Analysis of the Engineering Judgement Influence on the Selection of Geotechnical Parameters' Characteristic Values

K. Ivandić, F. Dodigović, D. Štuhec, S. Strelec

***Abstract*—**A characteristic value of a certain geotechnical parameter results from an engineering assessment. Its selection has to be based on technical principles and standards of engineering practice. It has been shown that the results of engineering assessment of different authors for the same problem and input data are significantly dispersed. A survey was conducted in which participants had to estimate the force that causes a 10 cm displacement at the top of an axially in-situ compressed pile. 50 experts from all over the world took part in it. The lowest estimated force value was 42% and the highest was 135% of measured force resulting from a mentioned static pile load test. These extreme values result in significantly different technical solutions to the same engineering task. In case of selecting a characteristic value of a geotechnical parameter the importance of the influence of an engineering assessment can be reduced by using statistical methods. An informative annex of Eurocode 1 prescribes the method of selecting the characteristic values of material properties. This is followed by Eurocode 7 with certain specificities linked to selecting characteristic values of geotechnical parameters. The paper shows the procedure of selecting characteristic values of a geotechnical parameter by using a statistical method with different initial conditions. The aim of the paper is to quantify an engineering assessment in the example of determining a characteristic value of a specific geotechnical parameter. It is assumed that this assessment is a random variable and that its statistical features will be determined. For this purpose, a survey research was conducted among relevant experts from the field of geotechnical engineering. Conclusively, the results of the survey and the application of statistical method were compared.

***Keywords*—**Characteristic values, engineering judgement, Eurocode 7, statistical methods.

I. Introduction

IN the field of structural engineering, the properties of a material or a product from which structure elements are constructed are prescribed by the requirements of a particular project task. As such, pre-known values, they are used in analyses without having to worry about their accuracy or spatial variability. Unlike the aforementioned, in geotechnical engineering, materials are modelled in their natural state (soil and rock) and their relevant properties have to be evaluated. In addition, the range of values of a particular geotechnical parameter within the same geotechnical environment can be quite wide. In Table I [1], variation of a particular parameter is described by the coefficient of variation (COV). Due to the lack of additional information (such as the mean value of the properties and the geological characteristics of the site), all the values shown in Table I [1] are suggested and are not applicable to specific cases.

TABLE I
COEFFICIENTS OF VARIATIONS OF DIFFERENT SOIL PROPERTIES [1]

Soil property	Soil type	COV [%]
Density	All soils	5-10
Undrained shear strength	Clay (triaxial)	5-20
	Clayey silt	10-30
Plastic limit	Clay	3-20
Liquid limit	Clay	3-20
Tangent of angle of friction	All soils	25-30
Compressibility	All soils	25-30

In geotechnical modelling tasks, the properties of geotechnical parameters are quantified by their characteristic values. The general definition of the term, the characteristic value of a product or material, is given in Eurocode 0, as follows: Characteristic value (X_k or R_k) is the value of a material or product property having a prescribed probability of being not reached in a hypothetical unlimited test series. This value generally corresponds to a specified fractile of the assumed statistical distribution of the particular property of the material, or product [2]. Two cases of characteristic values are distinguished:

A. The case where the lower value of the material or product properties is unfavourable, the characteristic value is defined as 5% fractile, $X_{k,low}$
B. The case where the higher value of material or product properties is unfavourable, the characteristic value is defined as 95% fractile, $X_{k,high}$ [2].

Additional clarifications and definitions, in the case of characteristic values of geotechnical parameters, are given in Eurocode 7. Apart from the facts to be taken into consideration when selecting it, a characteristic value is also defined as follows:

C. The case when the mean value of soil properties govern the behavior of the geotechnical structure at the boundary state, the characteristic value is defined as a cautious estimate of the mean value $X_{k,mean}$.

In the case of „C ", a cautious estimate of the mean value is a selection of the mean value of the limited set of geotechnical parameter values, with a confidence level of 95% [3].

