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CORRELATIONS BETWEEN IN SITU DCP TEST AND LABORATORY TEST RESULTS

BY

ELENA-IRINA PLĂTICĂ[*] and DANA-MĂDĂLINA POHRIB

"Gheorghe Asachi" Technical University of Iaşi
Faculty of Civil Engineering and Building Services

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Abstract. Geotechnical engineers are interested in investigating the actual behavior of the soil. Currently there are several methods available for assessing the properties of the soil. The variability of the geotechnical parameters resulting from these methods is neglected assuming that the mass of the soil is homogeneous and the variation of these parameters at various is rareli considered. Heterogeneity is a characteristic of the soil because their parameters vary from one point to another. To get an accurate characterization of the soil wich take into account their heterogeneity, it would require a large number of field and laboratory tests, unfeasible given the costs necessary. To reduce costs and to increase the number of the samples analyzed, it have been developed several types of in situ testing for determining geotechnical parameters (Phoon & Kulhawy, 1999; Chenari & Dodaran, 2010).

This paper aims at obtaining correlation between the number of blows N_{30DCP} and the results obtained in the laboratory on undisturbed samples. The goal is to obtain for a large site relationships correlations between different parameters, in order to reduce the number of boreholes and laboratory tests. To obtain the values of correlation coefficient $r \geq 0.80$ it was intended to achieve correlation at fixed depth, where undisturbed samples were taken which were then subjected to laboratory tests. Correlations were obtained between N_{30DCP} and bulk density (γ), the angle of internal friction (φ) and cohesion (c).

[*]Corresponding author: *e-mail*: irinaplatica@yahoo.com

Key words: DPSH-B; mathematical regression; correlation; standard deviation, probabilistic variability.

1. Introduction

Geotechnical engineers are interested in investigating the actual behavior of the soil. Currently there are several methods available for assessing the properties of the soil. The variability of the geotechnical parameters resulting from these methods is neglected assuming that the mass of the soil is homogeneous and the variation of these parameters at various is rareli considered. Heterogeneity is a characteristic of the soil because their parameters vary from one point to another. Heterogeneity of the soil parameters can be attributed to the following factors:

a) spatial variability of soils, due to the variation of the deposition conditions and the stress history;

b) increasing stiffness of the earth with depth due to increased geological pressure.

To get an accurate characterization of the soil wich take into account their heterogeneity, it would require a large number of field and laboratory tests, unfeasible given the costs necessary. To reduce costs and to increase the number of the samples analyzed, it have been developed several types of in situ testing for determining geotechnical parameters. In general, in situ tests does not requiere to obtaind undisturbed samples, but for obtaining correlations for different soil parameters, it require the execution of a number of boreholes (at least one) with undisturbed sample collection and laboratory analysis. In the work performed, the data from the laboratory test was analyzed to determine the ranges, the changes in trends and to make comparisons with the results of the dynamic cone penetration test. Correlations performed refers to parameters determined by laboratory tests and parameters determined by in situ tests (Phoon & Kulhawy, 1999; Chenari & Dodaran, 2010).

This paper aims at obtaining correlation between the number of blows N_{30DCP} and the results obtained in the laboratory on undisturbed samples. The goal is to obtain for a large site relationships correlations between different parameters, in order to reduce the number of boreholes and laboratory tests. To obtain the values of correlation coefficient $r \geq 0.80$ it was intended to achieve correlation at fixed depth, where undisturbed samples were taken which were then subjected to laboratory tests. Correlations were obtained between N_{30DCP} and bulk density (γ), the angle of internal friction (φ) and cohesion (c).

2. Conducted Research

The research was carried out on undisturbed samples taken from 6 boreholes from the depths 3.00, 6.00, 9.00, 12.00, 15.00, 18.00, 21.00 and 24.00 m and the number of blows N_{30DCP} recorded at the depth mentioned above. The DPSH tests have been carried out with the following equipment according to SR EN ISO 22476-2/2006 : falling weight 63.50 kg, height of fall 75.00 cm, nominal area at the base of the cone 20.00 cm^2, the nominal diameter of the base of the cone 50.50 mm, specific nominal energy on stroke 238.00 mgh/A (SR EN ISO 22476-2/2006). The equipment was provided with a bubble level to maintain therods vertically. During the execution of the DPSH-B tests it was aimed that the rods inserted in the soil by driving to maintain verticality so as not to apply corrections to the number of blows N_{30DCP} due to friction between the rod and the walls of the lateral surface of the hole created during the tests. This is prevented also by the fact that the cone diameter is $D =$ = 50.5 mm and the diameter of the rods is 32.00 mm.

