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Research paper

Triple correlation states between in-situ tested soil parameters

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Abstract: When testing soil parameters, the measured parameter values are only approximations of the true values. The measurand is determined based on metrological uncertainties or using statistical models for analysing data. Some parameters of the soil state present strong correlations, but others do not always provide simple correspondences. Multiple correlations between geotechnical parameters can provide a new perspective regarding the mutual relations between these parameters and may improve the fit of different soil parameters in geotechnical design procedures. Statistical modelling based on observed data generally involves a comparison between theoretical expectancies and practical surveys. Multidimensional regression models are useful for revealing the influences of several independent variables on one dependent variable. Statistical parameters and a quantitative approach can be used to define the relationships between several factors. Presented results claim that triple depended correlations may bring some corrects in relationships of soil parameters as against to double depended correlations. The differences in coefficients of determination are significant. Three variables involved stronger correlations.

Keywords: soil parameters, correlations, measurements, statistical modelling

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1. Introduction

Embankment constructions based on proper standards and technical specifications require suitable mineral aggregate and soil compaction technologies to ensure that the recommended stiffnesses are achieved in the formed soil layers [1]. The most widely used recommendations concern soil parameters such as the coefficient of uniformity (C_U), coefficient of curvature (C_C), effective internal friction angle (ϕ'), effective cohesion (c), oedometric modulus (E_{oed}), optimum water content (w_{opt}), and maximum dry density ($\rho_{d\,\max}$), dry unit weight (γ_d). Geotechnical parameters dependent on the soil compaction state are difficult to control in field investigations. Therefore, other types of geotechnical tests are used to describe such parameters, e.g. the primary and secondary static moduli of deformation (E_{V1}, E_{V2}), dynamic modulus of deformation (E_{Vd}), and bearing ratio (CBR). Although these parameters are evaluated using different devices, it is possible to establish relationships between them. It allows for the correlations to be defined for controlling other state parameters, e.g. based on another parameter determined in a field test.

The key task comprises describing the relationships between geotechnical parameters. Some studies consider correlations between two geotechnical parameters [2]. However, multiparametric mutual states are rarely established. Triple-dimensioned soil properties may enable enriched identification of soil states and may allow for more accurate descriptions of the nonlinearity of correlations in different ranges of the load-deformation dependency. Multiparametric relations may also facilitate the identification of potential measurement errors, e.g. one incorrect parameter among other properly evaluated parameters.

Field investigation methods use different devices to measure values, from which the expected parameters are calculated. Nevertheless, there is a difference between the measured value of a quantity and its true value. Measured values contain errors. The identification of such errors and their influences on the final result should be understood as thoroughly as possible.

Correlations between soil parameters are mostly presented as double depended variables. The strength of correlations is strictly depended on thoroughness and accuracy of measurement conditions. The material must be regular in properties. Before filling the embankment the process of homogeneity of soil deposit should be strictly controlled. Also uniformity of compaction is very important condition. Even small disturbances in soil structure or soil moisture involve poor correlation factors of soil parameters. The conditions are difficult to ensure in the frame of in situ tests, so that higher level of correlation is achieved during laboratory tests after preparing remoulded soil in constant moisture of soil.

The example of laboratory tests [3] involved the coefficient of determination $R^2 = 0.844$.

How important is the process of the soil compaction is featured in literature, however as an example can be shown three tests performed into different sites [4]. Results from West Virginia site and New York site involved high coefficient of determination ($R^2 = 0.7$ and $R^2 = 0.82$), and results from Michigan site involved low coefficient of determination ($R^2 = 0.36$), in opposite. Detailed information about tests and correlated parameters can be found in [2, 3] and [4].

The primary purpose of the article is discussion on the problem of uncertainty of the measurement in geotechnical in situ tests. The secondary purpose is evaluation of the correlation strength between triple depended soil parameters.

2. Measurement of physical quantities

The measurement of a physical quantity refers to the empirical operations for assigning physical processes or phenomena to mathematical objects, specifically numbers. The operations involve a quantity description (JCGM 2008) essential for statistical data analysis [5].

