The effect of sand grain roundness on the interpretation of CPTU penetration characteristics

L’effet de degré d’arrondi des grains de sable sur l’interprétation des caractéristiques de la pénétration par CPTU

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ABSTRACT

A characteristic element for the structure of subsoil in Poland is the occurrence of different geological formations in the construction-subsoil collaboration zone. For example, frequently sands of different genesis are found. Thus the assessment of their mechanical parameters is of considerable practical significance. Several factors, including overconsolidation ratio and roundness value of sand grains, affect the CPTU penetration characteristics used in the determination of strength and stress parameters. Especially the latter factor is relatively little known. In order to investigate the effect of roundness value of sand grains on cone resistance, CPTU were performed using a Hyson 20 Tf heavy static probe. Testing was conducted in the subsoil where glaciifluvial, fluvial and eolic sands were found. In the analysis of recorded results existing correlations were analyzed in terms of their suitability for the determination of the relative density and effective friction angle.

RÉSUMÉ


Keywords: CPTU, grains roughness, relative density, friction angle

1 INTRODUCTION

One of the most commonly applied methods in subsoil analyses is the static penetration test, referred to as CPTU (Lunne et al. 1997, Mayne 2006). As it was observed among other things by those authors, other parameters apart from those measured directly during that test need to be included when analysing testing results in that case (Młynarek 1978, Juang et al. 1998, Jamiolkowski et al. 2001). These parameters are connected with characteristics of soil structure and texture. Texture characteristics of soil are related with the shape and properties of grains comprising the soil skeleton. In terms of strength the most crucial texture characteristics, at the same time distinctly differentiating soils in relation to the geological deposition environment, is grain roundness.

Grain roundness as a factor directly affecting soil strength parameters was indicated e.g. by Juang et al. (1998), who analyzed the statistical effect of individual soil characteristics on the value of friction angle, stated explicitly that characteristics connected with grain roundness and roughness may constitute the decisive factor in the assessment of strength parameters. Jamiolkowski et al. (2001), as well as Radaszewski and Wierzbicki (2006) stressed the effect of texture characteristics on results of static penetration in non-cohesive soils. Excluding such factors as petrographic composition and grain roundness from analysis may lead to a biased interpretation of CPTU results and as a consequence the adoption of incorrect geotechnical parameters. This problem comprises the subject matter of this paper.

2 FACTORS AFFECTING CONE RESISTANCE IN THE PROCESS OF STATIC PENETRATION OF NON-COHESIVE SOIL

The process of static penetration in the non-cohesive soil medium was described by Młynarek (2007) with a function (1).

\[ F_I(P, \theta_1, \theta_2) = 0 \]  

(1)

where: \(P\) – measured parameter of the process, e.g.: \(q\); \(v\) – rate of penetration; \(\theta_1\) - characteristics of the soil medium; \(\theta_2\) - cone characteristics.

A solution to this equation may by found using different methods (Młynarek 2007). For practical purposes the searched for extreme comprises partial functions which result from function (1). For non-cohesive soils, \(DR=f(q)\) and \(\phi=f(q)\) may be assumed to be the two most important variables. It clearly results from function (1) that a significant limitation for the set of these functions is the identification of the effect of grain size composition, petrographic composition, grain roughness, etc., on these variables. An example of the solution to one of the partial functions is a formula proposed by Baldi et al. (1986) for use in the assessment of the degree of consolidation, in which it
is necessary to adopt constants connected with lithological properties of deposit (2).

\[
DR = \frac{1}{C_2} \ln \left[ \frac{q_c}{C_0 (\sigma_{vo})^{C_1}} \right]
\]

(2)

where: \(C_0, C_1, C_2\) empirical correlation factors, dependent on soil composition.

The effect of subsoil properties on the assessment friction angle \(\Phi\) (\(\theta_{CPTU}\)) was presented by Juang et al. (1998) and Jamiołkowski et al. (2001), who investigated the effect of petrographic composition, grain roundness, sediment sorting and grain roughness on CPTU results. The statistical evaluation, conducted based on the analysis of archive data of ASCE (American Society of Civil Engineers), was assumed as the criterion of significance for the effect of individual factors. Silva and Bolton (2004) showed that the location of both the roof and floor of the geotechnical layers of different rigidity had a significant effect on CPTU results. In view of these studies the analysis of the effect of grain roughness on CPTU penetration characteristics seems to be of special interest.

