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SIMILARITY OF SHALLOW FOUNDATIONS ACCORDING TO ČSN 73 1001

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Summary: *Now, that the translation into Czech and the National Annex of EC7-1 (EUROCODE 7 - Geotechnical design, Part 1: General rules) are carried out it seems convenient to make a broad comparative analysis of the EC7-1 and ČSN 73 1001 design procedures. The calculating procedure according to ČSN 73 1001 requires 8 inputs, the similar procedure according to EC7-1 requires 10 inputs. These numbers of inputs yield a huge number of combinations for a comparative analysis.*

The paper deals with a similarity solution of bearing capacity of shallow foundations according to ČSN 73 1001. The solution should form the base of the comparative analysis base for simpler numerical analysing.

1 Introduction

The Czech standard ČSN 73 1001 "Subsoil under shallow foundations" is the oldest Czech LSD standard (1966). It was slightly amended several times but its original creators have done very good work. The standard is still of high professional level and is widely used by practicing professionals. Its long-term application of the standard has granted applying professionals much knowledge and certainty.

The standard contains not only the requirements and instructions for the design of shallow foundations, but also a complete set of important and verified tables of soil classification and soil material parameters. Now, that the translation into Czech and the National Annex of EC7-1 (EUROCODE 7 - Geotechnical design, Part 1: General rules) are carried out it seems convenient to make a broad comparative analysis of the EC7-1 and ČSN 73 1001 design procedures.

The calculating procedure according to ČSN 73 1001 requires 8 inputs, similar procedure according to EC7-1 requires 10 inputs. These numbers of inputs yield a huge number of combinations for a comparative analysis. Most of them are due to geotechnical material parameters (especially angle of soil resistance and cohesion) which can vary broadly and their influence at bearing capacity is strong. An easier approach to problem solution is provided by the theory of similarity. The paper deals with a similarity solution of bearing capacity of shallow foundations according to ČSN 73 1001. The solution should form the basis comparative analysis for simpler numerical analysing.

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2 Bearing Capacity According to ČSN 73 1001

The Czech standard ČSN 73 1001 “Subsoil under shallow foundations” is based on the Limit State Design (LSD) theory like EC7-1. Its procedure requires the following 8 inputs:

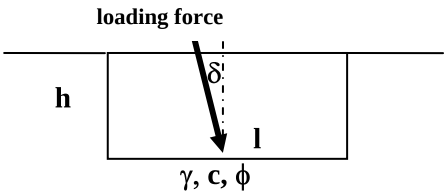

Fig.1 Scheme of shallow foundation and parameters.

- b - width or radius of the foundation,
- h - depth (height) of the foundation,
- l - length of the foundation,
- δ – deviation of loading force from vertical direction,
- γ_1 - unit weight of soil above foundation plain,
- γ_2 - unit weight of soil below foundation,
- ϕ_d - angle of soil resistance - design value,
- c_d - cohesion - design value.

All parameters should be considered as design values. The first four quantities are geometrical, the last four material properties.

The solution is based on three following dimensionless functions of the angle of soil resistance which characterize the influence of foundation width, cohesion and angle of soil resistance:

$$N_b = 1.5\,(N_b - 1)*tg\,\phi_d \tag{1}$$

$$N_c = (N_b - 1)*cotg\,\phi_d \qquad \phi_d > 0 \tag{2}$$

$$N_c = 2 + \pi \qquad \phi_d = 0 \tag{2`}$$

$$N_d = tg^2\,(45+\phi_d/2)*exp(\pi * tg\,\phi_d) \tag{3}$$

Bearing capacity is determined by equation

$$R_d = c_d * N_c * s_c * d_c * i_c + \gamma_1 * h * N_d * s_d * d_d * i_d + \gamma_2 * 0.5 * b * N_b * s_b * d_b * i_b \tag{4}$$

where coefficients *s, d, i* follow from

$$s_c = 1 + 0.2 * b/l \qquad d_c = 1 + 0.1\sqrt{h/b} \qquad i_c = (1 - tg\delta)^2 \qquad (5,6,7)$$

$$s_d = 1 + b/l * \sin\phi_d \qquad d_d = 1 + 0.1\sqrt{(h/b) * \sin 2\phi_d} \qquad i_d = (1 - tg\delta)^2 \qquad (8,9,10)$$

$$s_b = 1 - 0.3 * b/l \qquad d_b = 1 \qquad i_b = (1 - tg\delta)^2 \qquad (11,12,13).$$

The coefficient equations are lined according to the standard.

The geotechnical design values (c_d, ϕ_d) are derived by the usual LSD procedure from "standard" (characteristic) values, which however, is basically different than the procedure of EC 7-1 deriving design values from characteristic values. These procedures play no role in similarity and they will not be distinguished in further text.

