IOP Conf. Series: Materials Science and Engineering **245** (2017) 022041 doi:10.1088/1757-899X/245/2/022041

Establishing Relationships between Parameters of the Controlled Compaction Soil by Using Various In-Situ Tests

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Abstract. The aim of research was evaluating reliable correlations between chosen soil parameters describing state of surface layers of soil. The paper presents site comparative tests based on the light falling weight deflectometer (LFWD), the static plate load tester (VSS), the dynamic probing light tester (DPL) and the bearing ratio tester (CBR in-situ) with relationships between soil state parameters. All featured in-situ tests were conducted based on Polish experiences and Standards used in engineering practice.

1. Introduction

In both of site engineering practice and design practice, correlations between geotechnical parameters are very important to describe proper view of technical circumstances. It is observed in engineering state of affairs for example that lack of correlations between soil parameters constraints the foundation design. Either contractors in geotechnics are often forced to obligatory present chosen soil parameters compared with others. It is common practice in investment jobs in Poland. But earthworks belong to engineering works undergoing to covering and sometimes is not possible to directly estimate expected parameters after finishing ground preparations for the construction setting.

With no doubt appropriate correlations between parameters can be useful to receive an acceptance of executed earthworks, or to certify quality of the work done, or to avoid spreading out filled layers of soil.

The correlations described below are obtained from the field testing made during a real building investment. The earthwork description demanded the large artificial bank of soil on 150 meters long and 100 meters wide site. The embankment consisted of layered soil to its final height of 1,8 meters. Every layer was gradually compacted and simultaneous field investigations were carried on.

For every step of compaction, series of tests in the field were conducted: the dynamic probing (DPL test), the dynamic plate test (LFWD test), the static plate test (VSS test), the soil bearing test (CBR test). Based on this investigation results, relationships between dynamic modulus, static moduli, density index, relative bearing ratio were established for medium/fine grained soil like sand with coarse silt [1].

2. Description of experiment

Before the embankment works started, subsoil was improved by a dynamic compaction. Improved subsoil was stable and stiff to place the embankment and no disadvantage effects was observed on the surface like an irregular subsidence.

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The embankment was constructed in layers and every layer of soil was compacted with a smooth wheeled roller in four number of passes. Before compaction, soil was brought to the near optimum moisture content as in-situ conditions allowed. The soil compaction process was fully controlled; the surface of the soil layer was not loosened during tests. Conditions within the depth range of the tested soil were assumed reliable and homogeneous. After every passing of a roller, soil tests were conducted.

Sieve analysis [2] on four samples of soil do not showed fundamental differences in granular composition. Representative granulometry analysis is shown on figure 1.

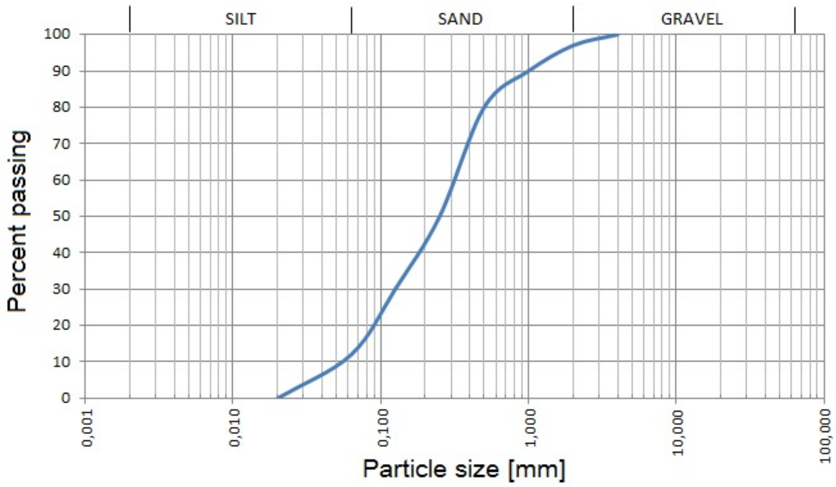

Figure 1. Representative sieve analysis

According to the Standard [3] values of sieve parameters were established: uniformity coefficient C_U = 5 and curvature coefficient C_C = 1.

2.1. Dynamic probing light (DPL test)

In particular, the DPL tester is an extensively used subsoil hand-held investigation device to obtain quantitative state parameters of a cohesionless soil. It is achieved by measuring the resistance to the cone penetration in the tested soil. The main aim of the DPL test is determining the compactness presented as the density index (I_D). Test procedure has been referenced in the Standard specification [4]. Four different dynamic probing types are recommended for use. They differ in a cone size, a hammer weight and a drop height to fit specific soil conditions.

