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IMPORTANCE OF SOIL SHEAR STRENGTH PARAMETERS FOR OPTIMAL DESIGN OF THE BUILDING FOUNDATION

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For the design foundation, it is important to know not only the structure and load of the building, but also soils properties in the subsoil. Ignoring soil properties may result in an incorrect design of foundation, which may later cause a failure in building structure, because generally known foundations function is to transfer load effects into the ground. In smaller buildings, an engineering-geological survey is not usually carried out, but basic data on the territory is obtained from archive reports. Geologists define recommended dispersion of values for single geology properties, which is reflected in bearing capacity of foundation soil and the dimensions of foundation foot. Base soil monitoring due to varying soil shear strength parameters under consistency changing and observation of changing bearing capacity of soil confirmed the importance of conducting and evaluating engineering geological surveys for optimal design of the foundation structure.

Key words: soil, fine soil, shear stress, bearing capacity, drained condition, undrained condition

Introduction

Problem of object's establishment can be divided into theoretical design and realization. Actual realization of final object often differs from theoretical design. Reason for this is, for example, imperfect geological-engineering backgrounds, which are based on archive reports in case of small buildings (Harabinová, Panulinová and Kotrasová, 2017). Geologists determine recommended dispersion of values, which cause inaccuracies in calculation and assessment of bearing capacity and dimensions of foundation structures (Panulinová, Harabinová and Kormaníková, 2017). Situation in subsoil may also complicate occurrence of extreme loads, for example by changing soil consistency in event of a sudden increase or decrease in degree of water saturation. The aim of the paper is to observe the bearing capacity with respect to changing parameters of the shear strength of the soil on undrained and drained conditions.

The strength of soil is a key design parameter in designing foundations and other earth structures (Kumar and Vishwas 2011, Kumar and Chakraborty, 2015). In shallow foundation design, the capacity of the foundation to support footing load is given by the soil´s bearing capacity, which is a function of its strength parameters (Kuklík, 2011). Bearing capacity is the maximum pressure that the soil can support at foundation level without failure (Kralik and Simonovic, 1994). It is an important design parameter for foundation design (Hulla and Turček, 1998, Ishibashi and Hazarika, 2010, Dixit and Patil, 2010). Proper interpretation of shear strength parameters and the application to bearing capacity problems are presented and reviewed in this paper.

Bearing Capacity of Soil

Bearing Capacity is a key design parameter for foundation design. The vertical bearing capacity of the foundation soil is verified according to the theory of limit states using the following inequality (Powrie, 2004):

$$\sigma \leq R_d \quad (1)$$

$$\sigma = \frac{V}{A_{ef}}, \tag{2}$$

where σ is the extreme design contact stress at the footing bottom, V is the extreme design vertical force and R_d is the design bearing capacity of foundation soil.

Bearing capacity of soil can be calculated for drained conditions or for undrained conditions particularly in fine-grained soils (Bhattacharya and Kumar, 2017).

For drained conditions, the design bearing capacity R_d, shall be calculated by using the effective shear strength parameters c_{ef} and φ_{ef}. Total shear strength parameters cu and φ_u must by use for calculate the design bearing capacity on undrained conditions. The difference between effective and total shear strength parameters shown in the following figure.

