EVALUATION OF STRENGTH AND DEFORMATION CHARACTERISTIC PARAMETERS FOR BOULDER CLAY AT SGGW CAMPUS CONSIDERING TEST LOCATION

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The selection of soil parameters suitable to the geotechnical design calculations is regarded widely as one of the most important and simultaneously difficult engineering task, which according to the EC 7 should be undertaken into distinct three steps. The second of these steps requires careful and caution estimation with application of the statistical methods even by using a Bayesian approach as shown in this paper. It presents the process of selecting a characteristic strength and deformation parameters from CPT and DMT investigation for boulder clays found in SGGW Campus (Warsaw). This layer was chosen for foundations of design academic buildings. In the selection of the characteristic parameters with application of the numerical program BAYANAL the spatial distribution was taken into account. Particular attention was focused to the affect resulting from in situ test locations at different distances from the design facilities. Finally, the remark conclusions were presented including an approach with weights proposed to determination of the conclusive characteristic values.

Keywords: Characteristic soil parameters, Statistical analysis, Bayesian approach.

1. INTRODUCTION

In geotechnical design with respect to Eurocode 7' rules and principles (EN 1997-1, 2) the step selection of geotechnical actions and resistances (Fig. 1), particularly characteristic material parameters, is considered as a crucial process creating the difficulties for designers. For selecting characteristic values of geotechnical parameters (step 2) the statistical methods are commonly recommended (Frank et al. 2004). The results of this step are affected by many factors, e.g. the uncertainty parameters that can be derived from natural variability, measurement errors and statistical uncertainty. In the classic statistics, based on a random sample drawn from the population, to determine the average value and standard deviation value with the required confidence level (e.g. 95%) a finite set of values derived from geotechnical parameters population is assumed. In this approach the parameters' values are particular though not known. If we are dealing with a homogeneous medium (ground), to determine the characteristic values of geotechnical parameters ( ) the Student's t-95 percent confidence level can be used according to the formula:

$$X_k = X_m\left[1 - k_n V_x\right] \tag{1}$$

where: X_m - average of soil parameter; k_n - statistical factor; V_x - coefficient of variation. Schneider (1990, 1997, 2010) and Schneider and Fitze (2009) proposed to assume k_n =0,5, it means one half a standard deviation below the mean value. The procedure for determination of characteristic value is presented in Fig. 1, where n is the number of samples, and x_i - parameters in a homogeneous layer.

In an alternative approach, derived from the Bayes' theorem (Alén 1998, Alén and Sällfors 1999, Uzielli 2008), deduction can be based not only on a random sample but also on so-called a priori information. To determine the characteristic values, e.g. strength and deformation of soils, it is proposed to use Bayesian analysis, in which there is possible to continue data collection parameters derived according to the following formula:

$$f(\theta \mid x) = \frac{f(x \mid \theta) \cdot f(\theta)}{\int\limits_{\Omega} f(x \mid \theta) \cdot f(\theta) d\theta} \tag{2}$$

where: f(θ|x) – the posterior density function of q parameter, after the sample's result x has been observed; f(θ) - a priori distribution density function of q parameter; f(x|θ) – credible function i.e. density function of conditional observation's result x with given value of θ; Ω – the set of θ parameter's possible values. The presented Bayes' theorem gives a valuable practical possibility of successive including of new information, coming from consecutively drawn random samples. On a consecutive step, the knowledge about posterior θ parameter's distribution is treated as a priori knowledge of this parameter. An order of including new portions of information does not affect a final result. Bayesian method is preferred when you want to include an objective a priori information about the parameter. You cannot use the classical approach, where only analyzed a random sample taken. it is also preferred the use of Bayesian approach, when we gradually turn to the analysis of a new data set (the idea of observation methods), for example, it can help you in choosing the number of probes required to obtain a satisfactory precision of the data.