Based on the results of the measurement processes obtained from the field investigations, the expressions for design values for soil model parameters can be determined after an evaluation of characteristic values combined with a proper partial factor, or as a direct evaluation of design values based on specific requirements regarding a reliability level (after EN 1990:2002). However, the actual value of a measured quantity cannot be obtained from the measuring device. Every measurement result is a random variable determined in a confidence interval. Every measurement result should consist of an estimated value of the measured quantity, and an uncertainty of the measurement.

Site conditions in geotechnical practice often limit investigations into the soil state, and statistical interpretation is difficult (or even impossible) with a small number of trials. Geotechnical standards, i.e. Eurocode 7 (EN 1997-2:2007), establish statistical methods for defining a single parameter. In addition, sets of proper partial factors or material factors are provided. This allows for a sufficient number of known effects to address the statistical model uncertainty or to address the uncertainty in calibration tests for measurement devices in geotechnical design procedures. However, recommendations given in EC7 are reasonable for designing practical engineering problems and may be disputable to characterize the statistical uncertainty in scientific research.

Based on popular field investigations used in geotechnics, measuring devices, and related metrological evaluations, the uncertainties are considered here.

From a practical perspective, a measurement is often executed directly, i.e. the measured quantity is compared with a pattern, or a device directly exposes the result. In contrast, indirect measurement involves an examination of several physical values and an evaluation of the next estimated parameter based on available functional dependencies. Thus, if the measured parameter is replaced by (y) and if each of the examined physical values is (x_i), then the relationship is considered valid:

$$y = f\left(x_1, x_2, x_3, \ldots, x_n\right) \tag{2.1}$$

Evaluation methods for measurement uncertainty also depend on direct or indirect examination. Standard uncertainty may be evaluated using an A-type or B-type method [5]. The A-type method is applied when the set of measurements for a physical value is conducted under the same (outer) circumstances. Then, statistical dependencies can be formulated based on the statistical spread of the results. The B-type method is used when only one or a few measurements are achieved and it is not possible to determine the dispersion of the values.

The type of device is also important in the process of uncertainty expression. For example, in mechanical gauges equipped with rulers or callipers for marking data, the absolute uncertainty is evaluated as one-half of the smallest scale size. In other analogue gauges, the absolute uncertainty is calculated from the class of the device and the measurement range, as follows:

$$\Delta_{\lim x_i} = \frac{\text{class} \cdot \text{range}}{100} \tag{2.2}$$

In digital gauges, the absolute uncertainty is established based on the calibration procedures employed by the manufacturer. It depends on the measured quantity (x_i) and the range of measurement (r), as follows:

$$\Delta_{\lim x_i} = c_1 \cdot x_i + c_2 \cdot r \tag{2.3}$$

The factors c_1, c_2 are provided in the calibration certificate as the measurement accuracy. Often, only the factor c_2 is revealed.

Scientific measurements more often use the standard uncertainty. The B-type method assumes that the distribution for the uncertainty estimation is rectangular, i.e. the value of standard uncertainty is described as follows:

$$u(x_i) = \frac{\Delta_{\lim x_i}}{\sqrt{3}} \tag{2.4}$$

The rectangular distribution means that the probability of the true value is constant within the range of absolute uncertainty. Evidently, this is a simplification of a difficult statistical problem. If more statistical data are available, other probability distributions can be used [8].

In the case of indirect measurements, after calculating the standard uncertainties of all physical quantities (x_i), the combined uncertainty of the measured value is determined (y) as follows:

$$u(y) = \sqrt{\sum_{i=1}^{n} \left(\frac{\partial f(x_i)}{\partial x_i} \right)^2 u^2(x_i)} \tag{2.5}$$

3. Metrological aspects of conducted field tests

The field investigations determined four geotechnical parameters in different compaction states of soil. The specified parameters were: the static deformation moduli (E_{V1}, E_{V2}) based on the plate load test and the Polish Standard (PN-S-02205:1998), dynamic modulus of deformation (E_{Vd}), based on a dynamic plate load tester from Zorn GmbH, and the bearing capacity (CBR in-situ), based on the Polish Standard recommendation (PN-S-02205:1998). The investigations, outer circumstances, test conditions, and measurement devices are described in [6].

3.1. Static plate load test

The measurement device (VSS plate) contains instruments for surveying data regarding the loading pressure and vertical displacements of the loaded plate. The manometer ensures a measurement range of 0–0.6 MPa in accuracy class 0.6, and the dial indicator ensures a measurement range of 10 mm and scale reading of 0.01 mm.

