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Representative values of geotechnical parameters derived from dynamic penetration test

Valeurs représentatives des paramètres géotechniques dérivées de l'essai de pénétration dynamique

E. Kucova*, M. Kuvik
Department of Geotechnics, Faculty of Civil Engineering, Slovak University of Technology in Bratislava, Slovakia

**eliska.kucova@stuba.sk*

ABSTRACT: Dynamic penetration test is a relatively simple field test, which is frequently used for testing of soil resistance. From the results of this test, it is possible to derive physical and mechanical geotechnical parameters of coarse-grained soils, namely relative density, angle of shear strength and deformation modulus. The representative values of these parameters can be furthermore used in design of geotechnical structures. The new Eurocode 7 provides a set of equations that should be followed to establish the characteristic value if the data is considered sufficient. In this article the results of dynamic penetration tests, performed in the locality of the capital city of Slovakia, were used for determination of mechanical properties of Danube gravels. Afterwards, results were statistically processed, and characteristic value was estimated according to Eurocode 7. The characteristic values of geotechnical parameters were compared with traditional evaluation procedures, where the average value is determined for each soil layer.

RÉSUMÉ: Le test de pénétration dynamique est un test sur le terrain relativement simple, fréquemment utilisé pour tester la résistance du sol. A partir des résultats de cet essai, il est possible de déduire des paramètres géotechniques physiques et mécaniques des sols à gros grains, à savoir la densité relative, l'angle de résistance au cisaillement et le module de déformation des graviers et des sables. Les valeurs représentatives de ces paramètres peuvent en outre être utilisées dans la conception de structures géotechniques. Le nouvel Eurocode 7 donne des lignes directrices pour l'estimation de la valeur représentative en tant que valeur caractéristique. Dans cet article, les résultats de tests de pénétration dynamiques, réalisés dans la localité de la capitale de la Slovaquie, ont été utilisés pour déterminer les propriétés mécaniques des graviers du Danube. Ensuite, les résultats ont été traités statistiquement et la valeur caractéristique a été estimée selon l'Eurocode 7. Les valeurs caractéristiques des paramètres géotechniques ont été comparées aux procédures d'évaluation traditionnelles, où la valeur moyenne est déterminée pour chaque couche de sol.

Keywords: Representative value of geotechnical parameter; coarse-grained soil; dynamic penetration test; statistics.

1 INTRODUCTION

In Slovak geotechnical practice the dynamic penetration test (DP) is frequently used in engineering geological surveys. The test is primarily intended for testing of coarse-grained soils due to less skin friction on the rod. The penetration rod is driven into the ground by dynamic force and the resistance of soil is measured.

From the measured data, it is possible to determine specific physical and mechanical properties of sands and gravels. These properties can be determined by using correlations of international and national significance (EN 1997-2:2008, DIN 4094-3:2002, EN ISO 22476-2, PN-B-04552:2002, STN 72 1032: 1997, Matys et al., 1990). The given literature offers both direct and indirect correlations to choose from.

Standards (EN 1997-2:2008, DIN 4094-3:2002, EN ISO 22476-2, PN-B-04552:2002, STN 72 1032: 1997) mention mainly direct correlations for the relative density (I_D) of sands and gravels that are directly derived from number of blows (*N)* measured during the penetration test. The indirect correlation is expressed for the angle of internal friction, that is evaluated based on the relative density of coarse-grained soil (Schnaid, 2009; Carter, Bentley, 2016; Sanglerat, 1972, Bolton, 1979; Robertson, and Hughes 1986, EN 1997-2:2008).

More direct correlations for the determination of coarse-grained soil geotechnical parameters are published in regional (Slovak) literature. These correlations are based on the results of dynamic penetration resistance (q_{dyn} in MPa).

From the derived geotechnical parameters, it is possible to determine a representative value, which is essential for the design of geotechnical structure. The new generation of Eurocode 7 (prEN 1997-1:2024) defines that the representative value can be either nominal or characteristic value.

