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Calibration of characteristic values of soil properties using the random finite element method

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ABSTRACT

In this paper the reliability assessment of the shallow strip footing was conducted using a reliability index β. Therefore some approaches of evaluation of characteristic values of soil properties were compared in order to check what reliability index β can be achieved by applying each of them. For this purpose, design values of the bearing capacity based on these approaches were referred to design values of the bearing capacity estimated by the random finite element method. Design values of the bearing capacity were estimated for various widths and depths of foundation in conjunction with design approaches defined in Eurocode 7. The cohesive soil was considered – clay from the area of Wrocław. The characteristic values of shear strength parameters were evaluated basing on the effective values of soil parameters.

1. Introduction

The random character of the soil properties is an essential problem in terms of estimating parameters applied in geotechnical analysis. These parameters have a major influence on the safety of a designed structure. The randomness of the soil properties is greater than other typical materials considered by solid mechanics. Random variability of soil parameters occurs even within homogenous layers of soil [1]. The reason of this phenomenon is a natural variability of the soil itself, which cannot be unambiguously defined by mathematical equations. The uncertainty in determination of the soil parameters aside from the natural randomness is associated with measurement errors, limited amount of data based on in situ tests and an uncertainty of transformation. Therefore, a universal algorithm of estimation of soil parameters, which would cope with all abovementioned sources of uncertainty, has not yet been created. Consequently many approaches used to define the soil properties were developed. However their goal is only the estimation of approximate values of soil parameters with a certain level of safety.

The explicit method of soil parameters evaluation cannot be found in the applicable standards – Eurocode 7. In general terms Eurocode leaves wide scope for interpretation. Therefore the present study is focused on comparing commonly used approaches for the evaluation of characteristic values of soil parameters (Duncan's method, Schneider's method, Schneider's method with influence of a fluctuation scale, Orr and Breysse's method, method based on 5% quantile which is included in Eurocode 7) by assessing a shallow foundation bearing capacity in accordance with the guidelines contained in Eurocode 7. Design values of the bearing capacity were evaluated by applying design approaches – DA1.C1, DA1.C2,

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DA2* and DA3. Reliability index β as adopted as a criterion for comparison of the above methods. Values of reliability index β were obtained on the basis of the bearing capacity estimated by random finite element method (RFEM).

2. Characteristic values of parameters and bearing capacity according to Eurocode 7

Eurocode 7 does not contain clarified method of evaluation of characteristic values of soil parameters. Only general guidelines can be found how these values should be estimated. Namely it is mentioned in Eurocode 7 that the characteristic value of a soil parameter shall be selected as a cautious estimation of the value affecting the occurrence of the limit state [2]. More precisely the characteristic value is a cautious estimation of a mean value over a certain zone of ground governing the behavior of a geotechnical structure at a limit state [2]. In fact this zone is more extensive than the zone of ground influenced by in situ tests. A crucial issue is the estimation of soil parameters that could represent whole area. Furthermore Eurocode 7 recommends that in case of employing statistical concept, the characteristic value should be defined as a value governing the probability of the limit state occurrence less than 5%. Abovementioned guidelines are insufficient and cause designers to rely on their experience and knowledge to evaluate characteristic properties to be taken in calculations.

A design value of a soil parameter X_d can be calculated from a characteristic value X_k using an appropriate partial safety factor γ_M by the following equation:

$$X_d = \frac{X_k}{\gamma_M}. \tag{1}$$

Eurocode 7 requires that for all ultimate limit state load cases the following inequality should be satisfied

$$V_d \le R_d, \tag{2}$$

where V_d denotes the design load normal to the foundation base and R_d is the design bearing capacity of a foundation against vertical loads. In the sequel a strip foundation with not inclined base subjected solely to normal loads is considered. In such a case the design value of the bearing capacity R_d of a footing in drained conditions can be evaluated according to Eurocode 7 from

$$R_d = (c' N_c + q' N_q + 0.5\gamma' B' N_\gamma) \cdot A', \tag{3}$$

where c' is cohesion in terms of effective stress, q' is the effective overburden pressure at the level of the foundation base, γ' denotes the effective unit weight of the soil below the foundation level, B' is the effective foundation width and A' is the effective foundation area. N_c, N_q, N_γ are the bearing capacity factors which are defined as

$$N_c = \mathrm{ctg}\phi' \left[\mathrm{tg}^2\left(\frac{\pi}{4} + \frac{\phi'}{2}\right) \exp(\pi\, \mathrm{tg}\,\phi') - 1 \right], \tag{4}$$

$$N_q = \mathrm{tg}^2\left(\frac{\pi}{4} + \frac{\phi'}{2}\right) \exp(\pi\, \mathrm{tg}\,\phi'), \tag{5}$$

$$N_\gamma = 2\left[\mathrm{tg}^2\left(\frac{\pi}{4} + \frac{\phi'}{2}\right) \exp(\pi\, \mathrm{tg}\,\phi') - 1 \right] \mathrm{tg}\,\phi', \tag{6}$$

Table 1 – Partial safety factors included in Eurocode 7.

Partial factors for permanent and variable actions γ_F			
Actions	Symbol	Set A1	Set A2
Permanent			
Unfavorable	γ_G	1.35	1.0
Favorable		1.0	1.0
Variable			
Unfavorable	γ_Q	1.5	1.0
Favorable		0	0

Partial factors for soil properties γ_M			
Soil parameters	Symbol	Set M1	Set M2
Friction angle	$\gamma_{\phi'}$	1.0	1.25
Cohesion	$\gamma_{c'}$	1.0	1.25
Undrained shear strength	γ_{c_u}	1.0	1.4
Soil unit weight	γ_γ	1.0	1.0

Partial factors for resistance γ_R				
Resistance	Symbol	Set R1	Set R2	Set R3
Bearing capacity	$\gamma_{R,v}$	1.0	1.4	1.0

where ϕ' is a friction angle in terms of effective stress.

In the case of undrained conditions the bearing capacity R_d according to Eurocode 7 can be evaluated from

$$R_d = [(\pi + 2)c_u s_c i_c + q] \cdot A', \tag{7}$$

where c_u is the undrained shear strength of soil, s_c is the factor of the shape of the foundation and i_c is the factor of the inclination of the load, caused by a horizontal load.

The Eurocode 7 introduces three design approaches DA1, DA2 and DA3 when checking ultimate limit states. Design approaches differ in combinations of partial safety factors, which in Eurocode 7 are divided into three groups: partial factors for permanent and variable actions γ_F, partial factors for soil properties γ_M and partial factors for resistance γ_R. Values of partial safety factors are given in Table 1.

In case DA1 two sets of partial factors were distinguished: combination DA1.C1: A1 + M1 + R1, combination DA1.C2: A2 + M2 + R1. Design approach DA2 consists of sets A1, M1 and R2, however case DA3 denotes partial safety factors: A1, M2 and R3. Case DA2* is a variation of DA2, which was introduced in national annex in Poland. In case of design approach DA2* the characteristic values of actions should be applied instead of design ones when computing a resistance.

Solely drained conditions are considered in the present study.

3. Methods of determination of characteristic values of soil parameters according to Eurocode 7

Eurocode 7, as it was mentioned in Section 2, recommends that in the case of applying statistical methods, the characteristic value of a parameter should be estimated with the level of significance $\alpha = 0.05$. It means that the characteristic value of a parameter should be estimated as 5% quantile basing on a probability distribution of this parameter. Properties of materials, such as concrete or steel, are often described by a