The measurement results estimated in the test are the primary (E_{V1}) and secondary (E_{V2}) static deformation moduli. The input quantities (measured values) surveyed during the test are the force, as represented by the pressure increment (Δp) exerted on the standard plate, and the displacement of the standard plate (Δs) for each fixed pressure increment (PN-S-02205:1998). The absolute uncertainty for the manometer can be described as follows:

$$\Delta_{\lim} = \frac{0.6 \cdot 0.6}{100} = 3.6 \cdot 10^{-3} \text{ MPa} \tag{3.1}$$

The standard uncertainty is determined as follows:

$$u\left(p\right) = \frac{3.6 \cdot 10^{-3}}{\sqrt{3}} = 2.08 \cdot 10^{-3}\ \text{MPa} \tag{3.2}$$

The absolute uncertainty of the dial gauge for displacement may be obtained as follows:

$$\Delta_{\text{lim}} = 0.5 \cdot 0.01\ \text{mm} = 5 \cdot 10^{-3}\ \text{MPa} \tag{3.3}$$

then, the standard uncertainty becomes as follows:

$$u\left(s\right) = \frac{5 \cdot 10^{-3}\text{mm}}{\sqrt{3}} = 2.89 \cdot 10^{-9}\ \text{m} \tag{3.4}$$

The output estimate, which is the result of the functional relationship, is given as follows:

$$E_V = 0.75 \cdot \frac{\Delta p}{\Delta s} \cdot D \tag{3.5}$$

In the above equation, $D = 0.3$ m is the diameter of the standard plate. The combined standard uncertainty of the estimate is calculated as follows:

$$u\left(E_V\right) = \sqrt{\left(\frac{\partial\left(0.75 \cdot \frac{\Delta p}{\Delta s} \cdot 0.3\right)}{\partial\left(\Delta p\right)}\right)^2 \cdot u^2\left(\Delta p\right) + \left(\frac{\partial\left(0.75 \cdot \frac{\Delta p}{\Delta s} \cdot 0.3\right)}{\partial\left(\Delta s\right)}\right)^2 \cdot u^2\left(\Delta s\right)} \tag{3.6}$$

The combined standard uncertainty is different for different measurements. This is because in each measurement value, (Δs) differs, assuming that the state of soil compaction is changing. The field investigations allowed for evaluation of the minimum and maximum quantities of the combined standard uncertainty for the primary and secondary static moduli, as follows:

$$u\left(E_{V1}\right)_{\text{min}} = 0.81\ \text{MPa} \tag{3.7}$$

$$u\left(E_{V1}\right)_{\text{max}} = 4.54\ \text{MPa} \tag{3.8}$$

$$u\left(E_{V2}\right)_{\text{min}} = 1.46\ \text{MPa} \tag{3.9}$$

$$u\left(E_{V2}\right)_{\text{max}} = 6.45\ \text{MPa} \tag{3.10}$$

3.2. Dynamic plate load test

This device (Zorn LFWD plate) contains a type of digital converter for automatically collecting data, and the user obtains the final result as the dynamic modulus of deformation (E_{Vd}). Transitional quantities are not required during the test to evaluate the modulus [5]. For this type of device, the absolute uncertainty is acceptable as $c_2 = 2\%$ of the measurement range, described in Zorn User's Manual as 5–70 MPa.

$$\Delta_{\text{lim}}(E_{Vd}) = 0.02 \cdot 65\ \text{MPa} = 1.3\ \text{MPa} \tag{3.11}$$

The standard uncertainty is given as follows:

$$u\left(E_{Vd}\right) = \frac{1.3}{\sqrt{3}} = 0.75\ \text{MPa} \tag{3.12}$$

3.3. Bearing capacity of soil (CBR in-situ test)

The CBR research kit consists of measurement instruments such as a ring dynamometer, with a measurement range of up to 50 kN. In the test, the dynamometer indicates the force (p) using a correlated dial gauge. Additionally, another dial gauge is installed to measure the deep of penetration of the standard circular plunger into the tested soil. Both dial gauges ensure a measurement range of 10 mm, and a reading scale of 0.01 mm.

The measurement takes place with a naked-eye observation of the values presented by dial gauges. The plunger penetrates the soil mass at a constant rate of speed, but the simultaneous readings from both dial gauges may be an additional source of errors in accuracy, increasing the measurement uncertainty.