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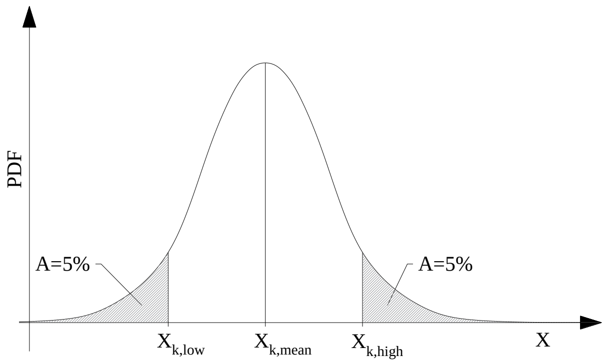

Fig. 1 Graphical representation of „A“,“B“ and „C“ types of characteristic values

Taking into account the complexity of geotechnical tasks, the procedure for selecting the characteristic values of geotechnical parameters is not unambiguous for all cases. Among the many factors relevant to its selection, detailed analyzes are required in each case, and the final selection of values follows from the engineering assessment of the project responsible for the project.

Expert judgements are the expressions of informed opinions, based on knowledge and experience, that experts make in responding to technical problems.[...] Expert judgements can be elicited quantitatively or qualitatively. When expressed quantitatively they can have several forms: probabilities; ratings; odds; weighting factors; and, possibly most importantly, probability distributions of the physical quantities of interest. Qualitative expression will involve a textual description of the experts' assumptions in reaching an estimate, and natural language statements of probabilities of events such as "likely", or statements as to the expected performance such as "generally poor" [4].

A schematic representation of the elements of the estimation of the objective and characteristic value of geotechnical parameters is presented, in the light of the engineering decision (Fig. 2).

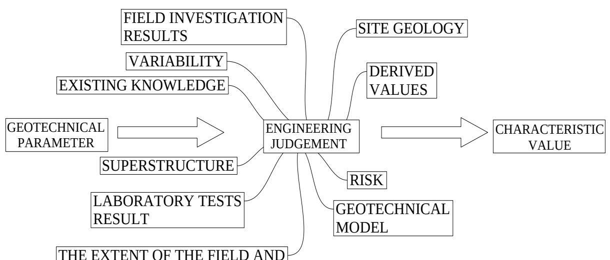

Fig. 2 Relationship between Geotechnical parameter and associated characteristic value with engineering judgement

II. PROBLEM

In the geotechnical analyses, for example, in the verification of the global slope limit state, different values of the design parameters of soil strength result in different geometry and depth of the sloping surface. Consequently, it is possible that the design solution of the same engineering task is significantly modified in relation to the selection of design parameters which depends on the engineering estimation of the designer.

This can be seen from the results of the research conducted on the Araquari experimental testing site in Brazil in 2015. [5] The main scope of the research developed at the Araquari Experimental Testing Site was to analyze the complex pile-soil interaction mechanisms which develop at pile shaft and base during loading [6]. As a part of the research, it was organized prediction event by the Universidade Federal do Rio Grande do Sul.

Experts from all over the world were invited to predict the displacement – force relationship, and the ultimate force of the axially loaded 24.4 m in length and 1.0 m in diameter pile. The ultimate value load of the pile is defined as the force that causes the pile head to move in the amount of 10% of its diameter, which was 10 cm in this case. The results of extensive field and laboratory tests, as well as all other relevant data, were provided to all participants. The study involved 72 participants, of which 42% were practitioners (designers), and 58% academics. Figure 1 shows a summary of the results of all participants together with the actual measured data. The value of the measured breaking force was ≈8600 kN, the lowest expected ≈3640 kN (42% of the actual value), and the highest ≈11650 kN (135% of the actual value).

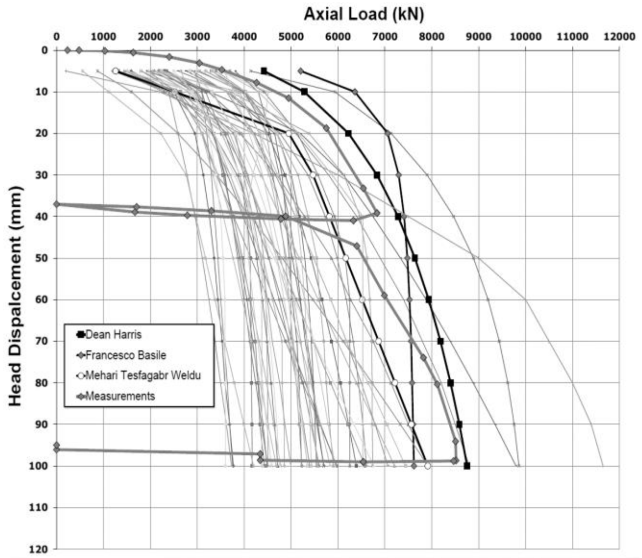

Fig. 1 Results from the prediction event - Axial load vs pile head displacement [5]

Although all predictors were from the field of geotechnical engineering and equal in terms of disposal of the relevant information needed to perform the analysis, the range of predicted values was significant. The dispersion of the value from the above example raises the question of evaluating the influence of engineering assessment as an important factor in assessing the possible end variants of the solution of a particular engineering task.