In the previous Eurocode 7 (EN 1997-2:2008) the the characteristic value was referred to as cautious estimate of the value affecting the limit state and the statistical procedure for its estimation was not precisely specified. This assessment was analysed by various authors (e.g. Schneider 2010, Orr 2019, Prästings et al. 2019). The conclusion of these studies was that procedure did not consider the uncertainty of geotechnical properties. Authors also pointed out that the statistical procedure was not clearly defined and the same statistical rules as for man-made materials cannot be followed.

Therefore, in the new Eurocode 7 (prEN 1997-1:2024) the characteristic value is defined using a statistical procedure that includes basic statistical characteristics as mean, standard deviation, and coefficient of variation.

In our research we used the statistical procedure from the new EC 7 to determine the characteristic value as a representative value of the angle of internal friction. The angle of internal friction was derived from the results of dynamic penetration resistance using Slovak correlations for Danube gravels.

The obtained results were compared with other foreign correlations and nominal values used in Slovakia with the intention to investigate appropriateness and accuracy of the regional correlations.

2 METHODOLOGY

To determine the representative value of the angle of internal friction we analysed 120 heavy dynamic penetration tests performed in gravels near the Capital of Slovakia.

2.1 Material

Investigated gravels belong to Quaternary sediments of Danube River. The river has in the region accumulative and sedimentary activity, due to which the gravel particles are fine, smooth, well rounded with size of 1 – 5 centimetres.

In this article we focused on the analysis of the poor-graded gravel (G2/GP) which is together with gravels G3/G-F, the most represented gravel class in the area. Poor-graded gravels of the investigated area consist of 54 – 77% of gravel fraction. Grading of gravel particles at d_{60} is from 5 – 15 millimetres (Figure 1).

2.2 Determination of the angle of internal friction and its characteristic value

The angle of internal friction (φ_{eff}) was derived from results of dynamic penetration test. Its values were derived from the number of blows (N_{10}) using correlation from to Slovak standard (STN 721032:1997) and dynamic penetration resistance using correlations according to Švasta (Matys et al., 1990). The mentioned correlations are summarized in Table 1 and Table 2.

The characteristic value of the angle of internal friction was determined by following recommended approach from the second generation of Eurocode 7 (prEN 1997-1:2024).

