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Comparative analysis of the CPT results obtained with the use of electric and mechanical penetrometer cone

K. Nepelski
Department of Geotechnical Engineering, Faculty of Civil Engineering, Lublin University of Technology, Lublin, Poland

A. Lal
Department of Geotechnical Engineering, Faculty of Civil Engineering, Lublin University of Technology, Lublin, Poland

M. Grzegorczyk
GeoNep Geotechnika Nepelski Chymosz Sp.J., Lublin, Poland

ABSTRACT: It is well known that the use of equipment from different manufacturers, and diverse measuring systems or types of penetrometer, affect the results obtained from CPT. As far as the types of penetrometer are concerned, cone geometry and the kind of measuring method prove to be equally crucial. For exactly the same soil, the values of the q_c and f_s measured with an electric and mechanical penetrometer, can be different. It is also indicated that owing to the applied interpretation method, correlations relevant for an electric cone are inappropriate for a mechanical cone. The most common CPT interpretations relate to the standard electric cone. The coefficients given by several studies could be used to convert values obtained in CPT with an electric penetrometer cone into the values appropriate for a mechanical cone, but those coefficients seem too general. This is the reason why research to determine the correlation between the results of CPT using different types of penetrometer cone was conducted. In-situ tests were carried out on Lublin loess, where the loess silt bed reaches a thickness of 10-15 metres. There were 15 comparative CPT in the distance 1.0 – 2.0 m between tests carried out with an electric cone and a mechanical cone. The same penetration device was used in both types of test. Obtained probing profiles were processed in order to eliminate measurement error caused by the distance between test locations. As a result, the proportional coefficient between tests with two types of penetrometer cone, suitable for Lublin loess, was determined.

Keywords: CPT test; loess; electric and mechanical cones;

1 INTRODUCTION

The cone penetration test (CPT) is a common method used to determine the properties of soils. The test was invented in the 1930s in the Netherlands and has been strongly developed ever since (Kardan 2014). It allows the obtaining of reliable results at depth in a continuous mode, with relatively small financial outlays, and in much shorter times when compared to dynamic penetration tests or drilling with the collection of samples for laboratory analyses. The CPT also provides much more data which, in terms of statistics, significantly increases the reliability of the obtained values. The values recorded directly during the CPT procedure include cone resistance q_c and sleeve friction f_s, and in the case of the piezocone penetration test (CPTU) also pore pressure u. These directly recorded values provide the basis for calculating parametric derivatives (e.g.

R_f, q_t) and interpreting state parameters such as L_I (the liquidity index), D_r (relative density), s_u (undrained strength), *c'* (effective cohesion), *φ'* (the effective friction angle), *M* (the constrained modulus), and *E* (the deformation modulus) (Kardan 2014; PN-EN-1997-2; Briaud and Miran 1992).

CPT procedures can be performed using mechanical cones (CPTm) or electric cones (CPT), and they can also involve measuring pore pressure (CPTU). If mechanical cones are used, pore pressure *u* cannot be determined, and the q_c and f_s values established by means of various end-parts are likely to differ (Cai, Liu, and Puppala 2015; Meisina et al. 2017; Schneider 2007).

The article presents an analysis of the CPT results obtained by means of mechanical (CPTm) and electric (CPT) cones on loess soils, along with determining the coefficients of transition between the two cone types.

2 DESCRIPTION OF THE ANALYSED SOILS

The research was conducted in the area of Lublin, situated in Eastern Poland. This region is characterised by loess cover, the thickness of which reaches several metres (around 10-15 m on average). In view of the geotechnical standards (PN-86 B-02480; PN-EN ISO 14688-1:2006), Lublin loess is mainly composed of silt which locally changes into sandy silt or silty sand. Clayey sandy silt and clayey silt are found less frequently, and mainly within the bedrock and bottom levels. Plastic forms occur only in the surface and loess bottom areas.