The absolute uncertainty (based on the technical data of the dynamometer) is 0.2% of measurement range; thus, the standard uncertainty is given as follows:

$$\Delta_{\lim}(\mathrm{Dyn}) = 0.002 \cdot 50\ \mathrm{kN} = 0.1\ \mathrm{kN} \tag{3.13}$$

$$u(\mathrm{Dyn}) = \frac{0.1}{\sqrt{3}} = 0.06\ \mathrm{kN} \tag{3.14}$$

The smallest measurable force of the dynamometer is 6.5 N. The force is translated from the dial gauge for displacement, through calibration. Thus, the absolute and standard uncertainties of the measured force are:

$$\Delta_{\lim}(p) = 0.5 \cdot 6.5 = 3.25\ \mathrm{N} = 3.25 \cdot 10^{-3}\ \mathrm{kN} \tag{3.15}$$

$$u(p) = \frac{3.25 \cdot 10^{-3}}{\sqrt{3}} = 1.88 \cdot 10^{-3}\ \mathrm{kN} \tag{3.16}$$

CBR is expressed as a percentage; it is the ratio of the force required to penetrate the tested soil with the plunger to that required for penetration in a comparable standard material (PN-S-02205:1998):

$$\mathrm{CBR} = \frac{p}{p_p} \cdot 100 \tag{3.17}$$

where: p_p – comparable force equal to 19.6 kN.

After assuming the uncertainty in the displacement reading of the loaded plunger, the standard uncertainty of the CBR is given as follows:

$$u(\mathrm{CBR}) = 0.45\% \tag{3.18}$$

4. Statistical analysis of the results

Statistical modelling based on observed data generally involves a comparison between theoretical expectancies and practical surveys. Multidimensional regression models are useful for revealing the influences of several independent variables on one dependent variable. Statistical parameters and a quantitative approach can be used to define the relationships between several factors, and it is possible to determine the requested value for the research procedure [7]. The regression model is a formal description, expressed in the form of mathematical formulae.

A paraboloidal surface was used to represent the model of triple-correlated soil parameters, as follows:

$$\hat{z} = a + b \cdot x + c \cdot y + d \cdot (x)^2 + e \cdot (y)^2 \tag{4.1}$$

where: $\hat{z}$ – theoretical value obtained from the model, and xy are the measured values.

The correctness of the model can be characterised by three statistical parameters [8], as described below. The standard deviation of the residuals is interpreted as the average deviation of the observed variable z versus the corresponding value given by the function $\hat{z}$.

$$S_{(z)} = \sqrt{\frac{\sum (z - \hat{z})^2}{n}} \tag{4.2}$$

The surveyed variables (x, y, z) are interdependent geotechnical parameters of the soil. However, in the model, (x) and (y) are independent variables, and $(\hat{z})$ is the predicted value.

The correlation coefficient (R) indicates how strongly the variables are interdependent [3].

$$R_{z,xy} = \sqrt{\frac{(r_{xz})^2 + \left(r_{yz}\right)^2 - 2 \cdot r_{xz} \cdot r_{yz} \cdot r_{xy}}{1 - \left(r_{xy}\right)^2}} \tag{4.3}$$

in the above, (r_{xz}, r_{yz}, r_{xy}) are the correlation coefficients between the variables (x, y, z). For example, the relationship between variables x and y can be defined as follows:

$$r_{xy} = \frac{\operatorname{cov}(x, y)}{S_{(x)} \cdot S_{(y)}} \tag{4.4}$$

The covariance between variables x and y is defined as follows:

$$\operatorname{cov}(x, y) = \frac{\sum_{i}^{n} (x_i - \overline{x}) \cdot (y_i - \overline{y})}{n} \tag{4.5}$$

where: (x_i, y_i) – surveyed values, $(\overline{x}, \overline{y})$ – the mean values.

Other correlation coefficients are defined in the same manner (however, for other variables).

