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PUNCHING SHEAR OF RC FLAT SLABS WITH OPENINGS

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Abstract: *The scope of this research is flat reinforced concrete slabs with opening near the middle column and without the special reinforcement for accepting the shear forces caused by punching shear. Three reinforced concrete slabs supported on rectangular column were analyzed. They differed only from the position of the opening in relation to the column. The opening for each slab had the same dimensions and shape, square with sides of 100 mm. The design values of the punching shear for the slabs with openings were obtained according to EC 2. Obtained values were compared with the design punching shear of the same slab without an opening, based on that, the influence of this parameter on the behavior of reinforced concrete slabs was determined.*

Key words: *RC flat slabs, openings, punching shear.*

1. Introduction

In this paper flat reinforced concrete slabs supported directly on column and their bearing capacity in relation to the punching were analyzed. Under directly supported slabs on columns are considered slabs without thickening at the point of contact with the column. When the slab is supported on a small surface, very complex three-axis stresses of high intensity are realized, which can not be estimated using the methods of classical bending theory. The complex three-axis state of the stresses is further complicated in the case of unsymmetrical geometry and load, i.e. presence of an opening near the column or due to the eccentric load of the plate. With the rise of the reaction of the column, the cracks in the slab around the columns has been developed, which eventually leads to the formation of a conical surface of the fracture just above and around the column. In the moment of fracture, a concrete body limited by a conical surface punches through the slab, and this break is called punching shear. The primary breakage due to punching shear occurs before the reinforcement for receiving longitudinal stress enters in the yield strength. This breakage is brittle, without prior notice and therefore a very dangerous. The most common application of the system of slabs directly supported by columns is in residential buildings and industrial buildings,

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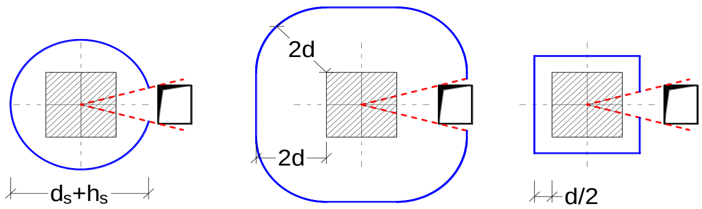
where often for the needs of installation, where in the areas near the column there are openings for the passage of various types of installations. The presence of the openings in this area of the slab reduces its bearing capacity, and in particular adversely affects the bearing capacity of the slab at punching [3,5,6]. For this reason, the special attention of this paper is devoted to centrically loaded slabs with an opening near the middle column while varying the position of the opening in relation to the column.

The influence of the opening near the column according to the regulations of most countries [1,2,4] is taken into account by neglecting the part of the critical cross section obtained by pulling the tangents from the axis of the column to the opening in the slab. In this way, the distance of the opening from the column is taken into account, with the punching shear being larger as the opening is farther away from the support slab. The critical cross-section is located at a certain distance from the face of the column that depends on the regulations and ranges from one half to a double static slab height (Figure 1).

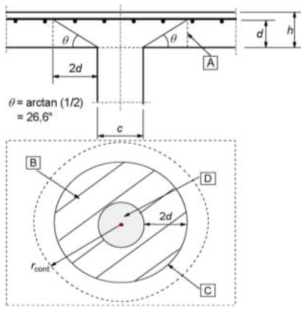


a) PBAB; b) EC2; c) ACI

Fig 1. *Determination of the critical cross-sectional area according to*

2. Punching Shear of Slab According to Eurocode 2

Revision of the boundary load capacity for punching slabs directly supported on columns or loaded with concentrated loads according to Eurocodes is carried out using the critical cross-section method. The shear resistance should be checked at the face of the column and at the basic control perimeter u_1. If shear reinforcement is required a further perimeter $u_{out,ef}$ should be found where shear reinforcement is no longer required. Other control perimeters, u_i, inside and outside the basic control surface, should be of the same shape as the basic control perimeter.



A – basic control section
B – basic control area
C – basic control perimeter, u_1
D – loaded area, A load
r_{cont} – further control perimeter

Fig. 2. *Verification model for punching shear at the ultimate limit state*

2.1. Load distribution and basic control perimeter

The basic control perimeter u_1 may normally be taken to be at a distance *2d* from the loaded area and should be constructed so as to minimise its length (see Figure 3).The effective depth of the slab is assumed constant and may normally be taken as:

$$d_{eff} = \frac{(d_y + d_z)}{2}$$

where d_y and d_z the effective depths of the reinforcement in two orthogonal directions.