The study (Nepelski and Rudko 2018) presents an analysis of the loess research results obtained for the Lublin area. The 300 CPT and CPTU procedures performed at a total length of over 2700 m within the Lublin area revealed that cone resistance q_c for loess soils generally ranged within 1÷15 MPa, most frequently amounting to 3÷9 MPa (above 80% of all results). The average cone resistance value was established at 6.5 MPa. If the cone resistance value is q_c>12 MPa, loess usually takes the form of silty sand with a significant share of silt and slight amounts of fine sand. The liquidity index (L_I) for loess takes positive values for cone resistance q_c fluctuating around 4.1÷4.5 MPa (Nepelski, Lal, and Franus 2016; Nepelski and Rudko 2018). A comparison of the values typical of the Lublin loess with the values obtained in the cone analysis is presented in Table 1. The statistical distribution of cone resistance q_c is shown in Figure 1, with the values typical of the Lublin loess being marked in grey, the results obtained with an electric cone in red, and those obtained with a mechanical cone in green.

Table 1.Comparison of cone resistance qc

	Lublin loesses	**CPT**	**CPTm**
Average [MPa]	6,5	6,1	5,8
The most often (>80%) [MPa]	3,0-9,0	2,0-8,5	2,0-8,5
Median [MPa]	6,5	5,8	5,6
Standard deviation [MPa]	2,4	2,7	2,5

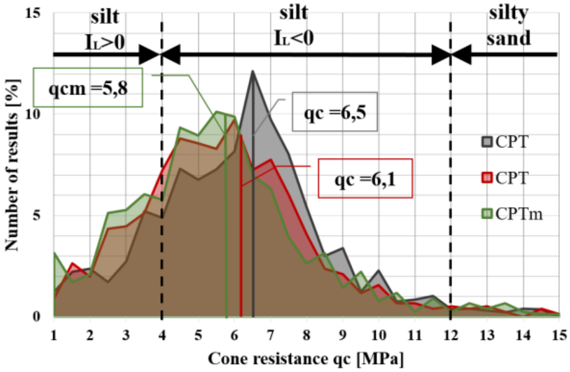

Figure 1. Statistical distribution of cone resistance q_c of the Lublin loess

3 RESEARCH METHODS

For analytical purposes, a total of 30 tests were performed in 15 different locations as part of the field research (Fig. 2). In each location, a CPT procedure was performed using a mechanical cone (CPTm), and then an electric cone (CPT) at a distance of 1-2 m. In addition, boreholes were made in selected places, close to the CPT areas, to collect samples for laboratory analyses. Whereas the conducted tests usually reached the sand and silt layers found below the loess layer, the analysis covered only the aeolian soils. Surface areas at a depth of around 0.6-0.8 m were also excluded from the analysis, due to both the high likelihood of anomalies and the technical conditions of the conducted tests. As regards the CPTm, the first reliable measure was taken at depths of 0.4 or 0.6 m below ground level.