In the works done it was used the specific nominal energy E_n, so the number of blows N_{30DCP} it was not altered by the consideration of energy loss during the fall of the weght. Due to the large thicknes of the inner walls of the rods number of blows N_{30DCP} it was not altered by the consideration of the buckling.

2.1. Statistical Analysis of Laboratory Data and their Correlation with the Number of Blows N_{30DCP} According to NP122:2010

The geotechnical parameter values resulting from the application of correlation relations are characteristic values (X_k) to wich one must apply the partial factors for material (γ_M) in order to become design values (X_d).

In order to establish the characteristic values of geotechnical parameters it is recommended to use statistical methods. In this case the assurance level of the X_k values will be 95%. For the local values $X_{k\ \mathrm{loc}}$ the estimation should be made so that the likelihood of an unfavorable values to be 5%. Geological elements for which characteristic values of geotechnical parameters are calculated, are delimited by geotechnical site investigation work carried out according to the requirements specified in SR EN 1997-2:2007 and NP 074:2014, based on geological information generated and classification criteria recommended in SR EN 14688-2:2005 and SR EN ISO 14688-2:200S/C91:2007.

The coefficinet of variation V_x for the values determined by testing and for derived values of geotechnical parameters that serve to identification and classification of the soil in the geological element is recommended not to exceed the maximum values $V_{x\ \max}$ according to design codes.

The coefficient of variation is calculated using the following relations:

$$V_x = \frac{s_x}{X_m}, \tag{1}$$

$$s_x = \sqrt{\frac{1}{n-1}\sum (X_i - X_m)^2}, \tag{2}$$

$$X_m = \frac{\sum X_i}{n}, \tag{3}$$

where: s_x is the standard deviation of individual values selected X_i , determined by tests or derived test data from field or laboratory; X_m – the arithmetic mean for the selected X_i values; n – number of selected values.

Geotechnical characteristic value of the parameter X_k is determined by the relation:

$$X_k = X_m(1 \pm k_n V_x), \tag{4}$$

where: k_n is the statistical coefficinet of mean variation which depends on the number of selected values and the average level of assurance.

The sign + or – from the above relation corresponds to superior characteristic value $X_{k\,\mathrm{sup}}$ respectively inferior characteristic value $X_{k\,\mathrm{inf}}$.

Local characteristic value $X_{k\,\mathrm{loc}}$ are determined by the relation:

$$X_{k\,\mathrm{loc}} = X_m(1 \pm 2V_x). \tag{5}$$

Linear correlations between two variables is used mainly in experimental data, due to the simplicity of calculations and graphic transposition. The regression function has the following form (Fig. 1):

$$y = ax + b. \tag{6}$$

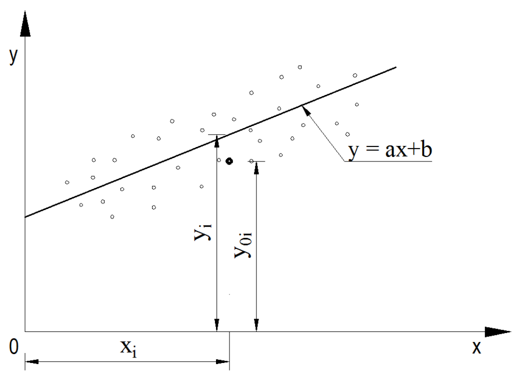

Fig.1 – Graphical representation of the regression function.