The standard deviations of x and y are denoted as $(S_{(x)})$ and $(S_{(y)})$, respectively:

$$S_{(x)} = \sqrt{\frac{\sum_{i}^{n} (x_i - \overline{x})^2}{n}} \tag{4.6}$$

$$S_{(x)} = S_{(y)} = \sqrt{\frac{\sum_{i}^{n} (y_i - \overline{y})^2}{n}} \tag{4.7}$$

The coefficient of determination, (R^2), indicates the part of the observed total variability of z that is explained by the adopted model. An adjusted coefficient of determination is introduced when an additional explanatory variable is added to the model (three or more variables), as follows [3]:

$$\left(R_{\text{adj}}\right)^2 = 1 - \frac{\left(1 - \left(R_{z,xy}\right)^2\right) \cdot (n-1)}{n-k-1} \tag{4.8}$$

where: k – the number of independent variables, and n – the number of data elements surveyed for (z).

5. Interdependencies of the geotechnical parameters

The figures presented below expose the values for the established soil parameters (on the left side) acquired from the field tests, and the statistical fitting models to the data (on the right side), as described with the mathematical equations in the tables. The tables also includes statistical characteristics of the models, as expressed by the parameters ($R\left(R_{\text{adj}}\right)^2, S_{(z)}$).

5.1. Functional representation of the dynamic modulus of deformation $E_{Vd} = f\left(E_{V1}, E_{V2}\right)$

Refer to (Fig. 1) and (Table 1).

The coefficients of correlation and determination highlight the excellent fitting of the model to the data (Fig. 1). In addition, the standard deviation is only 4.3 MPa (Table 1) in the range of the dynamic modulus values, i.e. 30–80 MPa.

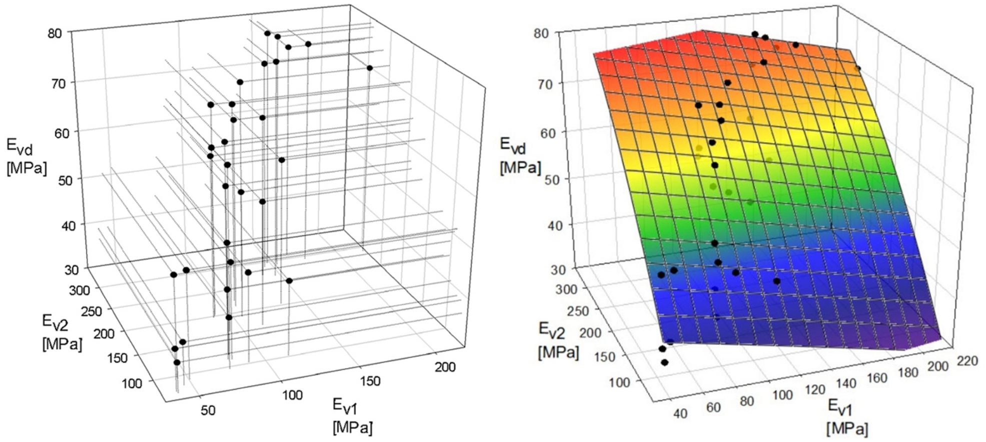

Fig. 1. Measured values E_{Vd}, E_{V1}, E_{V2} (left side), statistical model (right side)

Table 1. Paraboloid surface (Fig. 1) represented by the function $E_{Vd} = f\,(E_{V1}, E_{V2})$

$E_{Vd} = -1.68 \cdot 10^{-5} \cdot (E_{V1})^2 - 3.1 \cdot 10^{-4} \cdot (E_{V2})^2 - 0.06 \cdot E_{V1} + 0.3 \cdot E_{V2} + 22.93$		
Correlation coefficient R	Coefficient of determination $\left(R_{\text{adj}}\right)^2$	Standard deviation $S_{(z)}$
0.9524	0.9070	4.2869

5.2. Functional representation of bearing ratio CBR $= f\,(E_{V1}, E_{V2})$

Refer to (Fig. 2) and (Table 2).