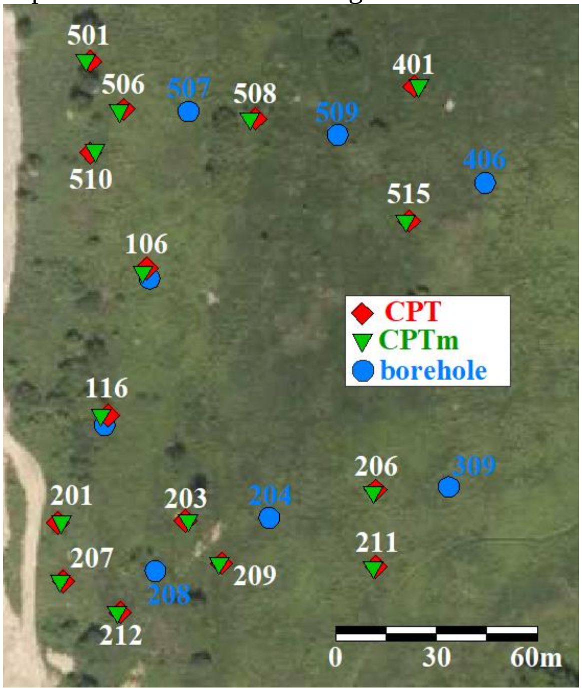

Figure 2. Locations of the exploratory points

Cone penetration tests were conducted using the Pagani T63-200 self-propelled penetrometer, with a maximum pressure of 200kN. The mechanical and electric cones used for this purpose displayed standard geometric properties, i.e. base area 10 cm^2, sleeve area 150 cm^2, and countersink angle 60°. The cone was pressed to the ground at a speed of 2 cm/s, whereas the penetration characteristics were recorded every 20 cm for the mechanical cone, and every 1 cm for the electric cone.

4 RESULTS

The analysis began with eliminating the measurement error caused by the distance between various test locations. The tests could not be performed exactly in the same places, and slight slopes within the geotechnical layers were likely to occur at a distance of 1-2 m, along with test level differences or other punctual anomalies. Considering the above, the diagrams obtained directly from the conducted tests (q_c, f_s) were filtered and adjusted in line with the upward-downward trends observed for q_c, which enabled eliminating the measurement errors caused by the distance between various test locations.

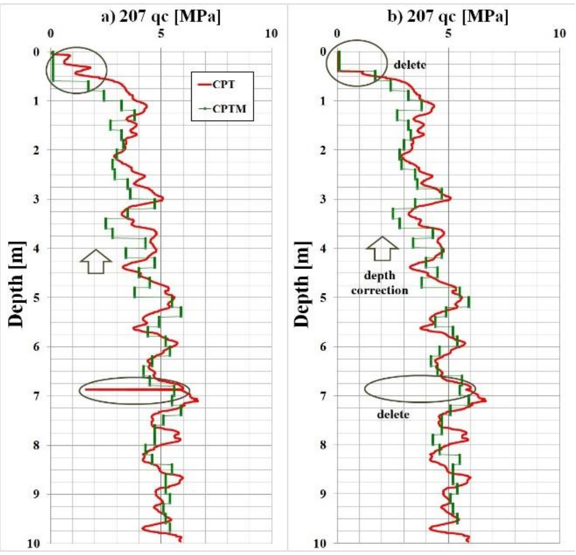

Figure 3. Plots of the Cone Penetration Test: a) actual, b) after results correction

Figure 3 presents an exemplar diagram 207 point before and after eliminating the measurement errors. This procedure made it possible to obtain values which accurately reflected the characteristics of both cones while disregarding the local anomalies independent of the applied equipment.

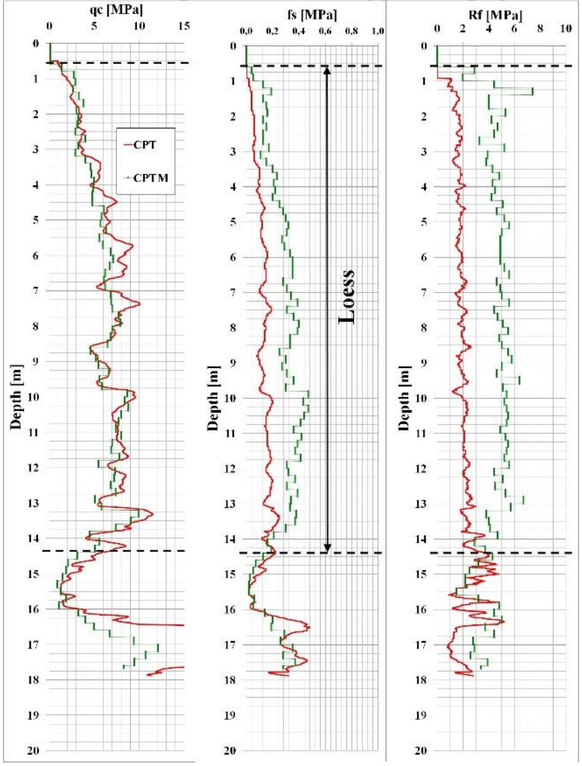

Figure 4. The diagrams of the CPT results in the 106 location

The final results obtained through the CPTm and CPT tests for each of the test locations are displayed in three figures, including cone resistance q_c, sleeve friction f_s and the standardised coefficient of friction R_f. In addition, Figure 4 shows diagrams for a selected location 106.