The DPL tester used in the experiment consists of drive rods set with mass equal to 3 kg and 1 m long each one. Apex angle of a cone tip have a measure 90°.

Managing the DPL test involves rising and dropping 10 kg hammer. On this way specific energy is transferred through the anvil and rods set to the cone driven into underlaying soil layers. After each 10 cm driven rod, number of blows are recorded (N_{10}). Based on N_{10} number of blows, test results are expressed in terms of the density index (I_D) defined after Polish experience [5] for sand characterized by $C_U > 3$:

$$I_D = 0.429 \cdot log\, N_{10} + 0.071 \qquad (1)$$

2.2. Static plate load (VSS test)

The VSS site investigation field test is one of the most popular methods of measuring bearing capacity and compaction for the soil surface during the embankment formation process in successive horizontal layers. Test procedures and evaluation of the static deformation modulus E_V are taken from Polish Standard for roads construction [6]:

$$E_V = \frac{3 \cdot \Delta p}{4 \cdot \Delta s} \cdot D \tag{2}$$

The main part of the VSS equipment is rigid steel plate with a diameter of $D = 0.3$ m. According to the standard procedure, quasi-static load on the plate is applied in fixed constant steps of 0.05 MPa. Each level of load is sustained for an equal time increment. Final load is 0.25 MPa for soil used as a fill. For another type of soil, the final load differs from mentioned above [1].

Two stages of load are fulfilled. In the first stage, load is applied and the primary static deformation modulus (E_{V1}) is determined. After complete load removal, the plate is reloaded in second stage and the secondary static deformation modulus (E_{V2}) is determined. Moduli evaluation are calculated for range of the load increment Δp = (0.15 – 0.05) MPa. The settlement increment for each stage and range of the load increment is evaluated as value $\Delta s = (s_{0,15} - s_{0,05})$.

Plate loading during the VSS test must be ballasted properly. For this purpose, heavy constriction machines are usually used as a truck or a road roller. It is important to ensure a kentledge at least 150% of the maximum plate load.

The device is equipped with a pressure manometer to keep proper force and a displacement gauge to determine the deflection. All data are acquired by the direct observation mode, so the test should be performed carefully to minimize errors.

2.3. Dynamic plate load (LFWD test)

The LFWD tester provides immediate repeatable results given as the dynamic modulus of deformation E_{Vd}. The ZFG 2000 equipment was used [7]. According to the operating manual the loading plate with diameter $D = 0.3$ m is subjected to a settlement due to the maximum impact force 7.07 kN. The plate displacement is recorded by means of the electronic meter.

The test starts with three seating drops to produce full contact between the plate and the soil surface. Then three further drops are made in the same manner, and the mean value of three peaks of vertical plate displacements forms a value of strain $\Delta z = z_{max}$ for which the dynamic deformation modulus E_{Vd} is determined. It appears that the dynamic deformation modulus is evaluated in the secondary loading of the plate. As a simplification is assumed the maximum mean load acting on the soil during the test is generally constant $\Delta\sigma = 0.1$ MPa. The dynamic deformation modulus is evaluated using the formula of the static load of the soil surface:

$$E_{Vd} = 1.5 \cdot \frac{D}{2} \cdot \frac{\Delta\sigma}{\Delta z} = \frac{0.0225}{z_{max}} \tag{3}$$

The ZFG 2000 equipment measures E_{Vd} in the range from 5 up to 70 MPa with assured tolerance.

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

Standard California Bearing Ratio test is a laboratory investigation of a sample of soil conducted in the cylindrical mould under strictly controlled density and moisture. For the purpose of the research project the CBR in-situ was evaluated. Tests were conducted on the surface of roller compacted ground in the field conditions of soil.

The test procedure and evaluation of the relative bearing ratio (CBR_{insitu}) are taken from Polish Standard for roads construction [6]:

$$CBR_{insitu} = \frac{p}{p_p} \cdot 100 \tag{4}$$

The CBR in-situ value is expressed as a percentage of an actual load (*p*) causing the penetrations of 2,5 mm or 5 mm into the soil surface to the standard load (p_p) which is equal to 7 MPa for 2,5 mm penetration and 10 MPa for 5 mm penetration. Load onto the soil surface was applied on the cylindrical plunger of 5 cm diameter, keeping the constant rate of penetration 1,25 mm/minute.