The aim of this study is quantification of engineering estimates in case of selection of characteristic values of geotechnical parameters in general method.

III. METHODS OF RESEARCH

For research purposes, an online survey of the influence of engineering assessment on the selection of characteristic values of geotechnical parameters was conducted. It is assumed that the engineering assessment is a continuous random variable with unknown probability density function. All members of the Croatian Geotechnical Society (N = 265) were invited to complete the survey. Survey responses are anonymous, so they cannot be linked to the participants. The survey consists of two parts. In the first part, the participants fill in general personal information: the place of employment (private company or scientific institution) and the number of years of work experience in the field of geotechnical engineering. In the second part a problem has been defined:

For the purpose of proving evidence of the ultimate (GEO) and serviceability limit state of the footing – soil interaction problem. field investigations and laboratory tests of soil samples were carried out. Taking into account the results obtained, a geotechnical model of soil composed of five geotechnical zones has been defined: 1. Deposit, 2. ClH, 3. SiH, 4. Or, 5. SiL. Values of drained soil strength and deformation parameters were determined by laboratory tests from undisturbed samples. The tests were carried out in a accredited laboratory (direct shear, oedometer test apparatus, soil moisture measurement and determination of Atterberg limits). Sampling procedures were conducted in compliance with the relevant standards and procedures.

For geotechnical zone 2, (brown-gray high plasticity clay of without smell) by carrying out laboratory tests, the following results were obtained:

Based on the values in the table II, participants selected characteristic values of soil parameters: drained cohesion, angle of internal friction and oedometer modulus.

TABLE II
INPUT (MEASURED) VALUES FOR ESTIMATING CHARACTERISTIC PARAMETER VALUES

Nr.	**depth**	**w_0**	**I_c**	**I_p**	**c'**	**φ'**	**E_{oed} (100 – 200 kPa)**
	[m]	**[%]**		**[%]**	**[kPa]**	**[°]**	**[kPa]**
1	1,8 - 2,2	30,7	0,89	23,3	4,1	26,4	6800
2	2,0 - 2,3	35,6	0,57	26,5	7,6	25,2	3400
3	2,4 - 2,8	30,0	0,92	22,3	10,7	25,1	6600
4	2,5 - 2,8	30,2	0,92	22,9	10,1	25,0	6400
5	1,8 - 2,2	28,3	0,97	27,3	6,8	24,7	6100
6	2,8 - 3,3	32,4	0,93	47,0	10,7	26,0	6800

Results from the second part of the survey were compared to the results obtained by applying statistical patterns according to the definitions of characteristic values of material or product properties given in Eurocode 1 and Eurocode 7.

IV. RESULTS AND DISCUSSION

A. Results of research

Total number of participants was 34, of which 33 were eligible for further processing. The average number of years of relevant work experience of the respondents was 13.3 years. The histogram of the number of years of relevant experience is shown in Figure 2.

For the purpose of describing and summarizing results, descriptive statistics methods were used. The data were tested for normality using Shapiro-Wilk test of normality.

The results in histograms are grouped into classes. The number of classes is determined using (1), and the bin size using (2).