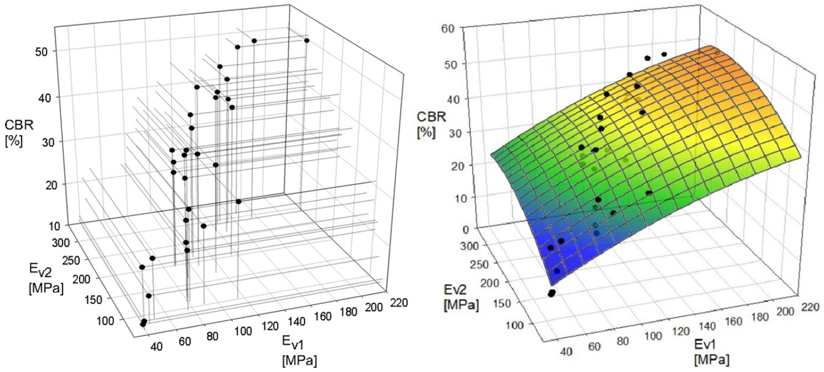

Fig. 2. Measured values CBR, E_{V1}, E_{V2} (left side), statistical model (right side)

Table 2. Paraboloid surface (Fig. 2) represented by the function CBR $= f\,(E_{V1}, E_{V2})$

$\text{CBR} = -4 \cdot 10^{-4} \cdot (E_{V1})^2 - 3 \cdot 10^{-4} \cdot (E_{V2})^2 + 0.23 \cdot E_{V1} + 0.18 \cdot E_{V2} - 5.45$		
Correlation coefficient R	Coefficient of determination $\left(R_{\text{adj}}\right)^2$	Standard deviation $S_{(z)}$
0.9623	0.9260	3.1442

5.3. Functional representation of bearing ratio CBR $= f\,(E_{Vd}, E_{V2})$

The coefficients of correlation and determination highlight the excellent fitting of the model to the data (Fig. 3). The standard deviation is only 4.0% (Table 3) in the range of the bearing ratio values, i.e. 10–60%.

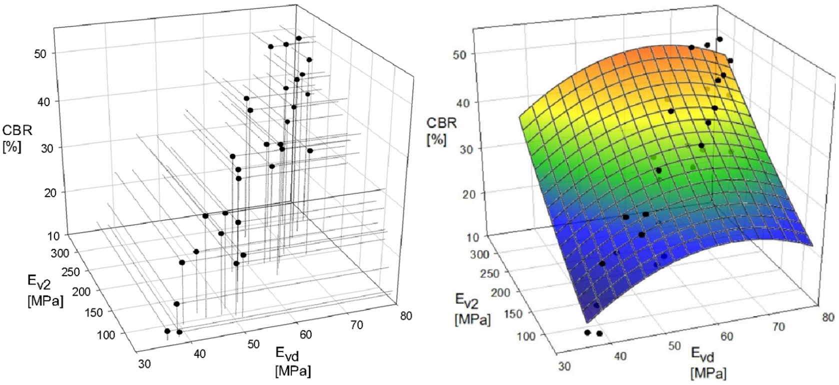

Fig. 3. Measured values CBR, E_{Vd}, E_{V2} (left side), statistical model (right side)

Table 3. Paraboloid surface (Fig. 3) represented by the function CBR $= f\,(E_{Vd}, E_{V2})$

$\mathrm{CBR} = -0.016 \cdot (E_{Vd})^2 + 9,27 \cdot 10^{-5} \cdot (E_{V2})^2 + 1.91 \cdot E_{Vd} + 0.07 \cdot E_{V2} - 42$		
Correlation coefficient R	Coefficient of determination $\left(R_{\mathrm{adj}}\right)^2$	Standard deviation $S_{(z)}$
0.9365	0.8770	4.0524

5.4. Functional representation of the dynamic modulus of deformation $E_{Vd} = f\,(\mathrm{CBR}, E_{V2})$

The coefficients of correlation and determination highlight the excellent fitting of the model to the data (Fig. 4). The standard deviation is only 4.4 MPa (Table 4) in the range of the dynamic modulus values, i.e. 30–80 MPa.

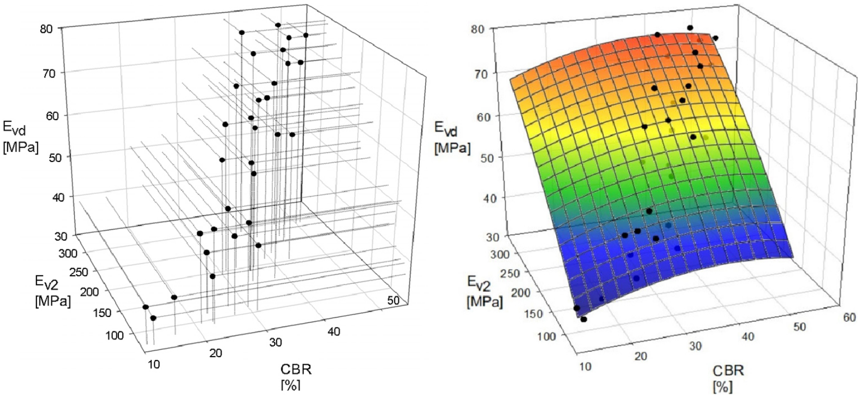

Fig. 4. Measured values CBR, E_{V2}, E_{Vd} (left side), statistical model (right side)