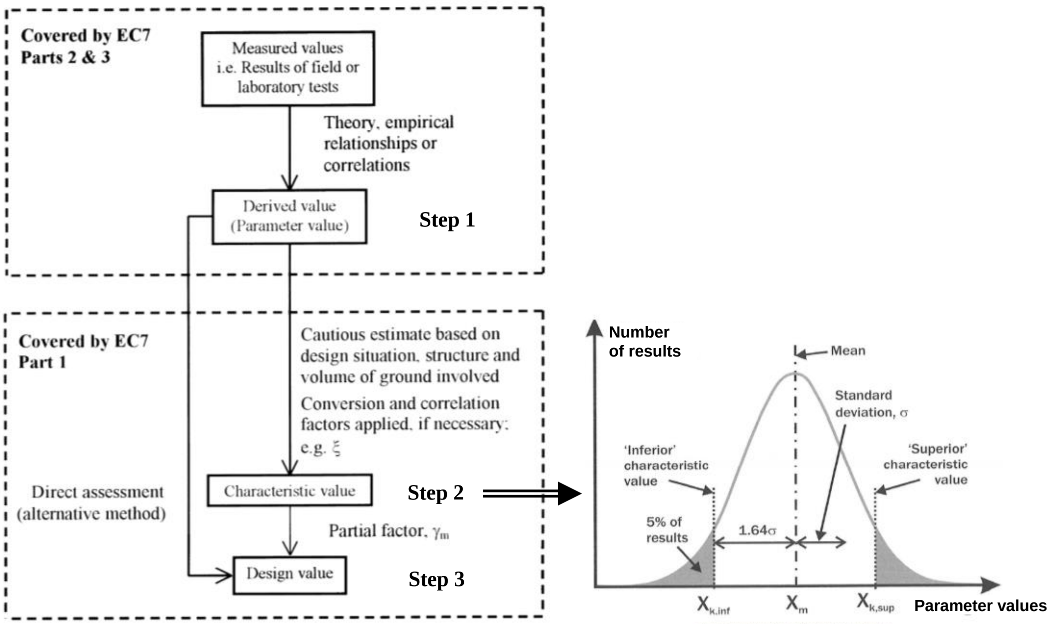

Figure 1. Process for obtaining design parameter values from test results (acc. to Bond and Harris 2008, Orr 2005, Garbulewski et al. 2009).

The paper addresses the applicability of the Bayesian approach to determine a characteristic parameters of boulder clays in geotechnical design of the SGGW Campus in Warsaw. The selection of the geotechnical characteristic parameters was carried out using the new numerical code called BAYANAL. Overview of BAYANAL code, its assumption and requirement and procedure of statistical analysis had been presented. In order to document the impact of in situ test localization the design calculations for selection of characteristic parameters for boulder clay layer in design building on the SGGW Campus were carried out. Finally, the code application in evaluation of characteristic parameters (strength and deformation) for boulder clay was describe.

2. BAYANAL CODE - ASSUMPTIONS AND REQUIREMENT

The basic assumptions and requirements for the BAYANAL code application are as follows: (1) full integration with Excel 2003 (or higher) operating in a Windows environment, (2) intuitive graphical interface, (3) the ability to automatically test of the null hypothesis ("H 0") on the normal random variable on the basis of individual tests samples. Due to the first two requirements it was chosen implementation of applications based on the Excel spreadsheet in 2003 with the support code in Visual Basic for Applications, and a system of MS Office object libraries (libraries Visual Basic for Applications and Microsoft Office Object Library version 11.0). Application forms/dialog boxes with a comprehensive description of the buttons and functions associated with them, depending on the context and the currently executed thread in the application, provided a clear and intuitive graphical interface. All calculations required to perform the analyses are conducted by the formula written on a permanent basis to work spread-sheet (invisible to the user). All input data required for the calculation of the iteration is copied to that worksheet to complete separation of data sources and applications. The procedure in BAYNAL code consists of 3 main steps as follows:

Step 1:

- provide initial data by the user, including the ability to select automatic operation,
- specify the file (s) to the data by the user (standard window opening set),
- open of the first file, activate the first sheet.

Step 2:

- identify (or waiting indication) data to analyze the parameters of initial,
- analyse of the data indicated, any error handling specified data range,
- construct of the Shapiro-Wilk test for a random sample indicated, the term action in the event of non-compliance with the Shapiro-Wilk.

Step 3:

- go to the next test / sheet / file in interactive mode or automatic,
- transit to the report generated by the resignation of the opening of the next set of statistical analysis ("Cancel" button in the dialog box to open files),
- close the source files (with the option: skip shift) and the creation of the report.