3. Results and discussions

3.1. Dynamic modulus vs. secondary static modulus

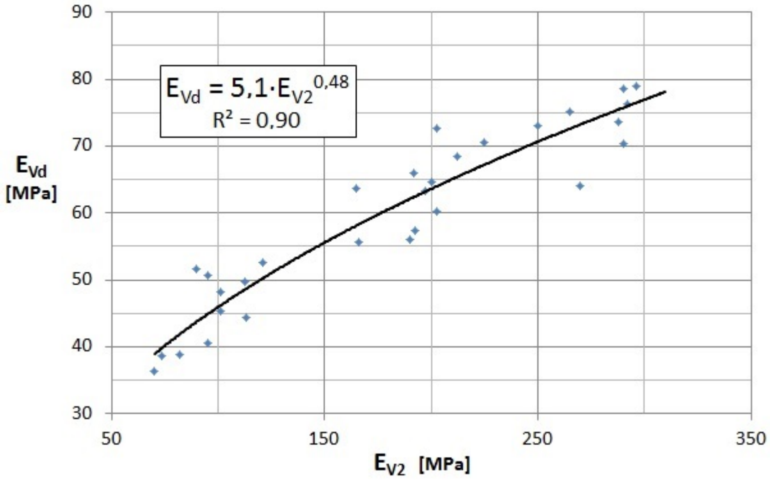

Figure 2. Correlation between dynamic modulus and secondary static modulus.

The power function describes the relationship between the dynamic modulus and the secondary static modulus:

$$E_{Vd} = 5.1 \cdot E_{V2}^{0.48} \quad (5)$$

Coefficient of determination $R^2 = 0.9$ indicates that 90% of changes in the amount of the dynamic modulus value is explained by the value of secondary static modulus. And 10% of change in E_{Vd} value is caused by other factors like a little irregular compactness, local differences in the soil moisture or even a weak precision of measurement [8].

The range of validity for the relationship refers to E_{V2} = 60 up to 300 MPa.

3.2. Dynamic modulus vs. primary static modulus

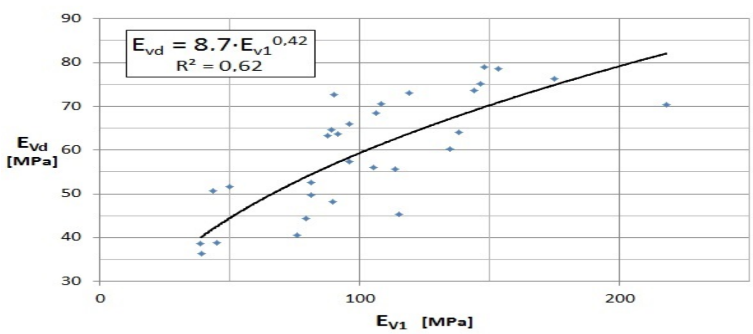

Figure 3. Correlation between dynamic modulus and primary static modulus

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The power function describes the relationship between the dynamic modulus and the primary static modulus:

$$E_{Vd} = 8.7 \cdot E_{V1}^{0.42} \tag{6}$$

In this measurement coefficient of determination $R^2 = 0.62$. It can be described like previously that 62% of changes in the amount of dynamic modulus value is explained by the value of primary static modulus. And 38% of changes in E_{Vd} value is caused by other factors.

The range of validity for the relationship refers to E_{V1} = 40 up to 200 MPa.

3.3. *Dynamic modulus vs. relative density index*

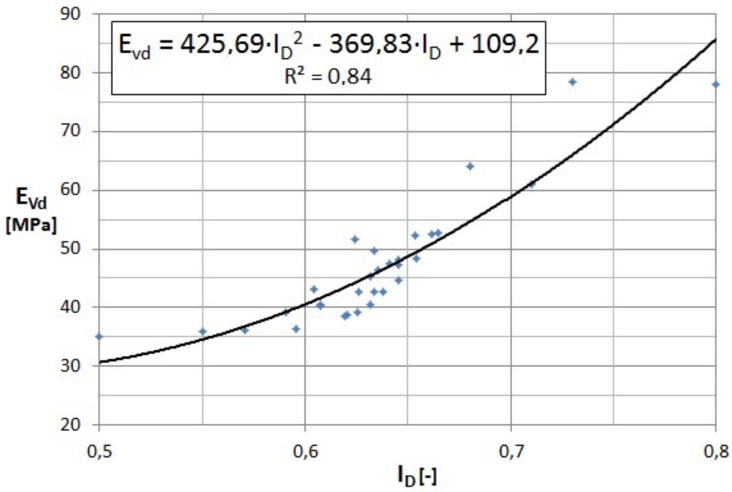

Figure 4. Correlation between dynamic modulus and density index

The polynomial function describes the relationship between the dynamic modulus and the density index:

$$E_{Vd} = 425.69 \cdot I_D^2 - 369.83 \cdot I_D + 109.2 \tag{7}$$

Coefficient of determination $R^2 = 0{,}84$ means that 84% of change in the amount of dynamic modulus value is explained by the value of density index. And 16% of change in E_{Vd} value is caused by other factors [9]. The range of validity for the relationship refers to I_D = 0,5 up to 0,8.

