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Preliminary validation of the dynamic probing methods used in estimation of the relative density of cohesionless soils

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Abstract. The dynamic probing methods are commonly used for the subsoil identification. For example, the relative density/density index (I_D) of cohesionless soils can be determined by using appropriate correlation relationships. The results obtained by various probing methods (DPL, DPH, DPM) may vary from one to another. Thus, the field tests were conducted in order to determine how important these discrepancies are. Each of the above mentioned methods were performed 10 times at one location. The effect of the influence of the penetrometer type on the relative density estimation results was determined. Based on the analysis, it can be concluded that the results obtained by the medium and heavy penetrometers are very close to each other. On the other hand, the discrepancies between the results obtained with the light penetrometer and the other two penetrometers are greater, both in terms of mean difference and scatter.

1 Introduction

Many methods are used to determine the parameters of a soil medium in the direct tests (in accordance with the definition of a given parameter) or in the approximate way using correlations. Such methods are often developed under specific soil conditions, and it is not clear how accurate they are when the conditions are different. Therefore, within the framework of a research project entitled "Modern Methods of Ground Recognition in Roads", research is being conducted to validate various methods of soil identification in Polish conditions. On this basis the new guidelines for the diagnosis of ground subsoil for road construction will be developed. The subject of this study is the validation of the methods using the results of the dynamic probe test to determine the relative density (I_D) of non-cohesive soils. According to the assumptions presented in [1], validation of methods consists of analysing the difference of the results obtained by the reference method and the validated method

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$$d = I_D(r) - I_D(v) \tag{1}$$

where d is discrepancy between I_D obtained by using reference (r) and validated (v) method.

Within the methodology adopted for the grant, the reference method is the test that defines the parameter. In the case of relative density, the reference method consists of the laboratory test. However, in practice, the I_D is usually estimated by the results of probing (static or dynamic). Subsequently, on this basis further conclusions about the other parameters of the soil can be drawn. Many studies available in the literature concern a study comparing results obtained from static (CPT) and dynamic (DP) surveys [2-5]. The purpose of this analysis is to compare the discrepancies in results from different dynamic penetrometers. These methods consist of determining the relative density by using the correlation dependence, based on the value of the resistance imposed by the soil. The measure of soil resistance is the number of strokes (N_{10}) needed to deepen the penetrometer by the assumed depth (10 cm). Dynamic probing are described in details in standard document [6]. The relative density interpretation was also performed on the basis of this document. For the purpose of the present study, the results of three methods of probing were used:

- light – DPL (10 kg),
- medium – DPM (30 kg),
- heavy – DPH (50 kg).

Due to the diminishing importance of direct determination of soil reference density by laboratory methods (due to their labor intensity) [7], the reference method was abandoned and the pairing method was compared to assess how the results obtained by the different methods are similar and whether they can be used interchangeably.

2 The site characteristics and the research methodology

Depending on the genesis of the soil, its density can be very diverse, even in a small area [8]. Therefore, the test was conducted on a compact area (probing was done on a grid of 2.0 m). This approach helped to minimize the impact of local factors on the obtained results [9]. In the middle of the area a borehole was drilled to a depth of 8.0 m. On this basis the soil layer depths was determined:

- 0. 0-0.15 – humus,
- 0.15-1.25 – FSa,
- 1.25-3.3 – MSa+Gr,
- 3.3-4.5 – FSa/MSa,
- 4.5-5.2 – MSa/FSa+Gr,
- 5.2-8.0 – MSa+Gr,
- water at a depth of 1.6 m.

As it can be seen in Figure 1, the results of the probes approximately reflect the lithology established on the basis of the borehole. According to the cumulative difference approach, uniformly spaced layers are separated along the sections with a constant slope of the cumulative sum.