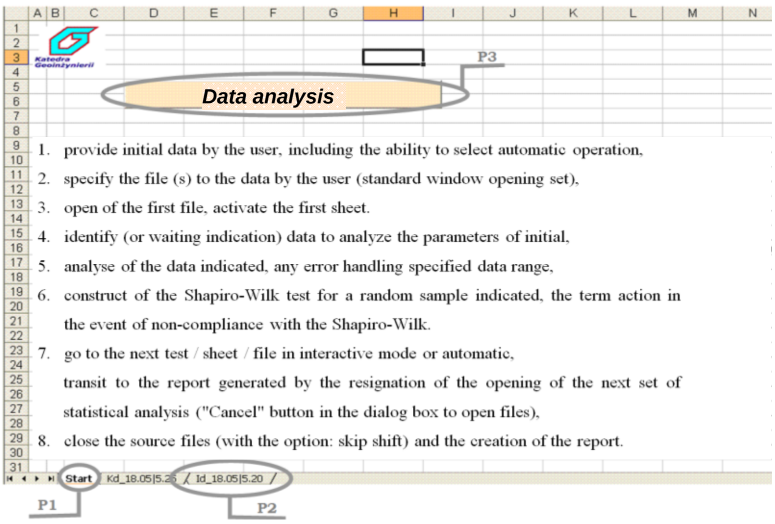

Figure 2. Main sheet of the BAYANAL code

The main sheet of the BAYNAL code is the sheet "Start" (Field 1 - P1) as shown in Fig. 2. The BAYNAL code also includes reports previously performed statistical analyses name" and "date" (no year), and "time" of the analysis and formatted as shown in the P2. Sheets reports of the analyses can move, copy and delete according to standard Excel commands. The work begins with an application of the button P3, constituting of one sheet (P2). The names of these sheets are created automatically according to the scheme: "analysed parameter.

3. SGGW CAMPUS – GEOTECHNICAL CONDITIONS

The geotechnical characteristics of grounds in the buildings designed in the frame of SGGW Campus development were recognized by the interpretation of boring data (102 boreholes), CPT & DMT tests (69 and 41 profiles, respectively) and comprehensive laboratory investigation. Analysing data gathered in the Ground Investigation Report, five geotechnical layers were identified in the campus test site (Fig. 3a), including a layer of brown glacial boulder clay noted in this paper as layer No. III (acc. to geotechnical classification sandy clay - saCL and sasiCL) of the Warta glaciation (gQpW), for which liquidity index values IL = (0.0÷0.11) and a layer of grey glacial boulder clay of the Odra glaciation (gQpO), sandy clay with boulders as layer No. IV, for which IL = (0.0÷0.12). The layer III was pointed out as layer with the most comfortable geotechnical conditions for foundation of the Campus buildings, among them building No 34 analysed in this paper. The distribution of strength and deformation parameters for boulder clay were determined based on CPT and DMT investigation and common used in practice relationships (Fig. 3b).