$$k = 1 + 1{,}33 \cdot logN \quad (1)$$

$$bin\ size = \frac{x_{max} - x_{min}}{N} \quad (2)$$

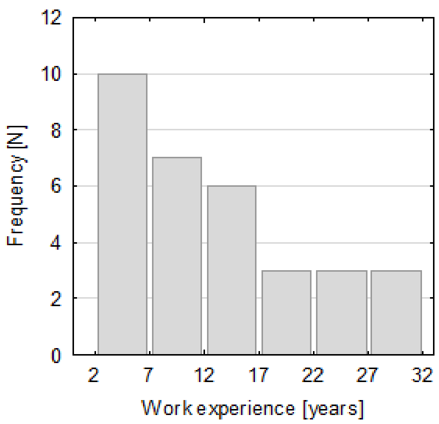

Fig. 3 Histogram of relevant work experience

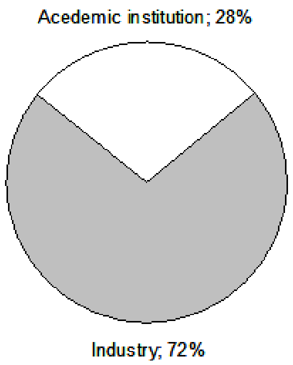

Fig. 4 Participants employment position

B. The results of selecting characteristic values

TABLE III
SUMMARY STATISTICS FOR GEOTECHNICAL PARAMETERS c', φ', E_{oed}

	Valid N	**Mean**	**Min.**	**Max.**	**Percentile - 5%**	**Percentile - 95%**	**Std.Dev.**	**COV [%]**
c' [kPa]	32	8,05	4	10,7	5	10,7	1,539	19,1
E_{oed} [kPa]	32	6061	3300	15000	3400	10000	2004	33,1
φ' [°]	32	24,772	20,8	26	22	25,4	0,972	3,9

TABLE IV
RESULTS OF SHAPIRO-WILK TEST OF NORMALITY

	c' [kPa]	φ' [°]	E_{oed} [kPa]
W	0,942	0,578	0,661
p-value	0,085	0,000	0,000
alpha	0,05	0,05	0,05
normal	yes	no	no