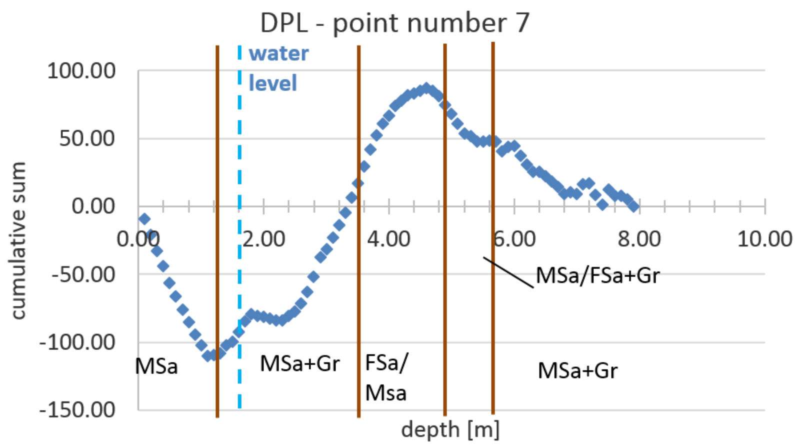

Fig. 1. Comparison of layer depths obtained on the basis of borehole and slope changes of cumulative sum of N_{10} results.

It should be emphasized that the results of the probing conducted in different locations (even by the same method) are different. The homogeneity of the results consists of the soil medium homogeneity and the repeatability of the method. It is not possible to separate these two factors, so their combined effect should be taken into account.

3 Analysis of the results

The analysis was based on the distribution of differences in the I_D results obtained between the methods (DPL-DMP, DPL-DPH, DPM-DPH). The results obtained in the nearest locations were paired (corresponding numbers and depth). About 700 results were obtained for the validation of the method in such a way. Results from a depth above 1.00 m were rejected due to the lack of the reliability requirements fulfilment (N_{10}> 3).

The confidence interval depends on the value of the standard deviation that is the measure of the scatter of results. The first proposal was to use the T-Student distribution in order to approximate results' distribution. This distribution is used for populations with unknown standard deviation values. In order to be able to apply the T-Student distribution, it is necessary to meet the condition of normality of the discrepancy between the values of the reference method and the validated method [10]

The unimodal and almost symmetrical histograms of the results were obtained, but the Shapiro-Wilk test showed a deviation from the normality assumption. Due to the slight skewness, log-normal distribution was sought, but the transformation of the variable to normal distribution failed. Frequency histograms are shown in Figures 2-4. Because of the very large sample, confidence intervals were estimated by using quantiles of the sample. It was assumed that confidence interval should be 95%. It means 95% of the results (discrepancy between I_D obtained by using different method in "the same" location) should be included in the interval. The confidence intervals for each method were determined on the basis of the sample quartiles (2.5% and 97.5%).

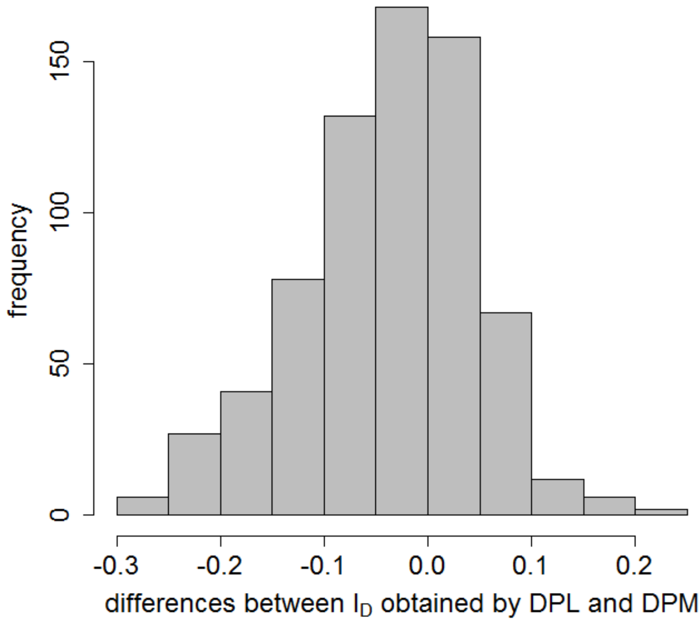

Fig. 2. Histogram of differences of ID results obtained using DPL and DPM.