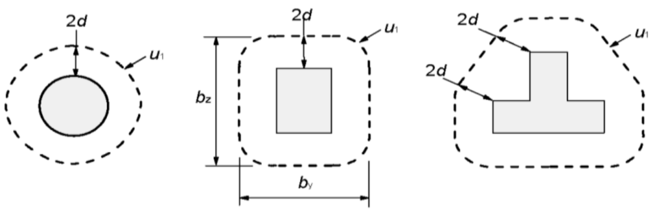


Fig. 3. *Typical basic control perimeters around loaded areas.*

For loaded areas situated near openings, if the shortest distance between the perimeter of the loaded area and the edge of the opening does not exceed 6d, that part of the control perimeter contained between two tangents drawn to the outline of the opening from the centre of the loaded area is considered to be ineffective (see Figure 4).

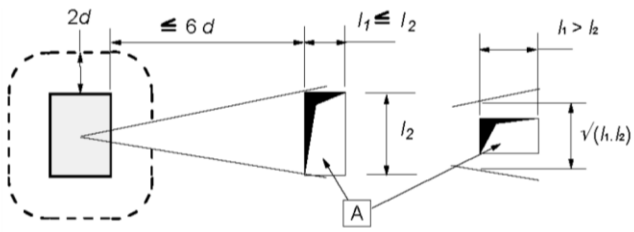


Fig. 4. *Control perimeter near an opening*

2.2.Punching shear calculation

The design procedure for punching shear is based on checks at the face of the column and at the basic control perimeter u_1. The design shear stresses (MPa) along the control sections, are defined as:

$v_{Rd,c}$ – the design value of the punching shear resistance of a slab without punching shear reinforcement along the control section considered;

$v_{Rd,cs}$ – the design value of the punching shear resistance of a slab with punching shear reinforcement along the control section considered;

$v_{Rd,max}$ – the design value of the maximum punching shear resistance along the control section considered.

The following checks should be carried out:

a) At the column perimeter, or the perimeter of the loaded area, the maximum punchin shear stress should not be exceeded:

$$v_{Ed} \leq v_{Rd,max}$$

b) Punching shear reinforcement is not necessary if:

$$v_{Ed} \leq v_{Rd,c}$$

c) Where v_{Ed} exceeds the value $v_{Rd,c}$ for the control section considered, punching shear reinforcement should be provided according to punching shear resistance of slabs and column bases with shear reinforcement.

2.3.Punching shear resistance of slabs and column bases without shear reinforcement

The punching shear resistance of a slabshould be assessed for the basic control section and the design punching shear resistance MPa may be calculated as follows:

$$v_{Rd,c} = C_{Rd,c}\, k\,(100\rho_1 f_{ck})^{1/3} + k_1\sigma_{cp} \geq v_{min} + k_1\sigma_{cp}$$

where:

f_{ck} in MPa;

$$k = 1 + \sqrt{\frac{200}{d}} \leq 2{,}0 \,;\, d \, u \, mm;$$

$$\rho_1 = \sqrt{\rho_{ly} \cdot \rho_{lz}} \leq 0{,}02;$$

ρ_{ly}, ρ_{lz} relate to the bonded tension steel in y- and z- directions respectively. The values ρ_{ly} and ρ_{lz} should be calculated as mean values taking into account a slab width equal to the column width plus 3d each side.

$$\sigma_{cp} = (\sigma_{cy} + \sigma_{cz})/2$$

where:

σ_{cy}, σ_{cz} – are the normal concrete stresses in the critical section in y and z-directions (MPa, positive if compression):

$$\sigma_{cy} = \frac{N_{Ed,y}}{A_{cy}} \; ; \; \sigma_{cz} = \frac{N_{Ed,z}}{A_{cz}}$$

$N_{Ed,y}, N_{Ed,z}$ – the longitudinal forces across the full bay for internal columns and the longitudinal force across the control section for edge columns. The force may be from a load or prestressing action.

A_c – the area of concrete according to the definition of N_{Ed}.

The recommended value for $C_{Rd,c} = 0{,}18/\gamma_c$, $k_1 = 0{,}1$; $v_{min} = 0{,}035k^{3/2} \cdot f_{ck}^{\frac{1}{2}}$.