The parameters a and b are determined from the condition that the sum of the squared deviations of the experimental values y_{0i} than those calculated using the regression line are minimized as follows :

$$a = \frac{n\sum_1^n x_i y_{0i} - \sum_1^n x_i \sum_1^n y_{0i}}{n\sum_1^n x_i^2 - \left(\sum_1^n x_i\right)^2}, \tag{7}$$

$$b = \frac{\sum_1^n x_i^2 y_{0i} - \sum_1^n x_i \sum_1^n x_i y_{0i}}{n\sum_1^n x_i^2 - \left(\sum_1^n x_i\right)^2}, \tag{8}$$

where: n is the number of experimental values; y_{0i} – experimental value recorded corresponding to the value of x_i.

The measure of dependence between y and x values is done using correlation coefficint r :

$$r = \sqrt{1 - \left(\frac{s_c}{s}\right)^2}, \tag{9}$$

$$\overline{y} = \frac{1}{n}\sum_1^n y_{0i}, \tag{10}$$

$$s_c = \sqrt{\frac{1}{n}\sum_1^n \left(y_i - y_{0i}\right)^2}, \tag{11}$$

$$s = \sqrt{\frac{1}{n}\sum_1^n \left(y_{0i} - \overline{y}\right)^2}, \tag{12}$$

where: s_c is the standard deviation of the experimental values y_{0i} towards the regression line; s – the standard deviation of the experimental values towards the average values $\overline{y}$.

In geotechnical engineering values r > 0.80 is generally considered suitable and regression calculations may be used in practice. Because the regression line $y = ax + b$ leads to mean values of the variable y, it is recommended to use a covering correlation, from which to result the characteristic value:

$$y_k = ax + b \pm t_\alpha s_c \tag{13}$$

Table 1
Summarizing Table with Laboratory and Field Data

Layer	Borehole	Depth, [m]	γ, [kN/m^3]	φ', [°]	c, [kPa]	N_{30DCP}, [blows/30 cm]
Yelow loam	F1	3	16.22	24.62	31.34	5
	F2		16.28	24.69	31.69	5
	F3		16.88	24.79	32.68	6
	F4		16.75	24.85	32.47	6
	F5		16.25	24.52	31.78	5
	F6		16.85	24.8	31.96	6
	F1	6	16.29	19.58	23.32	6
	F2		17.81	21.51	26.88	7
	F3		17.85	22.88	28.56	7
	F4		16.45	20.32	24.63	6
	F5		17.03	21.89	29.12	7
	F6		18.22	22.34	30.44	8
	F1	9	16.93	19.26	32.48	10
	F2		19.03	24.12	46.33	14
	F3		16.54	20.12	29.45	11
	F4		17.25	20.44	35.47	12
	F5		17.41	21.47	40.45	12
	F6		17.88	23.33	37.96	13
Yelow sandy loam	F1	12	19.02	26.79	20.00	13
	F2		20.08	26.57	28.45	14
	F3		19.15	25.69	27.67	14
	F4		20.48	25.45	31.48	14
	F5		21.12	23.78	36.89	15
	F6		21.48	24.31	40.42	16
	F1	15	18.31	24.64	22.33	19
	F2		19.45	27.47	25.48	22
	F3		17.56	26.48	25.33	20
	F4		18.48	26.48	24.78	21
	F5		19.22	26.32	27.56	23
	F6		19.26	28.32	32.49	25
	F1	18	17.73	28.37	19.33	27
	F2		19.96	31.45	21.45	35
	F3		17.48	27.66	19.33	27
	F4		18.22	29.48	19.47	31
	F5		19.03	26.99	20.56	29
	F6		18.78	29.32	19.88	30
	F1	21	17.49	25.87	17.67	28
	F2		19.17	29.9	18.33	33
	F3		16.84	26.34	15.67	28
	F4		17.55	27.45	15.44	27
	F5		17.32	28.33	13.28	28
	F6		18.46	29.76	20.48	34
	F1	24	19.13	29.45	14.67	36
	F2		19.21	28.81	11.67	36
	F3		17.03	25.34	6.33	29
	F4		18.45	25.41	7.56	30
	F5		17.55	23.78	8.93	30
	F6		18.68	26.44	10.22	36

where: t_α is a statistical coefficint calculated based on the numebr n of experimental values for a level of insurance 95% (SR EN ISO 22476-2/2006).

Table 1 presents the values of geotechnical parameters analyzed after carrying out laboratory test and the number of blows N_{30DCP} associated.