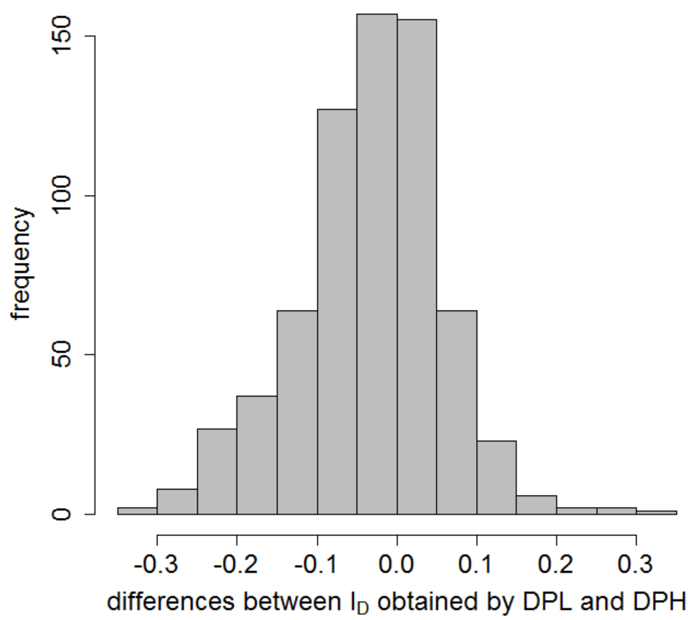

Fig. 3. Histogram of differences of ID results obtained using DPL and DPH.

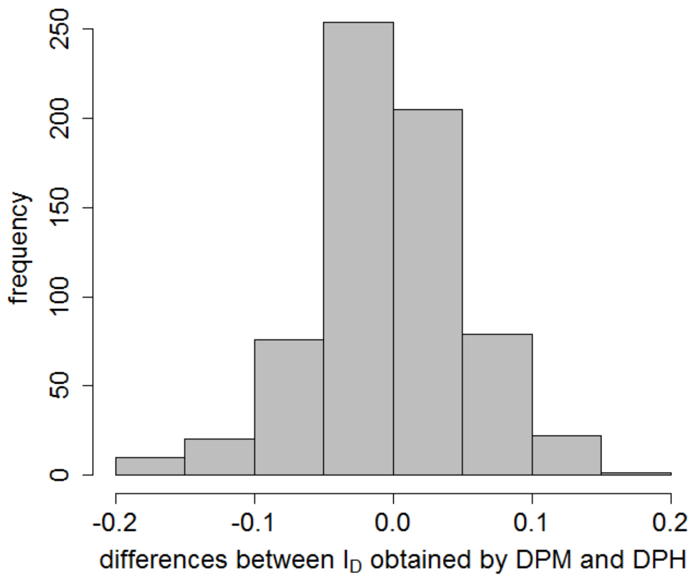

Fig. 4. Histogram of differences of ID results obtained using DPM and DPH.

Analysing the histograms one can see some dependencies, which are summarized in Table 1. The differences between the light penetrometer and the other penetrometers (medium and heavy) are similar in terms of both the average and the scatter. In contrast, the differences between the medium and heavy penetrometers results are much smaller.

Table 1. Basic statistics of discrepancies between I_D obtained by using different methods of probing.

	$d = I_D(DPL) - I_D(DPM)$	$d = I_D(DPL) - I_D(DPH)$	$d = I_D(DPM) - I_D(DPH)$
mean, μ	-0.033	-0.029	0.003
std. dev., sd	0.084	0.092	0.056
95% conf. interv.	-0.220÷0.116	-0.232÷0.132	-0.114÷0.120

4 Conclusions

An attempt was made to analyse differences in the density results of I_D obtained by various dynamic probing methods (DPL, DPM, DPH). Shapiro-Wilk's test showed failure to meet the normality of distribution. The attempts to find transformations of results that would make use of normality assumptions (e.g. log-normal distribution) also failed. The confidence intervals were directly derived from the distribution, based on the sample quantiles, because of the large number of results. The 95% confidence interval was 0.34 width for the DPL-DPM comparison and 0.36 for the DPL-DPH method. In contrast, the DPM-DPH method comparison resulted in significantly smaller differences,(the confidence interval width of 0.23). The average difference between DPL and the other validated methods was about -0.03. Thus, medium and heavy penetrometers give similar results to each other, but they slightly overestimate the degree of compaction of the I_D relative to the results obtained with a light probe.

The I_D parameter itself is rarely used in design process. By knowing its value, one can indirectly draw conclusions about other parameters of the tested soil. Therefore, the presented results will be used to further validation of the methods to determine other parameters of the soil and to optimization of the recommended methods of field testing.

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