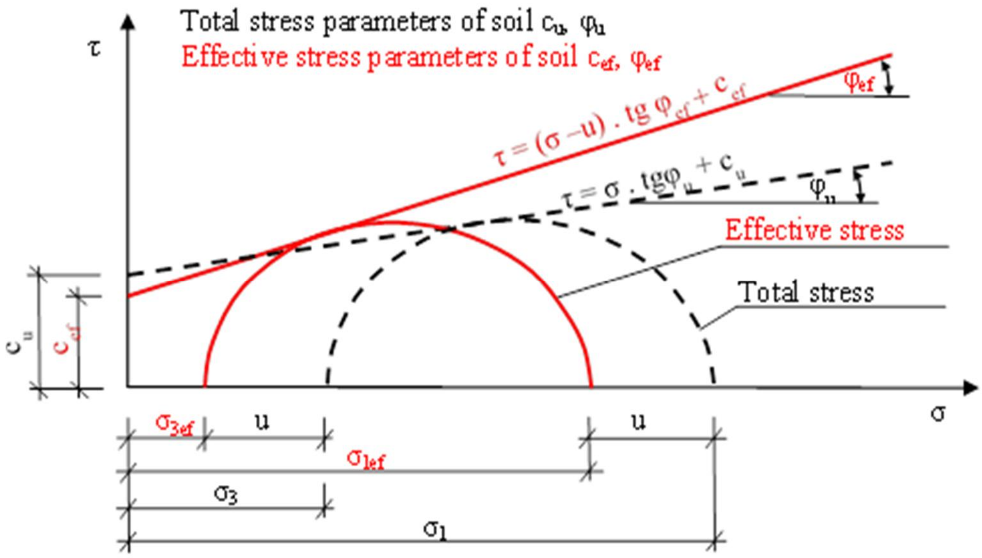

Fig. 1. Difference between total and effective parameters of shear stress

Nevertheless, the total parameters are generally used for fine-grained soil (Atkinson, 2007, Erickson and Drescher, 2002, Alemdağ, Cinoğlu and Gacener, 2016).

Bearing Capacity Design on Undrained Subsoil

For undrained conditions, the design bearing capacity of soil Rd, shall be calculated as follows (STN 73 1001, STN EN 1997-1):

$$R_d = [(\pi + 2)c_{u,d}s_c\, i_c + q_d]/\gamma_R, \tag{3}$$

where γ_R is partial factor for a resistance ($\gamma_R = 1.4$), $c_{u,d}$ is the design value of undrained shear strength (total cohesion).

s_c is the shape of foundation factors:

$$s_c = 1 + 0.2\frac{B}{L}, \tag{4}$$

where B is width of foundation and L is the length. i_c is the inclination factors of the load from the horizontal load H:

$$i_c = 0.5\left(1 + \sqrt{1 - \left(\frac{H}{A_{ef}c_u}\right)}\right) \qquad for \quad H \leq A.c_{u,d}, \tag{5}$$

where A_{ef} is the effective area of foundation ($A_{ef} = B$ x L) and q_d is the design overburden pressure at the level of the foundation base.

Bearing Capacity Design on Drained Subsoil

The design bearing capacity of the soil Rd [kPa] for drained conditions is determined according to (STN 73 1001, STN EN 1997-1):

$$R_d = (c_d' N_c s_c d_c i_c j_c + q' N_q s_q d_q i_q j_q + \gamma' \frac{B}{2} N_\gamma s_\gamma d_\gamma i_\gamma j_\gamma)/\gamma_R, \tag{6}$$

where γ_R is the partial factor for a resistance, c_d' is the design value of the effective cohesion, q' is the design effective overburden pressure at the level of the foundation base ($q' = \gamma_1 D$), γ_1 is the effective unit weight of soil above the base of footing level, D is the embedment depth, B *is* the foundation width, L *is* the foundation length, γ' *is* the design effective weight density of the soil below the foundation level.

N_c, N_q, N_γ are the bearing capacity factors (dependent on the design value of effective angle φ_d):

$$N_c = (N_q - 1) cotg\varphi_d \quad for \quad \varphi_d > 0, \tag{7}$$

$$N_q = \tan^2\left(45 + \frac{\varphi_d}{2}\right) e^{(\pi \, tan\varphi_d)}, \tag{8}$$

$$N_\gamma = 1.5(N_q - 1) tan\varphi_d \qquad N_\gamma = 2 + \pi \quad for \quad \varphi_d = 0 \tag{9}$$

s_c, s_q, s_γ are the shape of foundation factors:

$$s_c = 1 + 0.2\frac{B}{L} \qquad s_q = 1 + \frac{B}{L} sin\varphi_d \qquad s_\gamma = 1 - 0.3\frac{B}{L}, \tag{10}$$

d_c, d_q, d_γ are the depth factors for deeper shallow foundations:

$$d_c = 1 + 0.1\sqrt{\frac{D}{B}} \qquad d_q = 1 + 0.1\sqrt{\frac{D}{B}\sin 2\varphi_d} \qquad d_\gamma = 1, \tag{11}$$

i_c, i_q, i_γ are the inclination factors of the load (of the vertical load):

$$i_c = i_q = i_\gamma = (1 - \tan\theta)^2 \tag{12}$$

where θ is the angle of deflection of the resultant force from the vertical. For $\theta > 30°$ is progressing individually.

j_c, j_q, j_γ – the inclination factors of the terrain surface:

$$j_q = j_\gamma = (1 - \tan\beta)^2 \qquad j_c = j_q - \frac{1 - j_q}{N_c \, tan\varphi_d}, \tag{13}$$

where β is the inclination angle of the terrain from the horizontal.