3 GEOLOGICAL CONDITIONS AFFECTING DEPOSIT ROUGHNESS

3.1 Measures of grain roughness

The fact that resistance to chemical weathering and transport varies in individual minerals is of paramount importance in the interpretation of grain roughness results. As a consequence of destruction processes the proportion of minerals with higher resistance, primarily quartz grains, increases. Over the years two groups of methods have been developed to investigate the shape and degree of roughness of quartz grains, each comprising opto- geometric methods and the other - mechanical methods. In order to determine the degree of grain roughness with an optical method the Powers scale is used most commonly (Powers 1953). According to Powers grains may represent one of the six roundness classes, i.e. 0 -1 well rounded; 1 – 2 rounded; 2 – 3 sub-rounded; 3 – 4 sub-angular; 4 – 5 angular; 5 – 6 very angular. Another method to determine sand grain roughness is the mechanical method (Krygowski 1964). The essence of this method is the application of an inclined plane (frosted glass plate), over which grains are rolled, while the angle of plane inclination is measured. The number of rolling grains is determined for angle classes, within the following ranges: class \(a\) 10º – 24º (grain with no roundness); class \(b\) 8º – 16º (intermediate); class \(c\) 0º – 8º (well-rounded). The first class - \(a\) comprises grains with no roundness, with sharp edges and corners. It includes very angular grains, where the value of sphericity \(W_s\) falls within the range of 0 – 400, and angular grains where sphericity \(W_s\) is within the range of 600 – 800. Class \(b\) divides grains into two subtypes, i.e. sub-angular grains with \(W_s = 1000 – 1200\) and sub-rounded grains with sphericity value of 1400 – 1600. Grains of type \(b\) are characterized by blunted edges and corners and slightly ground walls. The degree of roundness, defined as well-rounded and rounded, characterizes grains belonging to angle class \(c\). The value of sphericity for thoroughly rounded grains is 1800 to 2000, while for ball-like grains it is 2200 – 2400, respectively.

3.2 The dependence of grain roughness on deposition environment

Roughness depends on the size of grains, their resistance to physical factors, the duration of their action as well as specific sedimentation conditions. The surface area of grains, texture characteristics and structural properties may indicate the sedimentation environment in which a given sedimentary rock was formed. In glacial deposits numerous striae and furrows on the surface of grains are formed during their transport through the glacier. In turn, in dune sediments grains are rounded, but their surface is matt and rough.

The dependence of grain roughness on the deposition environment in relation to the results of mechanical analysis of roundness was analyzed e.g. by Krygowski (1964). As it may be observed on the diagram for classes \(\alpha, \beta, \gamma\) (Fig. 1), the dune environment is located towards corner \(\gamma\), which means that in sands of this environment well-rounded grains are found in large quantities. The moraine environment to a considerable degree represents roundness value type \(\beta\); however, with a certain proportion of grains belonging to type \(\alpha\) (angular). A fundamental difference may be observed in case of the fluvial environment. In mountain rivers sands are located in the lower, narrow part of the triangle and there are no grains of type \(\gamma\) there. For the environment of a lowland river the proportions of grains of all the three types of rounding are almost equal. In turn, the environment of a seashore beach, expressed by small areas in the lower side of the triangle, refers in this way to the bottom moraine environment.