3 Similarity solution

Similarity solution depends above all on the extraordinary variability of soils and their material properties. The solution does not consider oblique load (angle δ of force) because, from the viewpoint of bearing capacity, it appears less important. Therefore the coefficients $i_b = i_c = i_d = 1$. The solution involves the examination of the effective stress state only; the solution of the total stress state does not appear substantial for further geotechnical comparative analysis. With regard to their use for geotechnical comparative analysis, the geometrical parameters except for the depth h are defined as dimensionless quantities and are considered as constants in the similarity solution (see eqs. below). The soil mass is homogeneous. Consequently, the solution considers the variable inputs h, γ, ϕ, c and the following constant inputs:

$$\beta = b/l \qquad \eta = h/b \qquad \kappa_\lambda = (c)/(\gamma)\, tg(\phi) \qquad \lambda = (c)/(\gamma)(h)\, tg(\phi) \qquad (14,15,16,16').$$

Then the functional of bearing capacity of shallow foundation according to equation (4) is expressed by

$$R_d = (c)^* N_c(\phi)^* s_c{}^* d_c + (\gamma)^*(h)^* N_d(\phi)^* s_d(\phi)^* d_d(\phi) + (\gamma)^* 0.5^* \eta^*(h)^* N_b(\phi)^* s_b{}^* d_b \qquad (17).$$

Using the simple set-up of previously shown equations we can define a more suitable similarity functional with the functions $F_1(\phi, c)$, $F_2(\gamma,\phi, h)$, $F_3(\gamma,\phi, h)$:

$$R_d = F_1(\phi, c) + F_2(\gamma,\phi, h) + F_3(\gamma,\phi, h) \qquad (18)$$

where

$$F_1(\phi, c) = (1 + 0.2\beta)\left(1 + 0.1\sqrt{\eta}\right)^* (c)(N_d(\phi) - 1)/\, tg(\phi) \qquad (19)$$

$$F_2(\gamma, h, \phi) = (1 + \beta \sin(\phi))\left(1 + 0.1\sqrt{2\eta \sin 2(\phi)}\right)^* (\gamma)^* (h)^* N_d(\phi) \qquad (20)$$

$$F_3(\gamma, h, \phi) = 0.75(1 - 0.3\beta)(1/\eta)^* (h)^* (\gamma)^* (N_d(\phi) - 1)^* tg(\phi) \qquad (21)$$

and after some adjustments also the functional

$$R_d = (\gamma)^* (h)\left[\lambda^* F_1^s(\phi) + F_2^s(\phi) + F_3^s(\phi)\right] \qquad (22).$$

The functions F_i^s depend on the variable ϕ only according to formulations below

$$F_1^s(\phi) = \lambda(1 + 0.2\beta)\left(1 + 0.1\sqrt{\eta}\right)^* (N_d(\phi) - 1) \qquad (23)$$

$$F_2^s(\phi) = (1 + \beta \sin(\phi))\left(1 + 0.1\sqrt{2\eta \sin 2(\phi)}\right)^* N_d(\phi) \qquad (24)$$

$$F_3^s(\phi) = 0.75(1 - 0.3\beta)(1/\eta)^* tg(\phi)^* (N_d(\phi) - 1) \qquad (25).$$

The last formulation of bearing capacity functional (22) involves two dimensional variables h and γ separated by the dimensionless geotechnical similarity coefficient λ (Janbu`s) which can be considered constant for a lot of (mathematically for an infinite number of) combinations . The dimensionless similarity function of bearing capacity of shallow foundations is defined as shown below.

$$\mathrm{P}_d = \lambda^* F_1^s(\phi) + F_2^s(\phi) + F_3^s(\phi) \qquad (26)$$

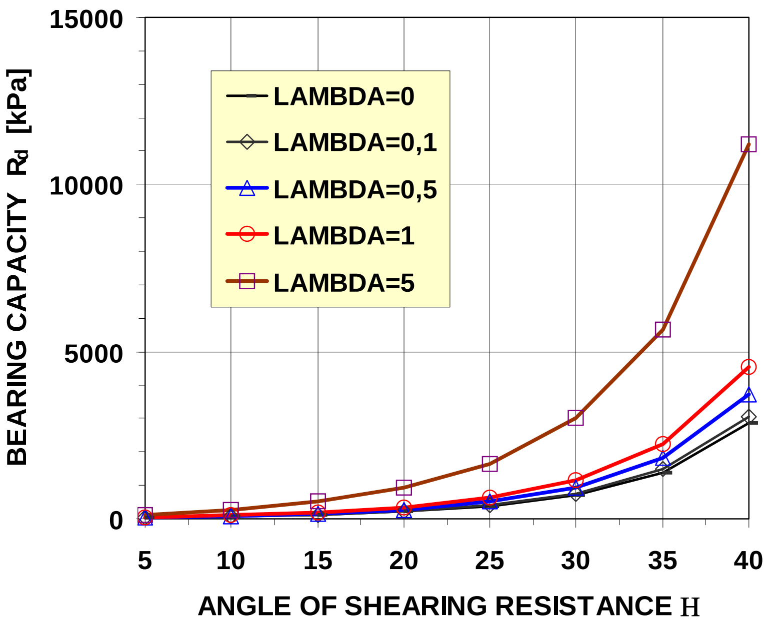

Fig. 1 Example of numerical analysis of bearing capacity R_d according to the functional (22) for inputs: $h=1, \beta=1, \eta=1, \gamma=20$ kN/m^3.

4 Results

The analytical solution has made it possible to separate the dimensional parameters *h* and γ from dimensionless ones and to define the dimensionless similarity functional P_d (26). This formulation keeps the standard separation of cohesion, angle of soil resistance and geometrical influences on the bearing capacity of foundations. The dependencies have been tested by an example of numerical analysis the results of which are shown in Fig.1. The input parameters of the example are given in the figure caption.

5 Conclusion

The presented analytical solution of the designs of shallow foundations according to ČSN 73 1001 results in relative simple formulae (22) and (26) which form the base of further numerical analyses and of a comparison of the LSD designs according to ČSN and EC7-1. The solution makes it possible to consider different approaches to the derivation of design values of geotechnical quantities.

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