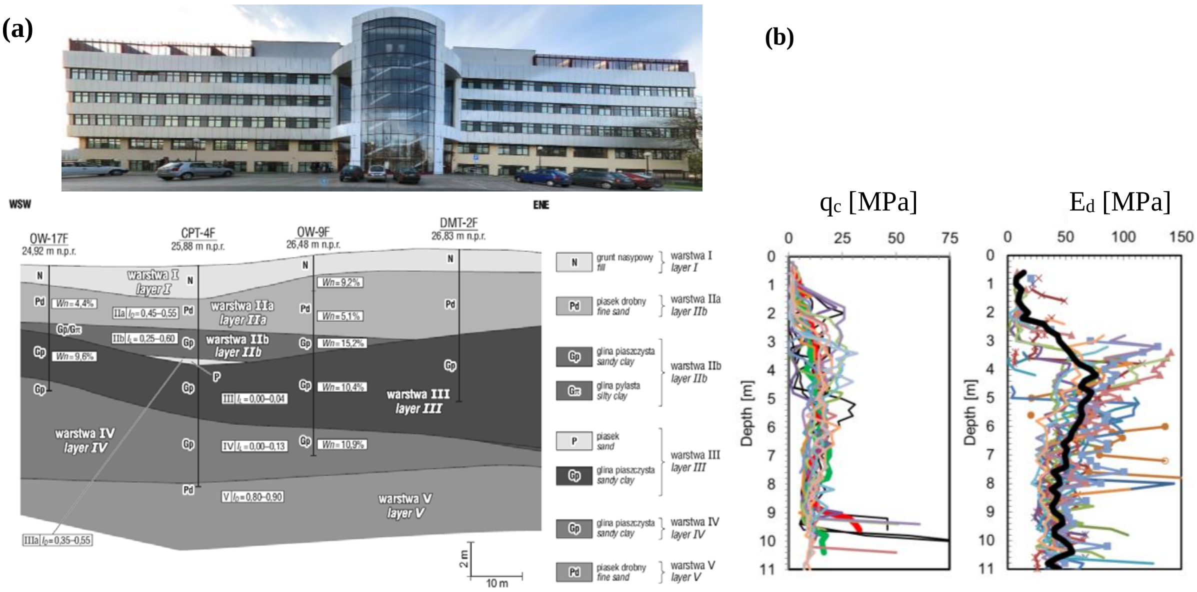

Figure 3. (a) Typical geotechnical cross section for building No 34; wn –moisture, ID – relative density, IL – plasticity index, 23.66 m - meter at Vistula level; (b) Distribution of cone resistance qc of CPT tests and parameter ED based on DMT tests performed on the SGGW Campus

4. SGGW CAMPUS – GEOTECHNICAL CONDITIONS

The BAYANAL code (Garbulewski et al. 2009) was applied to determine the strength and deformation characteristic parameters of boulder clay (layer No III). Because of the availability of all test data both the classical and Bayesian approach could be used. Moreover the characteristic parameters were evaluated according to the Schneider's formula. Taking into account all qc values from CPT tests and Ed from DMT tests (Fig. 3b) for boulder clay in layer No III the characteristic strength (τ_{fu}) and deformation (M – constrained modulus) parameters were calculated as follows:

From classical and Bayes approaches respectively:

τ_{fu} = 0.208 MPa (average value) with standard deviation s_d ± 0.003 MPa;
τ_{fu} = 0.213 MPa (with confidence coefficient = 0,95);
M = 137.4 MPa (average value) with s_d ± 27 MPa;
M = 150.4 MPa (with confidence coefficient = 0,95).

Based on the Schneider formula (2009): τ_{fu} = 0.202 MPa with standard deviation s_d ± 0.012 MPa; M = 124.0 MPa with standard deviation s_d ± 27 MPa.

In order to determine the impact of the test location on the characteristic values of geotechnical parameters (τ_{fu} and M), a statistical analysis was carried out assuming the weight values of the parameters. To determine the weighted values of the parameters the following formula is proposed:

$$\overline{X}_k = \frac{\sum_{1}^{n} x_i \cdot w_i}{\sum_{1}^{n} w_i} \qquad (3)$$

where: $\overline{X}_k$ – average weighted geotechnical parameter; x_i - value of the geotechnical parameter; w_i – the weight of the geotechnical parameter as the ratio of the smallest distance from the object and the distance from the remaining tests.

The values of weights for the analysed building No 34 (Fig. 4a) were in the following range: 0,27÷ 1,0 for CPT and 0,43 ÷ 1.0 for DMT. The smallest distance of CPT and DMT location from the design building No 34 were 20.77 m and 31.25 m respectively, however the largest distance were 77.07 m and 73.13 m.