3.4. *CBR in-situ vs. dynamic modulus*

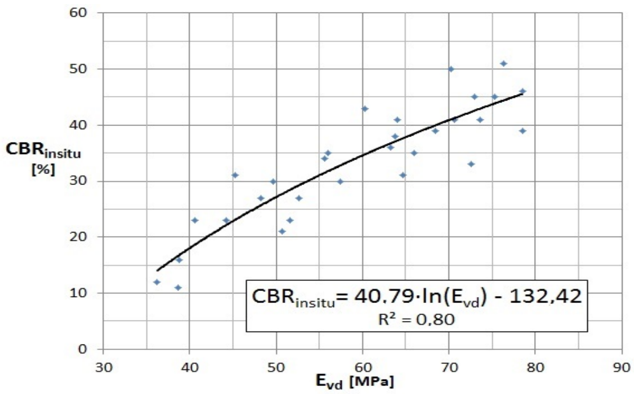

Figure 5. Correlation between in-situ bearing ratio and dynamic modulus.

The logarithmic function describes the relationship between in-situ bearing ratio and the dynamic modulus:

$$CBR_{insitu} = 40.79 \cdot \ln E_{Vd} - 132.42 \quad (8)$$

Coefficient of determination for the relationship is $R^2 = 0.80$. The coefficient can be explained like previously.

3.5. CBR in-situ vs. secondary static modulus

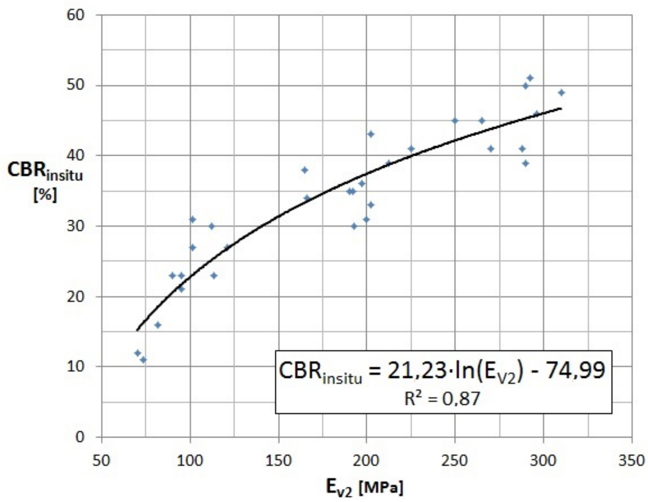

Figure 6. Correlation between in-situ bearing ratio and secondary static modulus

The logarithmic function describes the relationship between in-situ bearing ratio and the secondary static modulus:

$$CBR_{insitu} = 21.23 \cdot \ln E_{V2} - 74.99 \quad (9)$$

Coefficient of determination for the relationship is $R^2 = 0.87$. The coefficient can be explained like previously.

3.6. CBR in-situ vs. primary static modulus

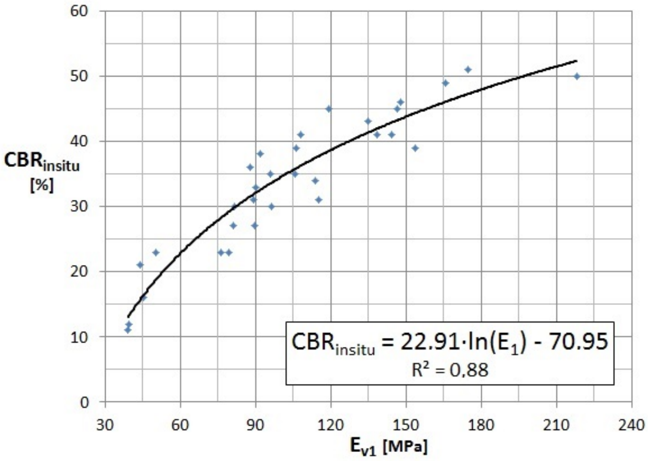

Figure 7. Correlation between in-situ bearing ratio and primary static modulus

The logarithmic function describes the relationship between in-situ bearing ratio and the primary static modulus:

$$CBR_{insitu} = 22.91 \cdot \ln E_{V1} - 70.95 \quad (10)$$

Coefficient of determination for the relationship is $R^2 = 0.88$. The coefficient can be explained like previously.

