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INFLUENCE OF GROUND STRESS DISTRIBUTION ON PUNCHING RESISTANCE

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Abstract: *The presented paper brings new aspects of ground stress distribution influence on punching resistance for two types of subsoil. After the analysis of punching phenomena, paper continues with a comparison of the uniform ground stresses and software numerical model ground stresses distribution and their influence on the calculation of three types of footings and their punching resistance.*

Keywords: Ground Stresses, Footings Stiffness, Punching, Shear Resistance.

1. Introduction

Punching as dangerous phenomenon in structural engineering needs two steps of verification. The first one is a diagonal strut failure verification (crushing of concrete) at control perimeter u_0 of a column and the second one is the shear-tension failure verification of concrete or transverse reinforcement in circumference of area surrounded by control perimeters u_i, which are analysed in distances from 0.5*d* to 2.0*d* (if possible) from face of column (Fig. 1).

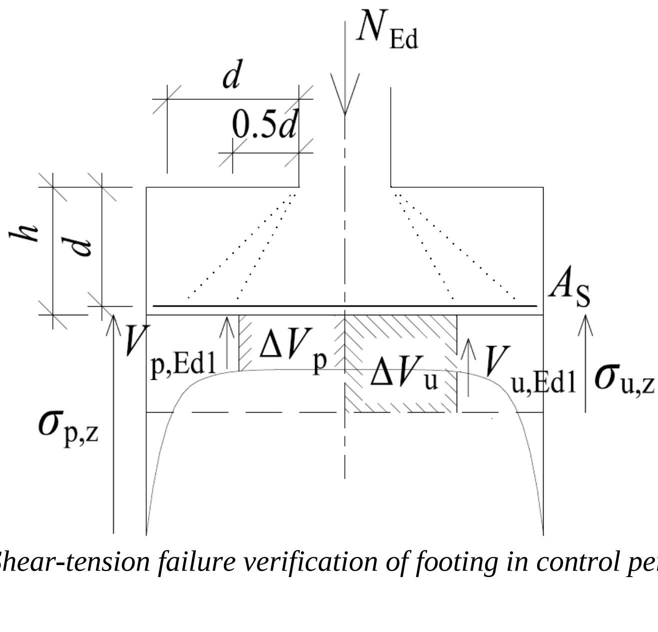

Fig. 1: Shear-tension failure verification of footing in control perimeters.

2. Soil Parameters

Two types of subsoil were used for calculation, according to geology of Bratislava. The first subsoil consisted of three soil layers. The second subsoil consisted of one soil layer. The properties of the soils are described in Tab. 1. For each subsoil the design resistance calculation (R_d) was done, after (1) (EN 1997-1:2004, 2010 and Cajka, 2016).

$$R_\mathrm{d} = (c'_\mathrm{d}\ N_\mathrm{c} s_\mathrm{c} d_\mathrm{c} \mathrm{i}_\mathrm{c} j_\mathrm{c} + q' N_\mathrm{q} s_\mathrm{q} d_\mathrm{q} i_\mathrm{q} j_\mathrm{q} + \gamma' B / 2 N_\gamma s_\gamma d_\gamma i_\gamma j_\gamma) / \gamma_\mathrm{R} \qquad (1)$$

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Tab. 1: Soil Parameters.

Parameters	Subsoil 1			Subsoil 2
	1. Layer	2. Layer	3. Layer	Layer
E_{def} [MPa]	5	70	5	100
v [-]	0.4	0.25	0.4	0.25
c_{ef} [kPa]	14	-	10	-
φ_{ef} [°]	18	33	15	33
γ [kN/m^3]	21	19	20	19
h [m]	4	4	10	20

3. Verification of Punching

The maximum shear force is limited by compressive capacity of the struts at the column perimeter. Crushing of the struts at column perimeter is controlled by reduced compressive strength of concrete (2) according to (EN 1992-1-1:2004/AC, 2010).

$$v_{\mathrm{Ed,max}} = \frac{\beta V_{\mathrm{Ed}}}{u_0 d} \le v_{\mathrm{Rd,max}} = 0.4 v f_{\mathrm{cd}} \tag{2}$$

$$\nu = 0.6\left[1 - \frac{f_{ck}[\mathrm{MPa}]}{250}\right] \tag{3}$$

Another limit for the punching resistance is also derived from concrete shear resistance (4) according to (EN 1992-1-1:2004/AC, 2010). Requirements concerning the maximum punching shear resistance are based on the $k_{\max}$ factor (Hanzel et al., 2014) and punching shear resistance without shear reinforcement v_{Rdc} (4) and (5).