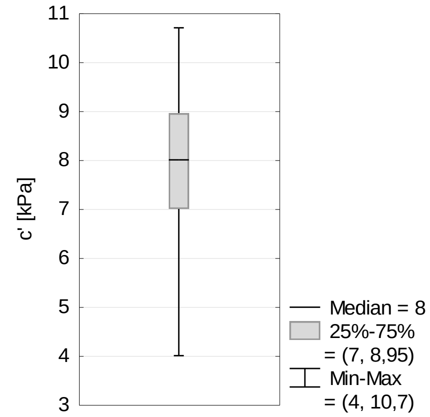

Fig. 5a Five number summary: c' values

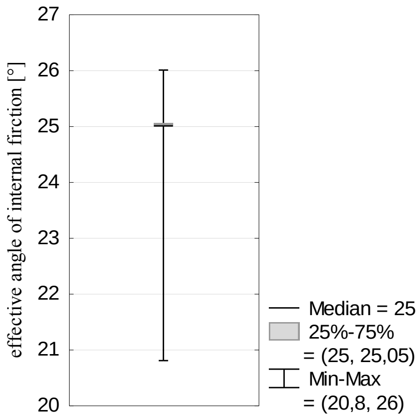

Fig. 5b Five number summary: φ' values

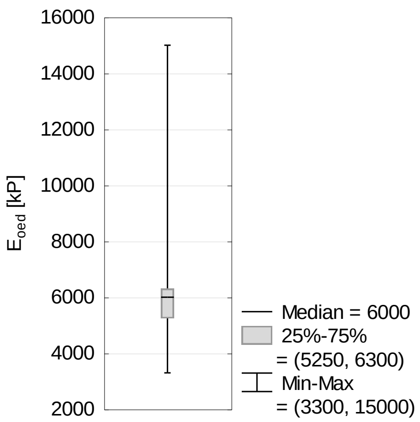

Fig. 5c Five number summary: E_{oed} values

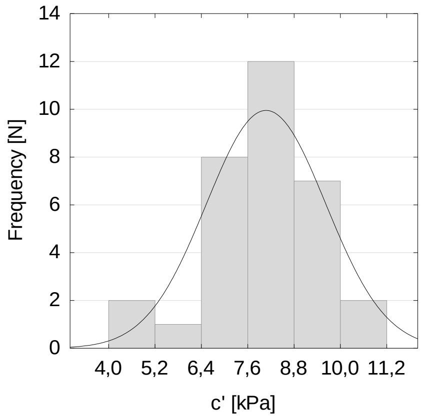

Fig. 6a Histogram of selected c' values

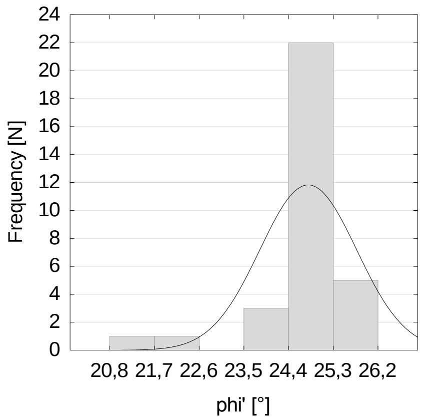

Fig. 6b Histogram of selected φ' values

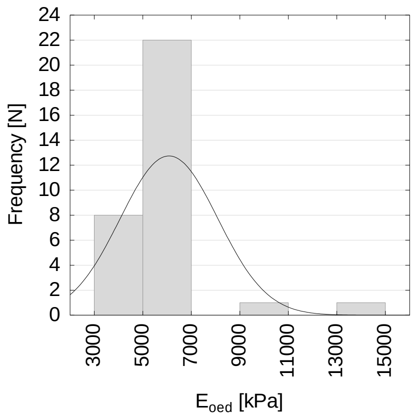

Fig. 6c Histogram of selected E_{oed} values

C. Determination of characteristic values using statistics

To determine the characteristic values c'_k, φ'_k and $E_{oed,k}$ it was assumed that c', φ' and E_{oed} are continuous random variables with unknown variance. Since their lower value is c', φ' and E_{oed} is unfavourable, X_k=$X_{k.low}$ is selected instead of X_k=$X_{k.high}$.

Based on the assumed, it is necessary to determine $X_{k,low}$ i $X_{k,mean}$. Considering all assumptions, characteristic values are determined using (3) [7].

$$X_k = X_{mean}(1 - k_n V_x) \quad (3)$$

Where are:

m_X Mean of the n sample results

k_n Statistical coefficient

V_x COV of X (since it is unknown, the value is estimated from the sample (6))

The coefficient k_n depends on: the number of samples, the type of characteristic value, whether the variance of the statistical population is known or unknown and the level of reliability for the estimation of the characteristic value. In this case two values of k_n are defined: $k_{n,low}$ (4) i $k_{n,mean}$ (5)

$$k_{n,low} = t_{n-1}^{0.95}\sqrt{\frac{1}{n}+1} \quad (4)$$

$$k_{n,mean} = t_{n-1}^{0.95}\sqrt{\frac{1}{n}} \quad (5)$$

Where are:

$t_{n-1}^{0.95}$ t factor of Student's distribution with n – 1 degrees of freedom and confidence of 95%

n the number of test results

Since the V_x value is unknown, it is evaluated from the sample (6).

$$V_x = \frac{s_x}{X_{mean}} \quad (6)$$

Where s_x is the standard deviation of the sample determined according to (7).

$$s_x^2 = \frac{1}{n-1}\sum(X_i - X_{mean})^2 \quad (7)$$

TABLE V
THE CHARACTERISTIC VALUES c', φ', E_{oed} OBTAINED USING STATISTICS

parameter	n	X_{mean}	$X_{k,mean}$	$X_{k,low}$
c'	6	8,3	6,1	2,5
φ'	6	25,4	24,9	24,0
E_{oed}	6	6017	4943	3163

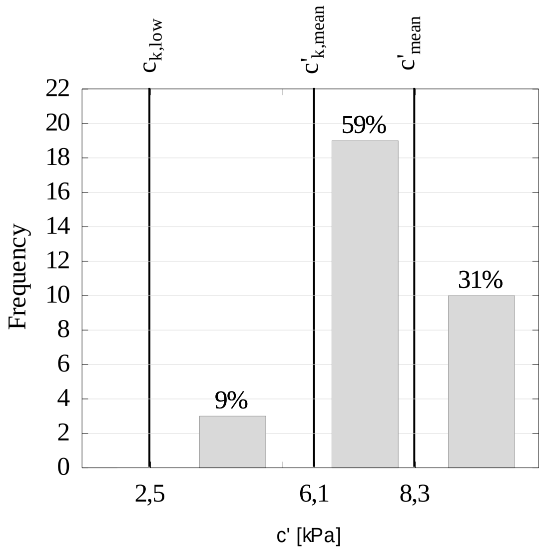

Fig. 7a A common view of values obtained by research and through the use of statistical expressions - c'

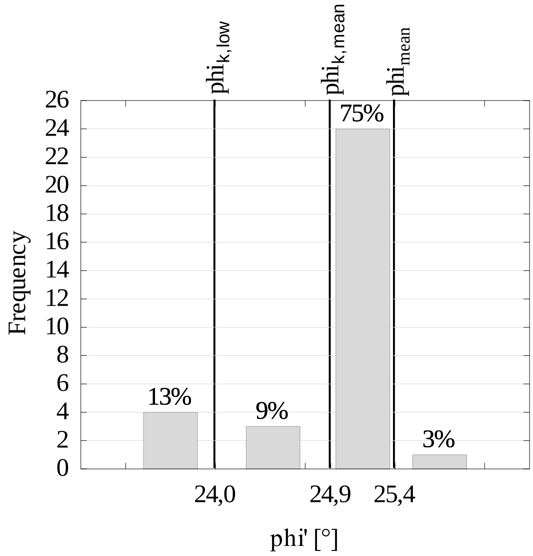

Fig. 7b A common view of values obtained by research and through the use of statistical expressions - φ'