3.7. *CBR in-situ vs. relative density index*

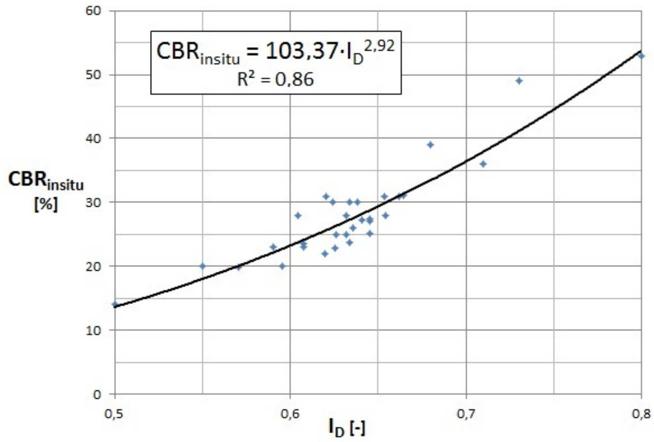

Figure 8. Correlation between in-situ bearing ratio and density index

The power function describes the relationship between in-situ bearing ratio and the density index:

$$CBR_{insitu} = 103.37 \cdot I_D^{2.92} \quad (11)$$

Coefficient of determination for the relationship is $R^2 = 0.86$. The coefficient can be explained like previously.

4. Conclusions

In statistical regression analysis, the coefficient of determination R^2 is interpreted as the proportion of the variance in one variable that is predictable from the other variable, i.e. what part of data taken to the analysis is explained by the established formula. If the coefficient of determination is higher than the regression curve is better fit to set of data. For additional information about the state of relationships, the coefficient of correlation R may also be done. This coefficient indicates the strength of the relationship between variables. In general, $R > 0$ indicates positive relationship, i.e. as the value of one variable increases, the value of the other variable also increases.

Table 1. Coefficients of correlation and coefficients of determination

Relationships	R	R^2
E_{Vd} (E_{V2})	0.95	0.90
E_{Vd} (E_{V1})	0.80	0.64
E_{Vd} (I_D)	0.92	0.84
CBR_{insitu}(E_{Vd})	0.91	0.82
CBR_{insitu}(E_{V2})	0.93	0.87
CBR_{insitu}(E_{V1})	0.94	0.88
CBR_{insitu}(I_D)	0.92	0.85

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Coefficients of correlation and coefficients of determination for presented soil parameters correlation are shown in table 1.

Almost all coefficients of determination have higher level than 0.8. It is evidence that established models can be used as good correlations between presented soil parameters.

The aim of presented works was evaluating reliable correlations between chosen soil parameters describing state of surface layers of soil. Disposal of such engineering data is very supportive if during conducted earthworks quick evaluation of the soil state is needed and quality of earthworks must be confirmed. Results can be used to convertible evaluation of soil parameters in the case of possibility managing only one type of the soil test mentioned above.

The correlations can be conclusive for some class of soil, i.e. for sands with coarse silt near the optimum moisture content and middle compacted and compacted one. For other types of soil correlations may differ [10].

References

[1] PN-EN ISO 14688-2:2006. Geotechnical investigation and testing. Identification and classification of soil. Part 2. Principles for a classification.

[2] PKN-CEN ISO/TS 17892-4:2009. Geotechnical investigation and testing. Laboratory testing of soil. Part 4. Determination of particle size.

[3] PN-EN ISO 14688-1:2006. Geotechnical investigation and testing. Identification and classification of soil. Part 1: Identification and description.

[4] EN ISO 22476-2:2005 Geotechnical investigation and testing. Field testing. Part 2: Dynamic probing.

[5] PN-B-04452:2002. Geotechnics. Field Investigations.

[6] PN-S-02205:1998. Roadways. Earthworks. Requirements and testing.

[7] Zorn Instruments GmbH & Co. KG. 2005. Operating Manual for Light Drop Weight Tester ZFG 2000. Maschinenbauingenieur Bernd Zorn, Stendal, Germany.

[8] M. Wyroslak, R. Ossowski, "Evaluation of deformation moduli in controlled soil embankment based on VSS plate and LFWD plate". Acta Sci. Pol. Architectura, 15 (3), pp. 111–118.

[9] M. Wyroslak, "Correlation of state parameters for controlled compaction soil based on light weight deflectometer test and dynamic probing test". Inzynieria i Budownictwo, 7/2016, pp. 382–384.

[10] M. Wyroslak, "Relationship between subgrade parameters obtained from field test of controlled compaction soil". *Inzynieria Morska i Geotechnika*, 1/2017, pp. 21–26.