Table 4. Paraboloid surface (Fig. 4) represented by the function $E_{Vd} = f\,(\mathrm{CBR}, E_{V2})$

$E_{Vd} = -8,4 \cdot 10^{-3} \cdot \mathrm{CBR}^2 - 2 \cdot 10^{-4} \cdot (E_{V2})^2 + 0.66 \cdot \mathrm{CBR} + 0.21 \cdot E_{V2} + 16.86$		
Correlation coefficient R	Coefficient of determination $\left(R_{\mathrm{adj}}\right)^2$	Standard deviation $S_{(z)}$
0.9494	0.9013	4.4158

5.5. Functional representation of the secondary modulus of deformation $E_{V2} = f\,(\mathrm{CBR}, E_{Vd})$

Refer to (Fig. 5) and (Table 5).

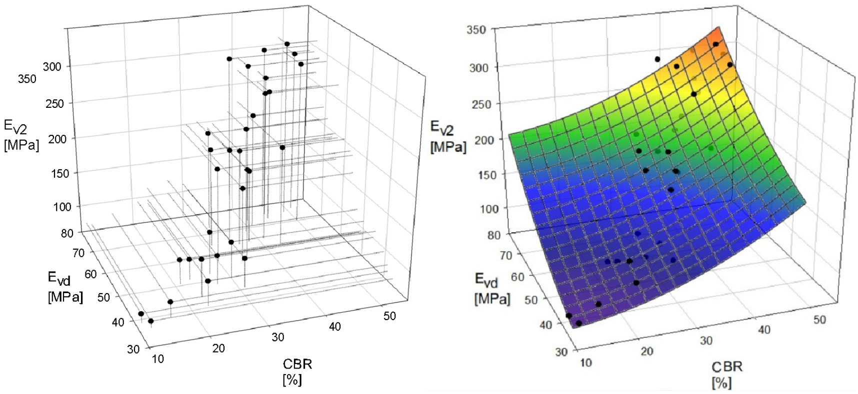

Fig. 5. Measured values CBR, E_{Vd}, E_{V2} (left side), statistical model (right side)

Table 5. Paraboloid surface (Fig. 5) represented by the function $E_{V2} = f\,(\mathrm{CBR}, E_{Vd})$

$E_{V2} = 0.05 \cdot \mathrm{CBR}^2 + 0.04 \cdot (E_{Vd})^2 - 0.3 \cdot \mathrm{CBR} - 1.05 \cdot E_{Vd} + 49,24$		
Correlation coefficient R	Coefficient of determination $\left(R_{\mathrm{adj}}\right)^2$	Standard deviation $S_{(z)}$
0.9636	0.9285	22.4946

6. Conclusions

Various situations in geotechnics (especially earthworking) require soil parameter correlations. These are helpful in the verification of the quality of the soil improvement. Thus, proper correlations are useful for geotechnical design [9].

Presented results claim that triple depended correlations may bring some corrects in relationships of soil parameters as against to double depended correlations. The differences in coefficients of determination are significant. Three variables involved stronger correlations.

Establishment of the soil state parameters based on field measurements acquired from devices is only an approximation of the true values. Inaccuracy in the obtained results can arise from the measurement uncertainty and/or the statistical model applied to elaborate on the data. More sophisticated analysis can also be used as generalized dynamical systems [10], however from practical point of view presented models seem to be sufficient.

The devices presented above represent simple forms of soil investigation, e.g. naked-eye data reading. Often, errors and uncertainties may add up, leading to increased scattering in the results. The may lead to underestimation or overestimation of the measured values.

Partial or material factors, commonly used in geotechnical design, can be used to normalise measurement imperfections. Design values of parameters, as derived from characteristic values, allow operators to conduct design procedures safely. Nevertheless, the factors often understate the design values, disproportionately to the real state.