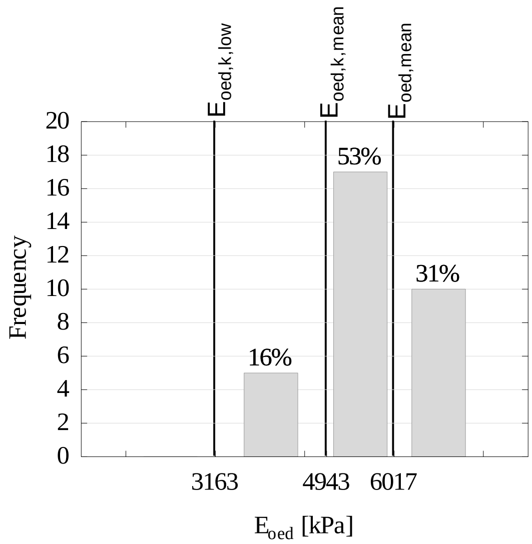

Fig. 6c A common view of values obtained by research and through the use of statistical expressions - E_{oed}

D. Discussion

From the Shapiro-Wilk test of the normality, it is concluded:

- for c': p = 0,085 > 0,5, null hypothesis is not rejected, the data fit the normal distribution
- for φ', i E_{oed}: p = 0,000 < 0,5, null hypothesis is rejected, the data doesn't fit the normal distribution

Coefficients of variation of calculated from samples are:

- $COV_{c'}$: 19,1%
- $COV_{φ'}$: 3,9%
- COV_{Eoed}: 33,1%

In the case of c'and φ', 9% participants, and 16% participants in the case of E_{oed} selected values which are lower than a cautious estimate of the mean. The most of participants, (59% for c', 75% for φ' i 53% for E_{oed}) had chosen a characteristic value between $X_{k,mean}$ and X_{mean}. These results show that the majority of participants selected values that are higher than prescribed ones in Eurocode 7.

Statistical dispersions of values, presented in Figures 5 and 6 are result of the experience of an individual engineer, which is gained when solving tasks of everyday engineering practice. On the other hand, members of the academic community have possibly broader and more thorough knowledge of the theory of formal selection of parameter values, but have no experience in designing and performing particular engineering tasks.

V. CONCLUSION

Calculable material properties in structural engineering are determined based on the implicit assumption on ensuring a limitless number of samples tested in controlled conditions. Besides that, loads are predictable with the known probability distribution.

The procedures from structural engineering cannot be uncritically used in geotechnical engineering, because of the much greater uncertainty of geotechnical parameters. The main reasons for that are the limited number of samples, and their unknown statistical properties. Further, the actions depend on material properties and vice versa, unfavourable and favourable actions have an influence on resistance.

The case shown in the paper is strongly simple. Even in this case, it is shown that there is relatively significant results dispersion.

The most of the participants in the part of the survey selected the mean value, calculated from the data obtained by laboratory tests. The mean value of the sample does not describe the characteristic of the whole statistical population (in this case the characteristic values of geotechnical parameters that represents a single geotechnical environment), but only that sample, and as such, it is not a valid indicator.

Advanced statistical analyses are not common in everyday engineering use. It is necessary to make a distinction between statistical processing of relevant parameters in structural and geotechnical engineering. Engineers from the second group are aware of the inability to supply a sufficient number of quality samples. It is shown that there is a significant dispersion of survey results, even under controlled conditions. Effects of uncertainty and variation in geotechnical parameters could be quantified by performing parameter analysis. By doing so, it is possible to evaluate different solutions of a specific task in geotechnical engineering, and among them, choose the optimal one. Application of structural engineering patterns (5% fractile) result in too conservative solutions. The proposed approach in geotechnical engineering should, besides statistical methods, predominantly adopt engineering experience accumulated on already built structures. It should be calibrated with modern statistical methods to ensure a uniform margin of safety for a unique construction-foundation-ground model.

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