The following summarizes the statistical processing performed on samples from the 3.00 m depth (Tables 2,…,4 and Figs. 2,…,4).

Table 2

Statistical Processing of Bulk Density Values

Item	Borehole	Depth, [m]	γ, [kN/m^3]	Bulk density					
1	F1	3	16.22	n =	6				
2	F2	3	16.28	X_m =	16.54				
3	F3	3	16.88	s_x =	0.32				
4	F4	3	16.75	Vx =	0.019	<	$V_{x\,\max}$ =	0.05	OK!
5	F5	3	16.25	$V_{x\,\text{necun}}$=	DA				
6	F6	3	16.85	k_n=	0.82				
				$X_{k\,\text{sup}}$ =	16.80				
				$X_{k\,\text{inf}}$ =	16.28				
				$X_{k\,\text{loc sup}}$ =	17.18				
				$X_{k\,\text{loc inf}}$ =	15.90				

Table 3

Statistical Processing of Angle of Internal Friction Values

Item	Borehole	Depth, [m]	φ', [°]	tg φ'	Angle of internal friction					
1	F1	3	24.62	0.46	n =	6				
2	F2	3	24.69	0.46	X_m =	0.46				
3	F3	3	24.79	0.46	s_x =	0.00				
4	F4	3	24.85	0.46	Vx =	0.01	<	$V_{x\,\max}$ =	0.10	
5	F5	3	24.52	0.46	$V_{x\,\text{necun}}$=	DA				
6	F6	3	24.8	0.46	k_n =	0.82				
					$X_{k\,\text{sup}}$ =	0.46	=	φ'=	24.8	[°]
					$X_{k\,\text{inf}}$ =	0.46	=	φ' =	24.6	[°]
					$X_{k\,\text{loc sup}}$ =	0.47	=	φ' =	24.9	[°]
					$X_{k\,\text{loc inf}}$ =	0.45	=	φ'=	24.4	[°]

Table 4

Statistical Processing of Cohesion Values

Item	Borehole	Depth [m]	c'/c_U, [kPa]	Cohesion					
1	F1	3	31.34	n =	6				
2	F2	3	31.69	X_m =	31.99				
3	F3	3	32.68	s_x =	0.50				
4	F4	3	32.47	Vx =	0.02	<	$V_{x\,\max}$ =	0.40	OK!
5	F5	3	31.78	$V_{x\,\text{necun}}$=	DA				
6	F6	3	31.96	k_n =	0.82				
				$X_{k\,\text{sup}}$ =	32.40				
				$X_{k\,\text{inf}}$ =	31.57				
				$X_{k\,\text{loc sup}}$ =	32.99				
				$X_{k\,\text{loc inf}}$ =	30.98				

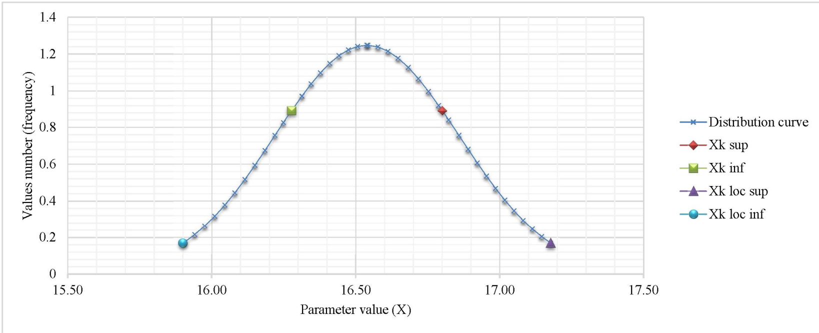

Fig. 2 – Normal distribution curve for γ_k values.