The main conclusion from the site tests is that the key task is properly prepare soil to the measure. Obviously, a trivial remark is stating that all those devices (VSS plate, LFWD plate, CBR device) differ in mechanical and physical manner of measurement. However, we do not exclude the possibility of achieving reasonable correlations between estimated parameters.

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Potrójne korelacje między parametrami gruntu badanymi in situ

Słowa kluczowe: parametry stanu gruntu; korelacje; pomiary; modelowanie statystyczne

Streszczenie:

Podczas badania parametrów gruntu zmierzone wielkości są jedynie przybliżeniami wartości rzeczywistych. Pomiar jest określany na podstawie niepewności metrologicznej lub przy użyciu modeli statystycznych do analizy danych. Niektóre parametry stanu gruntu wykazują silne korelacje, ale inne nie zawsze wyrażają prostą zgodność. Korelacje między parametrami geotechnicznymi są najczęściej przedstawiane jako zmienne podwójnie zależne. Jednak wieloparametryczne wzajemne stany są rzadko ustanawiane. Wielokrotne korelacje między parametrami geotechnicznymi mogą zapewnić nową perspektywę spojrzenia na problem synchronizacji parametrycznej i usprawnić geotechniczne procedury projektowe. Takie zależności mogą lepiej wyprofilować identyfikację stanów gruntu i mogą pozwolić na dokładniejsze opisy nieliniowości korelacji w różnych zakresach zależności obciążenie-deformacja. Relacje wieloparametryczne mogą również ułatwić identyfikację potencjalnych błędów pomiarowych, np. jednego nieprawidłowego parametru wśród innych poprawnie wyznaczonych. Metody badań terenowych wykorzystują różne urządzenia do pomiaru wartości, z których obliczane są oczekiwane parametry. Niemniej jednak istnieje różnica między zmierzoną wartością wielkości a jej prawdziwą wartością. Zmierzone wartości zawierają błędy. Identyfikacja takich błędów i ich wpływ na efekt końcowy powinny być opisane tak dokładnie, jak to możliwe. Pomiar wielkości fizycznej odnosi się do empirycznych operacji przypisywania procesów fizycznych lub zjawisk do obiektów matematycznych, w szczególności liczb. Operacje obejmują opis ilościowy niezbędny do analizy danych statystycznych. Na podstawie wyników procesów pomiarowych uzyskanych z badań terenowych wartości projektowe dla parametrów modelu gruntu można określić po ocenie wartości charakterystycznych w połączeniu z właściwym współczynnikiem częściowym lub jako bezpośrednią ocenę wartości projektowych w oparciu o szczególne wymagania dotyczące poziomu niezawodności. Jednakże rzeczywista wartość zmierzonej wielkości nie może być uzyskana z urządzenia pomiarowego. Każdy wynik pomiaru jest zmienną losową określoną w przedziale ufności. Każdy wynik pomiaru powinien składać się z szacunkowej wartości mierzonej wielkości i niepewności pomiaru. Warunki terenowe w praktyce geotechnicznej często ograniczają badania stanu gruntu, a interpretacja statystyczna jest trudna (lub nawet niemożliwa) przy niewielkiej liczbie prób. Normy geotechniczne, tj. Eurokod 7, ustanawiają metody statystyczne do definiowania pojedynczego parametru. Ponadto, dostarczane są zestawy odpowiednich współczynników częściowych lub współczynników materiałowych. Pozwala to na uzyskanie wystarczającej liczby znanych efektów, aby rozwiązać problem niepewności modelu statystycznego lub rozwiązać problem niepewności w testach kalibracyjnych dla urządzeń pomiarowych stosowanych w geotechnicznych procedurach badawczych. Współczynniki częściowe lub materiałowe, powszechnie stosowane w projektowaniu geotechnicznym, mogą być wykorzystane do normalizacji niedoskonałości pomiarowych. Wartości projektowe parametrów, pochodzące z wartości charakterystycznych, umożliwiają geotechnikom bezpieczne przeprowadzanie procedur projektowych. Niemniej jednak czynniki te często zaniżają wartości projektowe parametrów geotechnicznych, nieproporcjonalnie do stanu rzeczywistego. Dlatego, im więcej zależności korelacyjnych między parametrami można ustanowić, tym bardziej precyzyjnie można opisać stan gruntu.

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