$$v_{\mathrm{Rd,c}} = \frac{0.18}{\gamma_{\mathrm{c}}} k\left(100\rho_{\mathrm{l}} f_{\mathrm{ck}}\right)^{1/3} \frac{2d}{a} \ \ge\ 0.035 k^{3/2} f_{\mathrm{ck}}^{1/2} \frac{2d}{a} \tag{4}$$

$$v_{\mathrm{Rd,cs}} = 0.75 v_{\mathrm{Rd,c}} + \left(\frac{1.5d}{s_{\mathrm{r}}}\right) \frac{A_{\mathrm{sw}} f_{\mathrm{ywd,ef}}}{u_1 d} \le k_{\max} v_{\mathrm{Rd,c}} \tag{5}$$

Latest experiments have also shown that the $k_{\max}$ value depends on many factors. The first and the most important factor is the type of shear reinforcement and particularly conditions for their anchoring. For this analysis $k_{\max}$ =1.46 (200 < d < 700 mm) was used (Fingerloos et al., 2012).

Calculation of the punching shear force V_{Ed} depends on influence of ground resistance distribution (Fig. 1). If we take into account uniform distributed ground stresses, ΔV_{u} is bigger than a part of force ΔV_{p}, which comes from a more precise distribution of ground stresses and therefore this simpler design of footings brings the unsafe solution, because the punching shear force on the load side is lower.

$$V_{\mathrm{Ed}} = N_{\mathrm{Ed}} - \Delta V_{\mathrm{u}} \tag{6}$$

This shear force enters into the condition of reliability similarly as in equation (1). ΔV_{u} is the result of the uniform ground resistance distribution (Fig. 1). If we consider a more precise distribution of ground stresses, ΔV_{p} (Fig. 1) is less than ΔV_{u} and therefore brings the bigger punching shear force and the verification of punching is more conservative but the safe side.

The more precise analysis of ground stresses comes from a numerical model, created in Sofistik – software, based on FEM (Finite Element Method) with Boussinesq subsoil.

The two types of footings were analyzed for the subsoil 1 – the thickness - 360 mm for the footing with shear reinforcement and the thickness 510 for the footing without shear reinforcement.

For the subsoil 2 only a footing with a thickness – 900 mm was analyzed, because in this case the limiting criterion for punching was the crushing of a concrete strut. All footings were made from the concrete C25/30, with column 500 x 500 mm.

Tab. 2: Footings parameters.

	1. Footing (1. subsoil)	**2. Footing (1. subsoil)**	**3. Footing (2. subsoil)**
Dimensions [mm]	2800 x 2800 x 360	2800 x 2800 x 510	2800 x 2800 x 900
ρ [kN]	0.0052	0.0021	0.0018
N_{Ed} [kN]	1850	1800	5400
ΔV_p [kN]	267	410	2856
ΔV_u [kN]	148	226	1555
$v_{p,Ed}$ [kN/m^2]	1679	835	723
$v_{u,Ed}$ [kN/m^2]	1562	736	479
$v_{Rd,c}$[kN/m^2]	1055	753	635
$v_{Rd,cs}$[kN/m^2]	1562	-	-

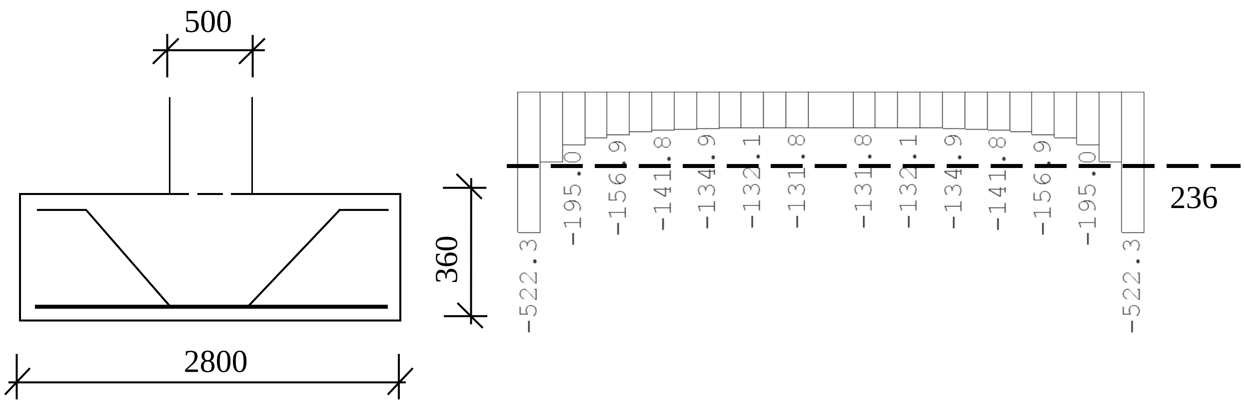

Fig. 2: Footing with shear reinforcement (left), ground stress [kPa] (right) – Subsoil 1.