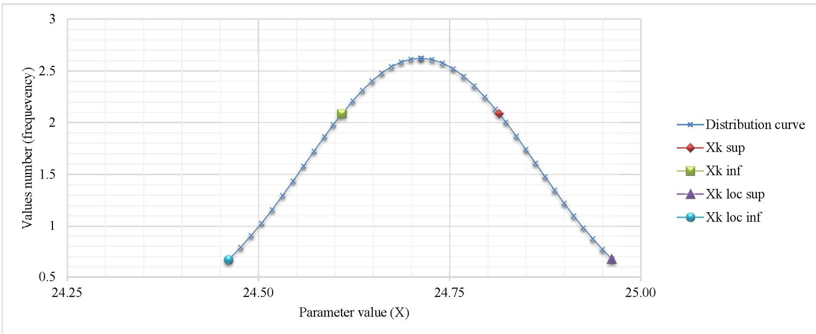

Fig.3 – Normal distribution curve for φ_k values.

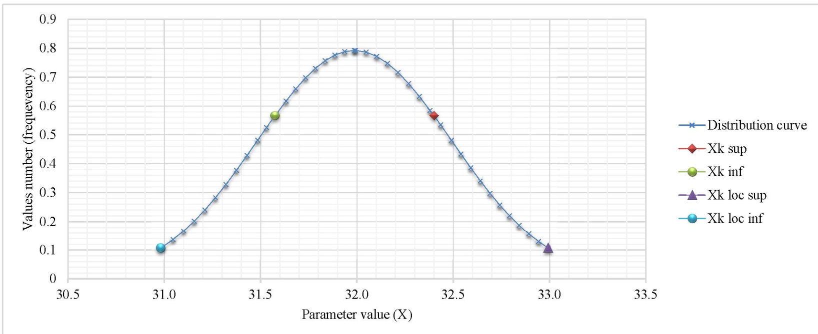

Fig.4 – Normal distribution curve for c_k values.

After the statistical processing it resulted that all the samples taken at the 3.00 m depth from boreholes F1,…,F6 belong to the same geological layer. The same conclusion was reached for the remaining samples taken from the others depths after the completation of statistical calculations.

The next step was to find a correlation equation between the value x (N_{30DCP}) and the values of y (γ, φ, c) using the formula (6). To obtain the values of correlation coefficient $r \geq 0.80$ it was intended to achieve correlation at fixed depth, where undisturbed samples were taken which were then subjected to laboratory tests.

Tables 5,…,7 presents the centralized resulted equations for all depths and all parameters and in Figs. 5,…,7 the graphical representation of the following correlations $N_{30DCP} - \gamma$, $N_{30DCP} - \varphi$, $N_{30DCP} - c$ for the samples taken at the depth of 3.00 m.

Tabelul 5

Table Summarizing the $N_{30DCP} - \gamma$ Correlations

Layer	Depth m	Correlation N_{30DCP}-γ kN/m^3
Yelow loam	3	$y = \gamma = 0.577N_{30DCP} + 13.366$
		$y_k = \gamma = 0.577N_{30DCP} + 13.366 \pm 0.086$
	6	$y = \gamma = 0.972N_{30DCP} + 10.630$
		$y_k = \gamma = 0.972N_{30DCP} + 10.630 \pm 0.604$
	9	$y = \gamma = 0.554N_{30DCP} + 10.858$
		$y_k = \gamma = 0.554N_{30DCP} + 10.858 \pm 0.703$
Yelow sandy loam	12	$y = \gamma = 0.866N_{30DCP} + 7.814$
		$y_k = \gamma = 0.866N_{30DCP} + 7.814 \pm 0.850$
	15	$y = \gamma = 0.181N_{30DCP} + 14.952$
		$y_k = \gamma = 0.181N_{30DCP} + 14.952 \pm 0.522$
	18	$y = \gamma = 0.265N_{30DCP} + 10.619$
		$y_k = \gamma = 0.265N_{30DCP} + 10.619 \pm 0.0837$
	21	$y = \gamma = 0.243N_{30DCP} + 10.600$
		$y_k = \gamma = 0.243N_{30DCP} + 10.600 \pm 0.799$
	24	$y = \gamma = 0.218N_{30DCP} + 11.173$
		$y_k = \gamma = 0.218N_{30DCP} + 11.173 \pm 0.799$