3. Numerical Example

The bearing capacity of the slab in relation to the punching depends on a large number of parameters (static height of a slab, dimensions and shape of the column, concrete strength, reinforcement coefficient, yield strength of steel, way of reinforcement the slab to the punching...), and that is the reason why it is necessary to limit the domain of research in order to estimate the influence of individual parameters on the influence of others or interaction with other parameters. In this regard, the subject of this research is limited to flat reinforced concrete slabs with an opening near the middle column and without additional shear reinforcement for accepting the punching shear caused by punching.

The concrete cover for the top and bottom bars of slab was 15 mm, the reinforcing bars had a specified yield strength of 500 MPa and the effective depth were 151 mm. Top bars of reinforcement of slab, Φ14/10, are shown in Figure 5b and bottom bars, Φ10/20, are shown in Figure 5a. For the concrete class it was chosen C30/37.

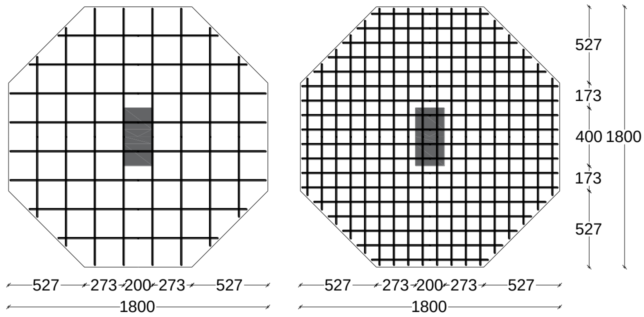


Fig. 5. *a)Bottom bars of reinforcement Φ 10/20; b)Top bars of reinforcement Φ 14/10*

In order to determine the influence of the position of the opening in relation to the column, three slabs supported directly on the middle rectangular column were analyzed. The opening for each slab was of the same dimensions and shape, square with sides of 100 mm. The position of the opening in the slab is shown in Figure 6. The calculating punching shear for the slabs with openings, obtained according to the data in Chapter 2 of this paper, are compared with the design punching shear of the slab without an opening (Table 1).

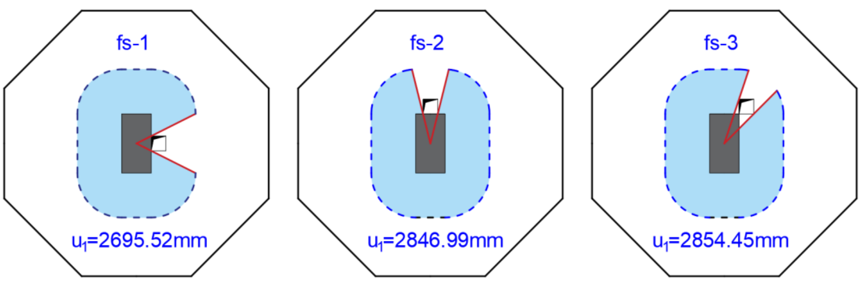


Fig. 6 .*Schematic description of the position of opening for the analysed slabs*

Comparative results of punching shear according EC2 *Table 1*

The design punching shear (kN)		Loss of force from the opening (%)
Slab without opening	305.26	-
fs-1	265.64	13.01%
fs-2	280.57	8.09%
fs-3	281.31	7.85%

4. Conclusions

The influence of openings near the column according to the regulation of most countries is taken into account by neglecting the section of the critical cross section obtained by pulling the tangents from the axis of the column to the opening in the slab. The regulations differ among themselves in determining the position and shape of the critical cross-section, which is located at a certain distance from the face of the column. This distance ranges from one half to a double static height of a slab. This paper presents a detailed procedure for the design of the punching shear of reinforced concrete slabs with an opening and without a reinforcement according to the Eurocode. Three different slabs were analyzed in which the only variable was the position of the opening in relation to the column. The obtained results were compared with the values of the punching shear for the slab without an opening. Although the hole in each slab was the same dimensions (square with sides 100mm), the greatest loss of force appeared at the fs-1 slab whose opening is along the longer face of the column. The smallest power loss was created for the position of the opening at the corner of the column (slab fs-3), and this position is recommended for useage if there is autonomy in choosing the position of the openings in the slab.

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