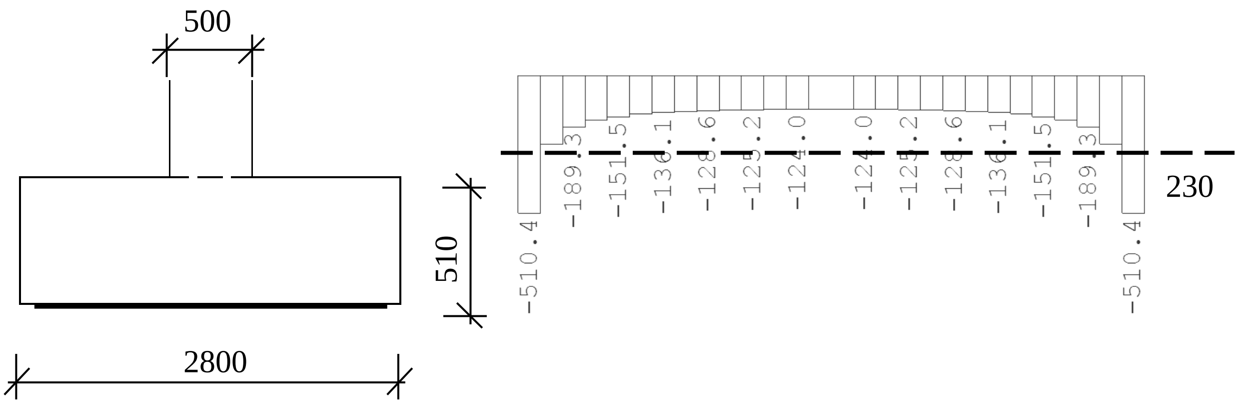

Fig. 3: Footing without shear reinforcement (left), ground stress [kPa] (right) – Subsoil 1.

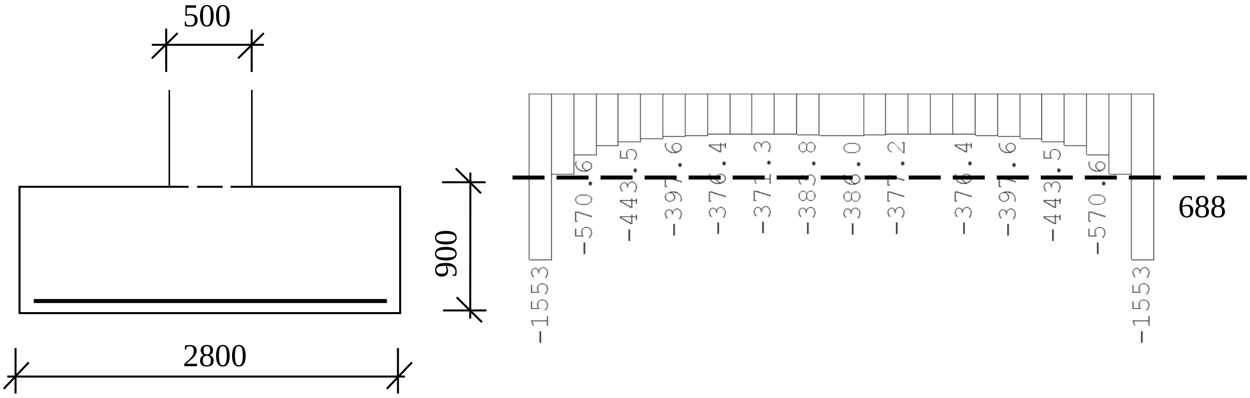

Fig. 4: Footing without shear reinforcement (left), ground stress [kPa] (right) – Subsoil 2.

4. Conclusions

The paper presents results of two types of subsoil and three types of footing analysis and their influence on punching resistance. After the analysis of punching phenomena, paper continues with a comparison of the uniform ground stresses and more precise - software numerical model ground stresses distribution and their influence on the calculation of the punching phenomenon. Tab. 2 confirms that suggestion of uniform stresses distribution brings results on unsafe side for all considered types of footings and subsoils, respectively.

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References

Cajka, R., Labudkova, J. and Mlynarcik, P. (2016) Numerical solution of soil-foundation interaction and comparison of results with experimental measurements. International Journal of GEOMATE 11(1) pp. 2116-2122.

Hanzel, J., Majtánová, L. and Halvonik, J. (2014) Punching Resistance of Flat Slabs without Shear Reinforcement. In 21. Concrete Days 2014. Proceedings of Conference. Prague, 6 p.

EN 1992-1-1:2004/AC (2010), Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings.

EN 1997-1:2004 (2010) Eurocode 7: Geotechnical – general requirements.

Fingerloos, F., Hegger, J. and Zilch K. (2012) EUROCODE 2 fur Deutschland. Ernst & Sohn, 387 p.