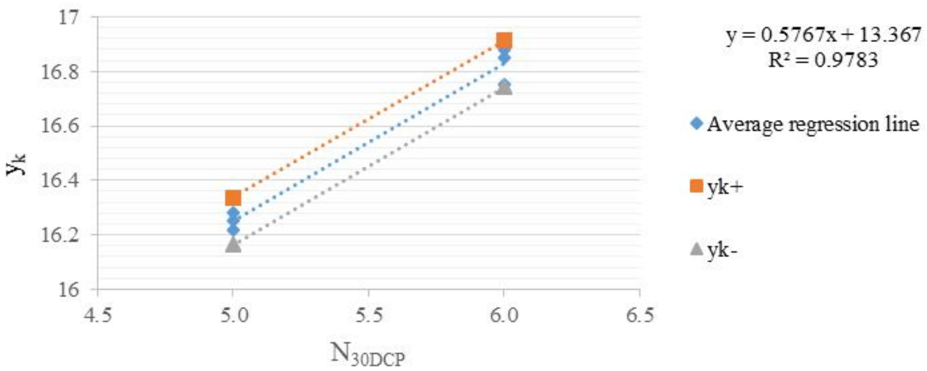

Fig. 5 – Correlation chart $N_{30DCP} - \gamma$.

Table 6
Table Summarizing the $N_{30DCP} - \varphi$ Correlations

Layer	Depth, [m]	Correlation N_{30DCP}-φ, [°]
Yelow loam	3	$y = \varphi = 0.203N_{30DCP} + 23.593$
		$y_k = \varphi = 0.203N_{30DCP} + 23.593 \pm 0.106$
	6	$y = \varphi = 1.362N_{30DCP} + 12.110$
		$y_k = \varphi = 1.362N_{30DCP} + 12.110 \pm 1.309$
	9	$y = \varphi = 1.293N_{30DCP} + 5.941$
		$y_k = \varphi = 1.293N_{30DCP} + 5.941 \pm 1.015$
Yelow sandy loam	12	$y = \varphi = -0.985N_{30DCP} + 39.550$
		$y_k = \varphi = -0.985N_{30DCP} + 39.550 \pm 1.166$
	15	$y = \varphi = 0.478N_{30DCP} + 16.259$
		$y_k = \varphi = 0.478N_{30DCP} + 16.259 \pm 1.252$
	18	$y = \varphi = 0.458N_{30DCP} + 15.218$
		$y_k = \varphi = 0.458N_{30DCP} + 15.218 \pm 1.440$
	21	$y = \varphi = 0.468N_{30DCP} + 14.072$
		$y_k = \varphi = 0.468N_{30DCP} + 14.072 \pm 1.737$
	24	$y = \varphi = 0.521N_{30DCP} + 19.425$
		$y_k = \varphi = 0.521N_{30DCP} + 119.425 \pm 2.238$

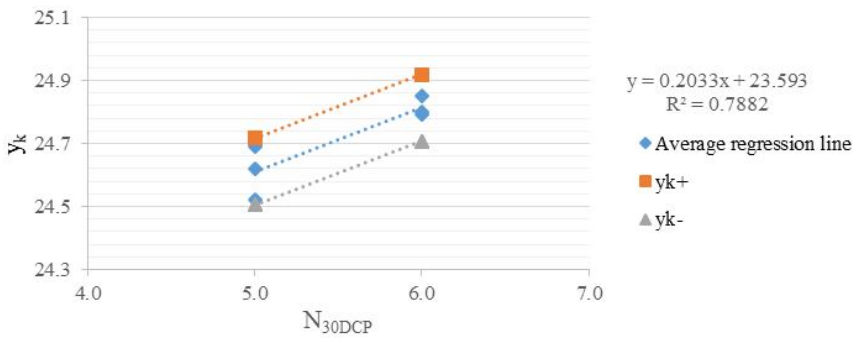

Fig. 6 – Correlation chart $N_{30DCP} - \varphi$.