5 RESULTS ANALYSIS

Given the different measuring intervals employed for CPT and CPTm (1 cm and 20 cm respectively), average values obtained for a 20-cm-long section were calculated for the CPT.

The values of cone resistance q_c should be viewed as very similar, although the CPTm results generated slightly lower figures. Significant differences, however, are found as regards sleeve friction. Both sleeve friction f_s and coefficient R_f, when measured with a mechanical cone (CPTm), are much higher than those obtained with an electric cone. In consequence, differences are likely to occur in the classification of soils by means of charts.

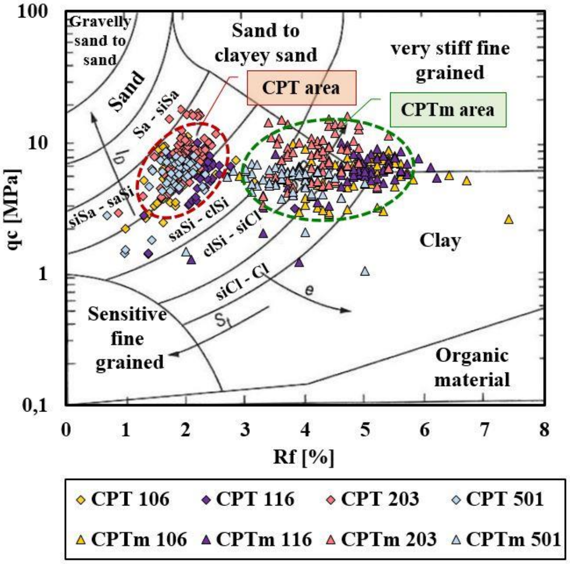

Figure 5. Identification of the loess soil type based on CPT results with the use of the Robertson chart

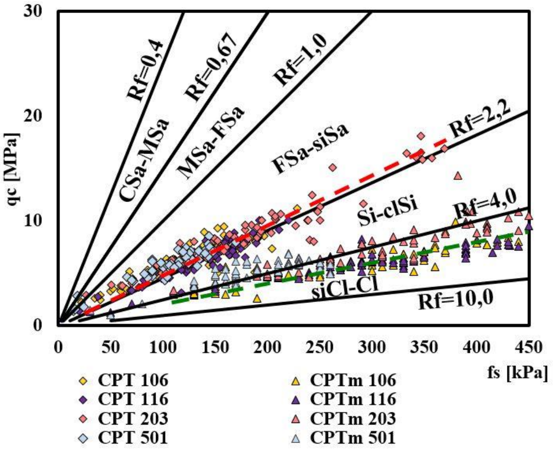

Figure 6. Identification of the loess soil type based on CPT results with the use of the Marr chart

Figures 5 and 6 display the classifications established by means of charts Robertson and Marr.

This issue has also been dealt with by (Shahri, Malehmir, and Juhlin 2015; Fellenius and Eslami 2000; Tumay et al. 2011). Nonetheless, it should be stressed that the classification diagrams, while determining soil behaviour types, cannot be directly used to classify soils according to the particle-size distribution as employed, inter alia, in PN-EN ISO 14688-1: 2006 (PN-EN ISO 14688-1:2006) or PN-86/B-02480 (PN-86 B-02480). As a result, in certain cases differences can occur between the soil type identified through drilling and the soil type determined on the basis of CPT-derived parameters. The soil type cannot be unambiguously determined on the basis of CPT results, but the test provides cone resistance values that accurately reflect bearing capacity, and are used in designing foundations. As the interpreted soil parameters are mainly derived on the basis of cone resistance q_c, this parameter merits special attention.