The bearing capacity must be calculated based on correct shear parameters of soil, since there may be a failure. The soil is assumed to fail along the potential failure surface. The following text discusses the different shear strength parameters for low plasticity clay (CL), group F6 (STN 72 1001) and their effect on the soil bearing capacity.

Experimental results

The bearing capacity was calculated for a square foundation (B×L =1×1 m) which based on the cohesive soil (CL) on depth (D = 1.4 m). The values of the geotechnical characteristics for low plasticity clay (CL), group F6 are given in the Table 1. In calculating Rd, the soil consistency soft to solid was considered.

Table 1

The geotechnical parameters of low plasticity clay (CL)

Properties	Group F6 – CL
Poisson's ratio υ [-]	0.40
Unit weight γ [kN.m^{-3}]	21.0
Total stress parameters – cohesion c_u [kPa]	25–50
Total stress parameters – angle of friction φ_u [°]	0
Effective stress parameters – cohesion c_{ef} [kPa]	8–16
Effective stress parameters – angle of friction φ_{ef} [°]	17–21

The design of the cohesion soils bearing capacity for undrained conditions was determined according to relations (3)–(5). For this conditions the frictional angle is φu = 0° and the cohesion is c_u = (25, 30, 35, 40, 45, 50) kPa. The impact of shear strength parameters on bearing capacity for undrained soil is shown in Fig. 2 and Table 2.

Table 2

The bearing capacity for undrained condition (total stress parameters of soil)

Total cohesion c_u, kPa	The bearing capacity for undrained soil
25	131.18
30	153.21
35	175.25
40	197.28
45	219.32
50	241.35

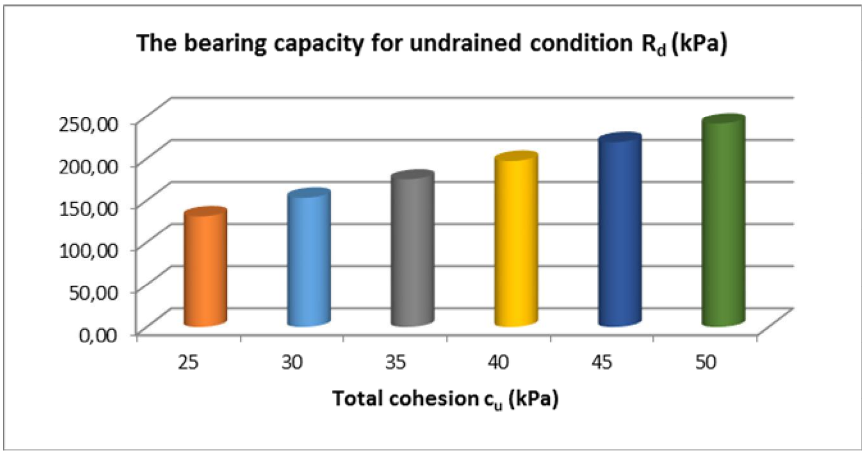

Fig. 2. The bearing capacity for undrained condition (total stress parameters of soil)

It has been found:

- Increasing cohesion causes an increase in bearing capacity of the subsoil.
- The increase is linear, for a change of cu of 5 kPa the difference is 22.03 kPa (Fig. 2 and Table 2).

The design of the cohesion soils bearing capacity for drained conditions was determined according to relations (6)–(13). Different values of cohesion cef = (8, 10, 12, 14 16) kPa and of frictional angle φ_{ef} = (17–21)° in calculation of bearing capacity was used. The impact of shear strength parameters on bearing capacity for drained soil is shown in Fig. 3 and Table 3.

Table 3

The bearing capacity for drained condition (effective stress parameters of soil)

Total cohesion c_{ef}, kPa	The bearing capacity for drained soil				
	φ_{ef}=17°	φ_{ef}=18°	φ_{ef}=19°	φ_{ef}=20°	φ_{ef}=21°
8	238.21	262.51	289.68	320.12	354.26
10	262.35	288.37	317.42	349.90	386.28
12	286.50	314.23	345.15	379.68	418.30
14	310.64	340.09	372.89	409.47	450.33
16	334.79	365.96	400.63	439.25	482.35