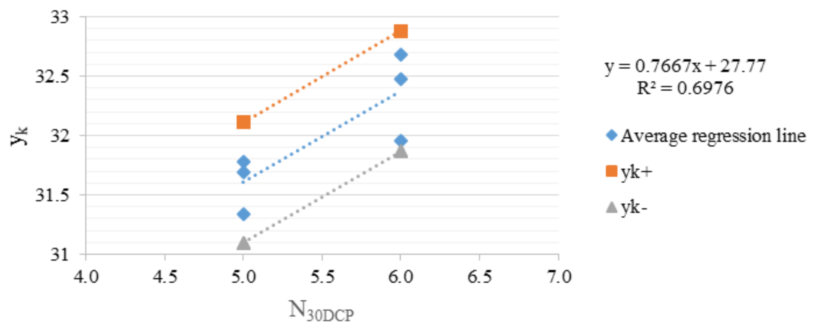

Fig. 7 – Correlation chart $N_{30DCP} - c$.

Table 7

Table summarizing the $N_{30DCP} – c$ correlations

Layer	Depth, [m]	Correlation N_{30DCP}-c, [kPa]
Yelow loam	3	$y = c = 0.767N_{30DCP} + 27.77$
		$y_k = c = 0.767N_{30DCP} + 27.77 \pm 0.507$
	6	$y = c = 3.405N_{30DCP} + 3.889$
		$y_k = c = 3.405N_{30DCP} + 3.889 \pm 1.822$
	9	$y = c = 3.621N_{30DCP} - 6.429$
		$y_k = c = 3.621N_{30DCP} - 6.429 \pm 5.716$
Yelow sandy loam	12	$y = c = 6.767N_{30DCP} - 66.182$
		$y_k = c = 6.767N_{30DCP} - 66.182 \pm 3.461$
	15	$y = c = 1.511N_{30DCP} - 6.410$
		$y_k = c = 1.511N_{30DCP} - 6.410 \pm 2.061$
	18	$y = c = 0.227N_{30DCP} + 13.227$
		$y_k = c = 0.227N_{30DCP} + 13.227 \pm 0.934$
	21	$y = c = 0.683N_{30DCP} - 3.458$
		$y_k = c = 0.683N_{30DCP} - 3.458 \pm 2.721$
	24	$y = c = 0.736N_{30DCP} - 14.276$
		$y_k = c = 0.736N_{30DCP} - 14.276 \pm 2.863$

4. Conclusions

The correlation equations were verified in other parts of the site studied where new boreholes was carried out and new undisturbed samples were collected, samples wich were analyzed in the laboratory. Also near the new boreholes new DCP test were carried out with recording of the numer of blows N_{30DCP}. From the new boreholes sample collection could not achieve exactly the same depth as the samples analyzed in this paper. Depth differences are between 30.00 cm and 50.00 cm.

Checking the correlations obtained for the first 6 boreholes versus the new boreholes and the new N_{30DCP} , somme differences occurred in the range of 3%,…,7%. These differences may have several causes among which we highlight:

a) inhomogeneity of the stratification;

b) the influence of the geological pressure.

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CORELAȚII ÎNTRE ÎNCERCAREA DCP ŞI REZULTATELE OBȚINUTE ÎN LABORATOR

(Rezumat)

Inginerii geotehnicieni sunt interesați în a investiga comportamentul real al pământurilor, în prezent existand mai multe metode disponibile pentru evaluarea proprietăților pământului. Variabilitatea parametrilor rezultați din aceste metode este neglijată presupunând că masa de pământ este omogenă iar variația acestor parametri în diferite puncte este rareori luată în considerare. Eterogenitatea este o caracteristică a pământurilor datorită căreia parametrii acestora diferă de la un punct la altul. Pentru a obține o caracterizare exactă a pământurilor, care să țină seama de eterogenitatea acestora, ar fi necesare un număr foarte mare de sondaje şi încercări de laborator imposibil de realizat având în vedere costurile necesare.

Lucrarea urmăreşte obținerea de corelații între N_{30DCP} şi rezultatele obținute în laborator pe probe netulburate. Scopul obținerii de corelații este generalizarea relațiilor obținute pentru un amplasament de dimensiuni mari în vederea reducerii numărului de foraje şi încercări de laborator. Pentru a obține valori ale coeficientului de corelație $r \geq 0,80$ s-a urmărit realizarea de corelații pentru adâncimi fixe de unde au fost prelevate eşantioane netulburate care au fost ulterior supuse analizelor de laborator. S-au obținut relații între N_{30DCP} şi greutatea volumică (γ), unghiul de frecare interioară (φ) şi coeziunea (c).