4 THE OBJECT OF THE STUDY AND METHODOLOGY

The effect of grain roughness on the measured cone resistance was analyzed in glacifluvial sediments, deposited in two areas with differing history of load. One of these areas comprised moraine sands, which presence is connected with the accumulative action of the ice-front (Maksiak and Mróz 1978). These deposits are strongly overconsolidated. The other area was connected with outwash glacifluvial deposits, which were not subjected to additional load in the past. Forms found in the latter area result from the action of large amounts of glacier waters, which circulated at the continental ice-sheet foreland (Maksiak and Mróz 1978). The petrographic composition of analyzed areas is similar. Dominant minerals are quartz and other hard minerals. With an increase in the fractions the content of sandstone increases, a rock with high roughness, but more brittle than monomineral grains. The grain size composition of analyzed soils was similar in both examined objects. They were mostly medium sands and fine sands with admixtures of coarse sands (Fig. 2).
4.1 CPTU

CPTU in analyzed soils were performed with category I equipment (Test Procedures for Cone Penetration (CPT) and Cone Penetration with Pore Pressure (CPTU)). Figure 2 presents penetration characteristics and basic geotechnical parameters of the sand zone included in the analysis.

4.2 Study of roundness

The analysis of roundness was performed by the mechanical method (Krygowski 1964), which made it possible to classify quartz grains to one of the three roundness classes. The examination consisted in the determination of the number of grains in 0.8-1.0, 1.0-1.4 and >1.4 mm fractions for individual angle classes $\alpha, \beta, \gamma$ (Chapter 3.1).

It results from the conducted grain form analysis that the examined quartz grains do not exhibit a distinct degree of sphericity. Grains of both glacifluvial sand and moraine sands are characterized by sharp edges and corners, with no roundness. Apart from the value of sphericity $W_0$ (3) the non-homogeneity index $N_m$ (4) was also determined, which illustrates the variation in the tested sample.

\[
W_0 = 2400 - \frac{\sum (ok \times 100)}{N} \quad (3)
\]

where: $N$-number of analyzed grains, $k$-average angle for individual class, $n$-number of grains for individual class.

\[
N_m = Q_{75} - Q_{25} \quad (4)
\]

where: $Q$ – values of quartiles form cumulative cure.

5 ANALYSIS OF RESULTS

In the assessment of the effect of roundness parameters on corrected cone resistance in CPTU, a step-wise multiple regression method was applied (Draper and Smith 1966). The general form of the regression equation, which constitutes a partial function, may be presented by equation (5).

\[
q_t = b_0 + \sum_{i=1}^{n} b_i x_{x,i} \quad (5)
\]

where: $q_t$-corrected cone resistance, $b_0$-constant of the model, $x_i$-parameters of the model (roundness and mean stress $\sigma'_m$ after Jamiołkowski et al. 2001), $n$-number of steps of the multiple regression.

In order to determine horizontal components of stress DMT results were used together with data concerning the geological history of soil (Wierzbicki 2008). In the set of data, parameters included in model (1): compaction, mineralogical composition and grain size composition, were constant.

As a result of multiple regression analysis an equation was formed, which determines the dependence of cone resistance on mean geostatic stress ($\sigma'_m$) and roundness parameters ($N_m$) (6).

\[
q_t = 29.9 + 0.1\sigma'_m - 1.6N_m^{1.0} \quad [R^2=0.62] \quad (6)
\]

Step-wise regression showed that the measured cone resistance is related in 80% with geostatic stress and in 20% with roundness non-homogeneity index ($N_m^{1.0}$).

In the second stage of analysis of the effect of roundness analyses were conducted on soils formed in different deposition environments. For this purpose two glacifluvial soils were used together with one dune soil, one soil from a seaside beach and one riverine. Similarly as in the first stage of analysis data were selected so that they pertained to soils with similar compaction and similar mineralogical and grain size compositions. The analysis of multiple regression was conducted on means for individual deposition environments. The obtained dependence between cone resistance and grain roundness and the mean geostatic stress is presented by equation (7).
Conducted analyses showed that the different genesis of sands is combined inevitably with their structure and texture. These two factors have an effect on cone penetration characteristics in CPTU and as a consequence - on the evaluated relative density and effective friction angle. In this study the effect of both grain roughness and roundness was combined for the dependence which describes the relationship between cone resistance and the relative density and friction angle in a relatively narrow range of variation in geostatic stress in subsoil. Finding both model dependencies determined from the conducted tests will probably facilitate a more detailed incorporation of the simultaneous effect of grain roughness, components of the state of stress in subsoil and OCR on CPTU results.

REFERENCES


