes on the load carrying capacity of reinforced concrete slab-column connections). Proceedings of XXVII Scientific Conference on "Actual Research Problems in Civil Engineering", Krynica, 1981
[33] Pająk Z.: Przebicie żelbetowych płyt z dużymi pionowymi otworami, (Punching shear of the reinforced concrete slabs with large holes). Archiwum Inżynierii Lądowej, No 2, 1986
[34] Pająk Z.: Strefa podporowa z otworami w stropach ustrojów płytowo-słupowych, (Column head region with holes in the floors of slab-column structures). Inżynieria i Budownictwo, No 3, 1986
[35] Pająk Z., Kliszczewicz R., Starosolski W.: Badania na przebicie grubych płyt żelbetowych, (Investigations of the punching strength of thick reinforced concrete slabs). Zeszyty Naukowe Politechniki Śląskiej, Budownictwo, No 60, 1985
[36] Pająk Z., Starosolski W.: Badanie szczególnego rozwiązania konstrukcyjnego skrajnej strefy podporowej stropu płytowo-słupowego, (Investigations on a special structural solution of the edge column head region of the slab-column floor). Proceedings of XXVI Scientific Conference on "Actual Research Problems in Civil Engineering", Krynica, 1980
[37] Pająk Z., Starosolski W.: Badania nośności i odkształcalności złączy płyta-słup w budynkach realizowanych metodą podnoszenia stropów, (Tests of load carrying capacity and deformability of slab-column connections in buildings erected by the lift-slab method). Proceedings of XXXV Scientific Conference on "Actual Research Problems in Civil Engineering", Krynica, 1989
[38] Pająk Z., Starosolski W.: Badania strefy podporowej stropów budynków mieszkalnych realizowanych metodą podnoszenia, (Tests of the column head region of floors in apartment buildings erected by the lift-slab method). Unpublished Technical Report, Silesian Technical University, Gliwice, 1979
[39] Regan P.E., Braestrup M.W.: Punching shear in reinforced concrete. Bulletin d'Information No 168, CEB, 1985
[40] Seible F., Ghali A., Dilger W.H.: Preassembled shear reinforcing units for flat plates. ACI Journal, No 1/2, 1980
[41] Starosolski W., Ajdukiewicz A., Kliszczewicz R., Pająk Z.: Wytyczne projektowania monolitycznych ustrojów płytowo-słupowych,

(Recommendations for the designing of monolithic slab-column structures). COBPBO, Warszawa, 1984

[42] Starosolski W., Badora T., Kliszczewicz R.:Badania połączenia płyty ze słupem obciążonego siłą i momentem, (Investigations on the slab-column connection loaded with force and moment). Proceedings of XVIII Scientific Conference on "Actual Research Problems in Civil Engineering", Krynica, 1971

[43] Urban T., Godycki-Ćwirko T.: Wpływ geometrii modeli na nośność monolitycznych złączy płyta-słup, (The effect of model geometry on the load carrying capacity of monolithic slab-column connections). Proceedings of XXIV Scientific Conference on "Actual Research Problems in Civil Engineering", Krynica, 1978

[44] Urban T.: Nośność na przebicie płaskich stropów w strefie słupów skrajnych, (Punching strength of flat slabs in the region of edge columns). Inżynieria i Budownictwo, No 7÷8, 1981

[45] Urban T.: Badania żelbetowych złączy płytowo-słupowych z dodatkiem drutu ciętego w strefie przysłupowej, (Investigations on reinforced concrete slab-column connections with an addition of cut steel fiber in the column region). Inżynieria i Budownictwo, No 10, 1984

[46] Urban T.: Badanie nośności żelbetowych płaskich stropów w strefie słupów skrajnych, (Investigations of the load carrying capacity of reinforced concrete flat floors in the region of edge columns). Zeszyty Naukowe Politechniki Łódzkiej, Budownictwo, No 33, 1984

[47] Urban T., Kozicki J.: Złącze dyblowe "płyta-słup" w świetle badań eksperymentalnych, ("Slab-column" dowel joint in the light of experimental tests). Inżynieria i Budownictwo, No 2, 1988

[48] ACI Committee 318: Building code requirements for reinforced concrete (ACI 318-83). American Concrete Institute, Detroit, Mich, 1983

[49] British Standard Code of Practice CP 110. The structural use of concrete. British Standards Institution, London, 1972

[50] CEB-FIP Model code for concrete structures. CEB-FIP International Recommendations, 3 rd. Edition, 1978

[51] CEB-FIP Model code 1990. Bulletin d'Information, No 190a and 190b, Dubrownik, 1988

[52] DIN 1045: Beton - und Stahlbetonbau - Bemessung und Ausführung. Deutsche Normen, January, 1972

[53] Joint ASCE -ACI Task Committee 426: The shear strength of reinforced concrete members-slabs. Journal of the Structural Division; Proceedings of the ASCE, vol. 100, No ST 8, 1974

[54] Polish code (PN-84/B-03264). Konstrukcje betonowe, żelbetowe i sprężone. Obliczenia statyczne i projektowanie, (The concrete reinforced concrete and prestressed structures. Static calculations and designing).

PUNCHING SHEAR RESEARCH OF REINFORCED CONCRETE PLATES IN POLAND

Summary

This report presents a reviev of home achievements in the scope of analysis of the phenomenon of punching shear in reinforced concrete slabs in comparison to world scientific knowledge. On the basis of bibliography of the works of home authors, the experimental investigations and the analysis of load carrying capacity and cracking resistance of reinforced concrete slabs at punching are presented, and the calculation methods, as well as code rules are discussed. Finally, the trends for future research works are mentioned.

Keywords: reinforced concrete plates, slab-column connetions, models, punching tests, punching shear strength, structural analysis, research.

POLSKIE BADANIA PRZEBICIA ŻELBETOWYCH PŁYT

Streszczenie

Referat prezentuje przegląd krajowych osiągnięć w zakresie analizy zjawiska przebicia w żelbetowych płytach. Na podstawie bibliografii prac autorów krajowych opisano badania doświadczalne, przedstawiono analizę nośnosci i zarysowania przy przebiciu żelbetowych płyt, omowiono metody obliczeniowe i przedyskutowano także zalecenia normowe. W podsumowaniu wskazano kierunki przyszłych badań dotyczących przebicia.

ПОЛЬСКИЕ ИССЛЕДОВАНИЯ ПРОДАВЛИВАНИЯ ЖЕЛЕЗОБЕТОННЫХ ПЛИТ

Резюме

В статье описаны странные достижения касающиеся анализа продавливания железобетонных плит в сравниванию к состаяния мирной науки. На основе библографии работ странных афторов описано експериментальные исследования, представлено анализ несущей способности и трещиностойкости при продавливании железобетонных плит, расмотрено расчетные методы и передискутировано также стандартные рекомендации. В заключению указано направления будущих исследований касающиеся продавливания.