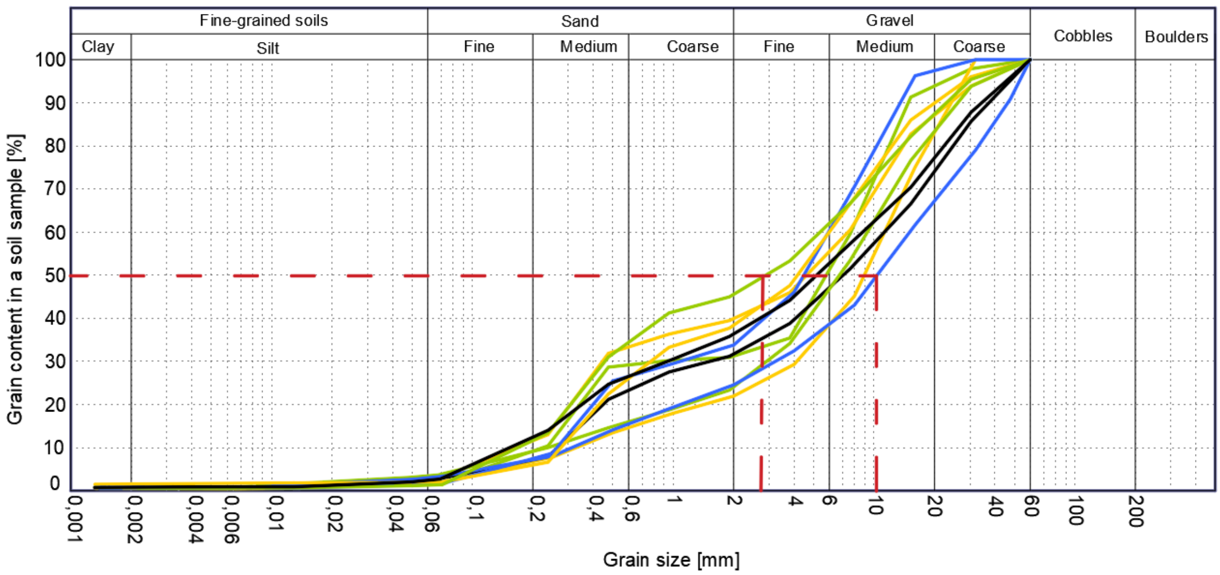


Figure 1. Grading curves of poor-graded gravel (G2/GP).

Table 1. Correlation between φ_{eff} and N_{10}.

Reference	Soil	Correlation	
		N_{10}	φ_{ef} (°)
STN 72 1032	Gravels	< 3	< 30
		3 – 6	30 – 35
		6 – 17	35 – 40
		17 – 30	40 – 45
		> 30	> 45

Table 2. Correlation between φ_{eff} and q_{dyn}.

Reference	Soil	Correlation	
Švasta	Gravels & Sands	$\varphi_{ef} = p\,(q_{dyn})^r$	[°]

Note: unitless coefficient p equals to 24
unitless coefficient r equals to 0,16

The characteristic value, denoted as X_k, corresponds to a specific quartile of the assumed statistical distribution of assessed soil parameter.

The second generation of Eurocode 7 recommends determining the characteristic value according to given formula:

$$X_k = X_{mean}[1 \mp k_n V_x] = X_{mean}\left[\frac{1 \mp k_n s_x}{X_{mean}}\right] \quad (1)$$

where X_{mean} is an average of measured values of soil parameter, V_x is coefficient of variation of the measured values of soil parameter, k_n is the coefficient depending on the number of the measured values (n) of the soil parameter and s_x is the standard deviation of the measured values of soil parameter.

The procedure is applicable for both, known and unknown coefficient of variation, which is decisive when evaluating the coefficient k_n (prEN 1997-1:2024).

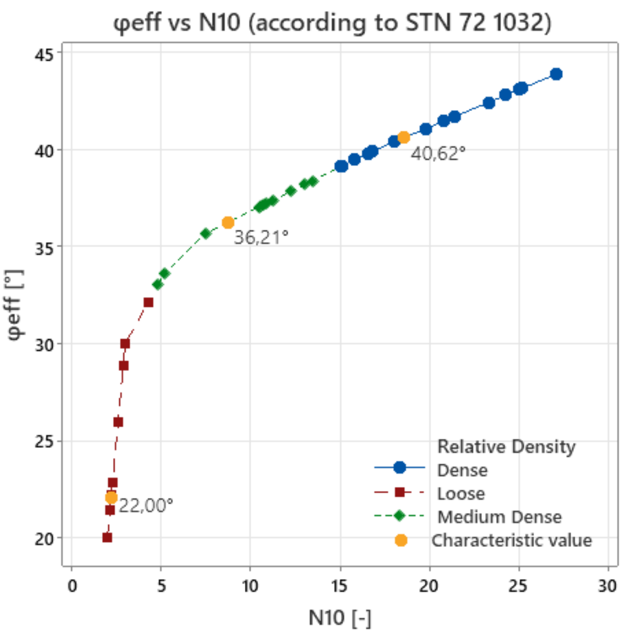
3 RESULTS

The values of the angle of internal friction obtained from the results of dynamic penetration are shown in Figure 2. The values of φ_{ef} were categorized according to relative density to three categories - φ_{ef} of loose, medium dense and dense poor-graded gravels. For each category the corresponding characteristic value was evaluated (Figure 2, Table 3).