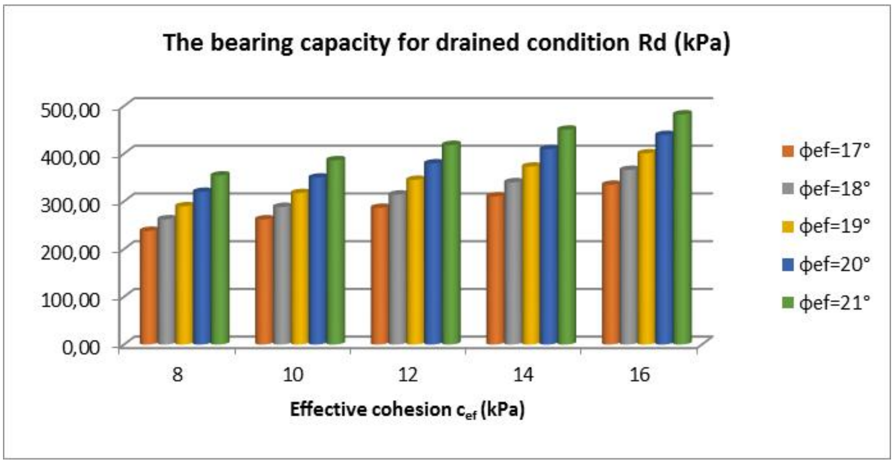

Fig. 3. The bearing capacity for drained condition (effective stress parameters of soil)

It has been found:

- Increasing cohesion (as well as increasing the angle of internal friction) causes an increase in bearing capacity of the subsoil. The impacts of shear strength parameters on bearing capacity for drained cohesive soil are shown in Fig. 3.
- When the angle of internal friction of soil is changing and cohesion is constant, the base soil bearing capacity has increased by about 116 to 148 kPa. Increase in change of effective cohesion (8–12 kPa) is the same for each value (Table 3).
- The change in soil cohesion for the constant value of the angle of internal friction (Fig. 3) causes a slower increase in the bearing capacity of subsoil, only about 100 to 130 kPa.

Conclusions

The experimental results represented by bearing capacity of soil in terms of the change mechanical properties of soil. The influence the shear strength parameters of soil on the bearing capacity are very important, especially when changing the angle of internal friction. After determining the correct values of soil friction angle you can calculate correct value of the bearing capacity of soil for the optimal design of foundation without failure. Use incorrect shear parameters of soil, leading to local shear failure. The reliability of the input data is the basic prerequisite for the optimal design of foundation without failure. The most important input for correct design of the foundation is exactly determination of effective angle of internal soil friction angle.

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ЗНАЧЕННЯ ПАРАМЕТРІВ МІЦНОСТІ ҐРУНТІВ ДЛЯ ПРОЄКТУВАННЯ ОПТИМАЛЬНОЇ КОНСТРУКЦІЇ ФУНДАМЕНТІВ БУДІВЕЛЬ

Під час проєктування важливо знати не лише структуру і навантаження будівлі, але також і властивості ґрунтів основи. Ігнорування властивостей ґрунту може призвести до проєктування неправильної конструкції фундаменту, а згодом спричинити руйнування у конструкціях будівлі, оскільки загальновідома функція фундаменту полягає в перенесенні впливу навантаження на ґрунт.

Для менших будівель зазвичай не проводять інженерно-геологічних досліджень, а основні дані про територію, де планується будівництво, отримують з архівних звітів. А геологи визначають рекомендовані значення дисперсії для одиничних геологічних властивостей, що відображається на несучій здатності конструкції ґрунту та розмірах підошви фундаменту.

Результати проведених експериментів подано оцінкою несучої здатності ґрунту з погляду зміни механічних властивостей ґрунту. Вплив параметрів міцності на зсув ґрунту та на несучу здатність дуже важливий, особливо в разі зміни кута внутрішнього тертя. Визначивши правильні значення кута тертя, можна розрахувати точне значення несучої здатності ґрунту для проєктування оптимальної конструкції фундаменту без руйнувань, тоді як використання хибних параметрів зсуву ґрунту може призвести до локальних руйнувань. Тому найважливішим для проєктування правильної конструкції фундаменту є саме визначення величини внутрішнього кута тертя ґрунту.

Крім того, базовий моніторинг ґрунту за рахунок різних параметрів міцності у разі зміни консистенції ґрунту та спостереження за зміною несучої здатності ґрунту також підтвердили важливість оцінювання інженерно-геологічних вишукувань для оптимального проєктування фундаментних конструкцій.

Ключові слова: ґрунт; тонкий ґрунт; напруження зсуву; несуча здатність; осушений стан; неосушений стан.