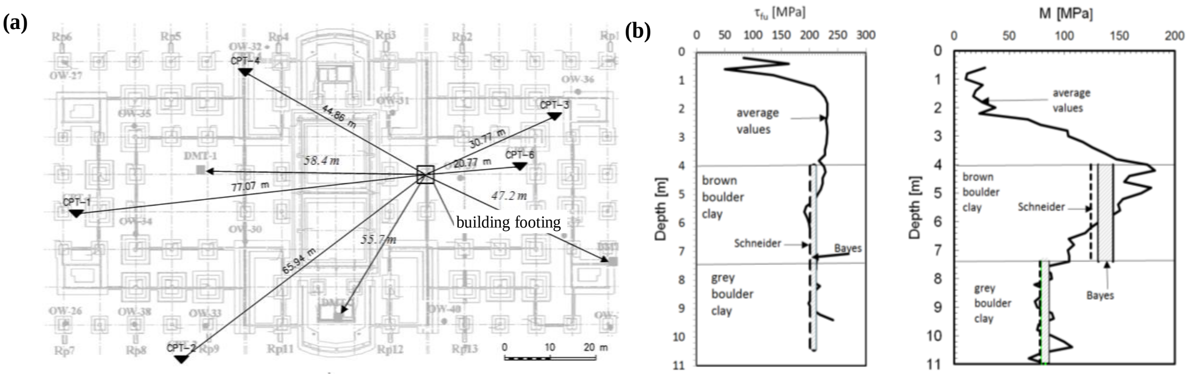

Figure 1. (a) Location of CPT and DMT tests at SGGW Campus (building No 34). (b) Characteristic values of undrained shear strength τ_{fu} and constrained modulus M recommended for geotechnical design

Taking into account q_c values from CPT tests (6 profiles) and E_D from DMT tests (3 profiles) for boulder clay in layer III only for building No 34 the characteristic strength τ_{fu}) and deformation (M) parameters were as follows:

From classical and Bayes approaches: τ_{fu} = 0.210 MPa (average value) with standard deviation s_d ± 0.014 MPa (classical approach) and ± 0.003 MPa (average deviation in Bayes approach at confidence coefficient = 0,95); M = 136.2 MPa (average value) with standard deviation s_d ± 30 MPa (classical approach) and ± 7.5 MPa (average deviation in Bayes approach at confidence coefficient = 0,95). Using the Schneider formula: τ_{fu} = 0.203 MPa with standard deviation sd ± 0.014 MPa; M = 136.0 MPa with standard deviation s_d ± 30.0 MPa.

After introducing weights for parameters from the classical and Bayes approaches the strength and constrained modulus are as follows: τ_{fu} = 0.120 MPa (average value) with standard deviation s_d ± 0.004 MPa (classical approach) and ± 0.001 MPa (average deviation in Bayes approach at confidence coefficient = 0,95); M = 89.0 MPa (average value) with standard deviation s_d ± 19 MPa (classical approach) and ± 4.6 (average deviation in Bayes approach at confidence coefficient = 0,95). Using the Schneider formula: τ_{fu} = 0.118 MPa with standard deviation sd ± 0.004 MPa; M = 79.4 MPa with standard deviation s_d ± 19.1 MPa.

5. CONCLUDING REMARKS

In order to select the deformation and strength parameters for the weakest layer - boulder clay (^{g}QpW), occurring in the ground under the B34 SGGW building statistical analysis of in-situ tests results was carried out. The analysis used indicator parameters (q_c and E_D) from 6 CPT soundings and 3 DMT tests. The mean value, the value with the specified confidence level of 95% and the standard deviation of the indicative parameters were determined using BAYANAL program. In order to take into account the location of in situ tests (test distances from the designed foundation) weights were introduced. The weights were defined as the ratio of the distance close to the foundation and the distance to the remaining soundings.

The values of the characteristic parameters (τ_{fu}, M) obtained for a single object (B34) are generally comparable with the values of the characteristic parameters obtained for the total area of the SGGW Campus. The strength and constrained modulus parameters of boulder clay recommended for design calculation (lower estimation) obtained using the classic and Bayes approaches and the Schneider formula are as follows respectively: τ_{fuk} 0.206 MPa, 0.207 MPa and 0.203 MPa, M_k 106 MPa, 129 MPa and 121 MPa. The characteristic values of τ_{fuk} and M_k obtained using the weight parameters are distinctly smaller: τ_{fuk} respectively 0.116 MPa, 0.119 MPa and 0.118 MPa, M_k respectively 70.0 MPa, 84.4 MPa and 74.4MPa. These parameter are too conservative taking into account the boulder clay states and preliminary measurements of building settlements.

It is important to underline that to determine the characteristic values of geotechnical parameters statistical methods should be used with caution. The BAYANAL code will be helpful in designing and therefore should be recommended to apply in geotechnical practice.

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