Compering the results the difference between the two correlations is approximately 2° for medium and dense gravels while correlation according to STN 72 1032 being more optimistic. The difference between the two correlations for loose gravels is bigger.

The results in Table 3 are furthermore compared with other foreign correlations and nominal values published in cancelled Slovak standard, which are still in use as comparable experience.

Analysing Table 3 we can see that in regional (Slovak) literature there is no recommendation of nominal values for loose gravels. But European standards (BS 8002, Eurocode 7, DIN 4094-3) recommend an indicative value of 30° for φ_{ef} of loose gravels. This value is higher than our characteristic value derived by regional correlations.



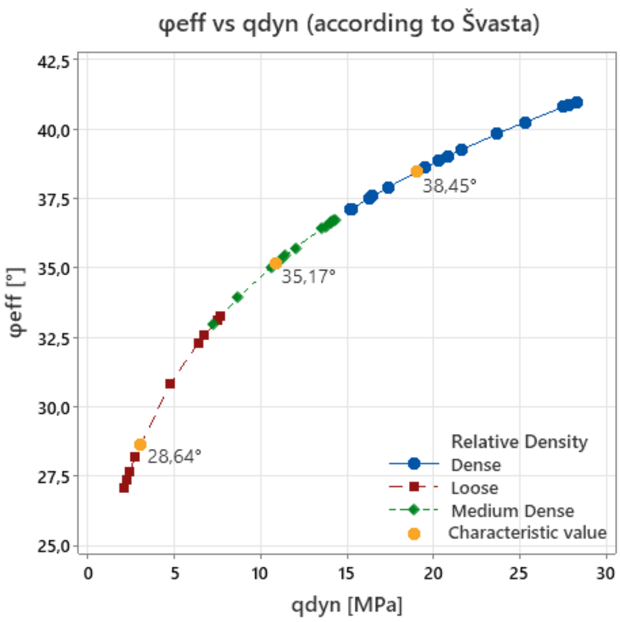


Figure 2. Evaluation of the angle of internal friction G2/GP according to regional correlations.

Table 3. Comparison of the characteristic and nominal values of φ_{eff}.

Soil	Relative density	φ_{eff} [°]				
		Characteristic values		Nominal values		
		Švasta	STN 72 1032	BS 8002	EC7/ DIN 4094-3	STN 73 1001
G2/GP	Loose	28,64	22,00	30,00	30,00	-
	Medium dense	35,17	36,21	32,50	34,00	35,50
	Dense	38,45	40,62	35,00	38,00	38,50

The characteristic values for medium dense gravels are in accordance with used nominal values and are more optimistic than the foreign correlations.

Dense G2/GP were also tested in laboratory using large-scale shear box machine, where we measured the values of φ_{eff} in range of 41,00° – 48,50°. Comparing the results, we can see that the British standard indicates the lowest value, and the laboratory tests designates the highest values for the angle of internal friction.

4 CONCLUSIONS

The article analyses the representative values of angle of internal friction for poor-graded river gravel.

Results of φ_{ef} were categorized according to the relative density of the soil and were compared with the laboratory test results, other correlations and nominal values used as comparable experience in Slovakia.

Characteristic values of φ_{ef} for loose G2/GP reaches according to Slovak correlations lower values than those specified by European standards. Moreover, there is no recommendation for nominal values in the Slovak standard.

Correlated results (according to Švasta in Matys et al. 1990, and STN 72 1032:1997) of medium dense and dense gravel show a good match with nominal values. Dense poor-graded gravels were also tested in laboratory and the results shows higher values of angle of internal friction. This can indicate that even higher values of φ_{eff} could be used as nominal values for Danube gravels in Slovakia.

To optimize regional correlations and suggest nominal values for the national appendix of new EC 7 the research will be complemented with the data from other localities in Slovakia by studying the coarse-grained soils of another genesis.

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