It was also noted that the results obtained for loess soils in the mechanical cone penetration test (CPTm) were easily readable for the operators. The resistance values markedly stopped at each subsequent Begemann cone phase, minimising the risk of error which is often encountered in the case of sandy and stony soils. Moreover, the diagrams for parameters q_c, f_s, R_f are characterised by very stable shapes and no suddenly rising or falling values. The diagram shape and moderation provide additional information that proves useful in determining the range of loess occurrence.

The diagram (Fig. 7) presents the cone resistance q_c values obtained with the electrical (CPT) and mechanical (CPTm) cones, along with the relevant trend line. The trend line provides the basis for determining cone coefficient β, serving the purpose of calculating the results obtained with both cones, in line with the following dependence (1).

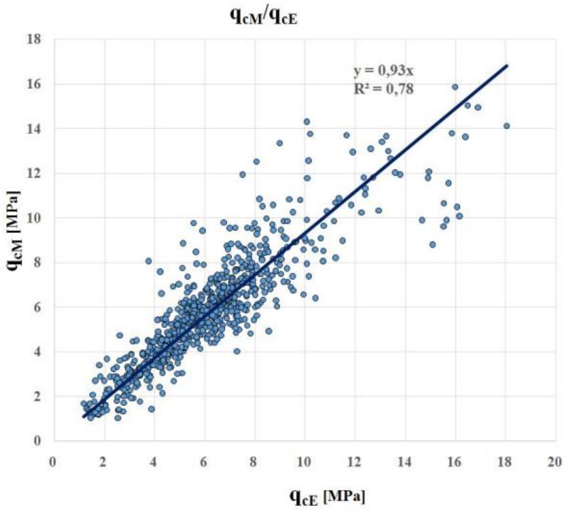

Figure 7. Comparision of the cone resistance q_c obtained from CPT/CPTm

$$q_{c(m)} = \beta q_{c(e)} \tag{1}$$

Where q_c (MPa) is the electric cone resistance, $q_{c(m)}$ (MPa) is the mechanical cone resistance, β (-) is the cone coefficient.

Following the analysis, based on the performed test, the coefficient β=0.93 was obtained, with R^2=0,78. This coefficient was found to match the trends described in the literature (Meisina et al. 2017; Briaund and Miran 1992). The derived coefficient β=0.93 was displayed in the coefficient β variance diagram (Fig. 8), depending on the range of the cone resistance q_c, and then compared with the trend presented in the study (Briaund and Miran 1992). In line with the observed correlation, $q_{c(e)}$ was found to display higher values within small ranges for mechanical cones, and within bigger ranges for electric cones. For the average value $q_{c.CPTm}$=5.8 MPa, as presented in the authors' study, the value of β, as derived from the diagram, equalled *0.87*, being slightly lower than the value obtained in the research.

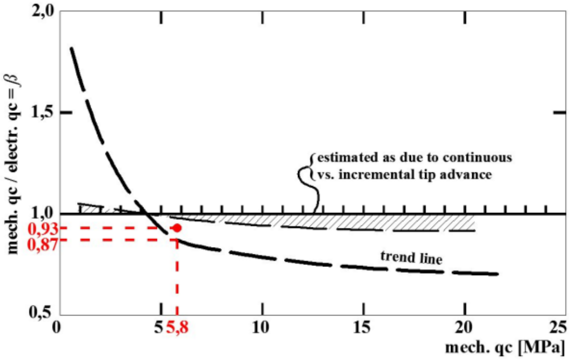

Figure 8. Reliance of the cone coefficient β on cone resistance according to (Briaud and Miran 1992)

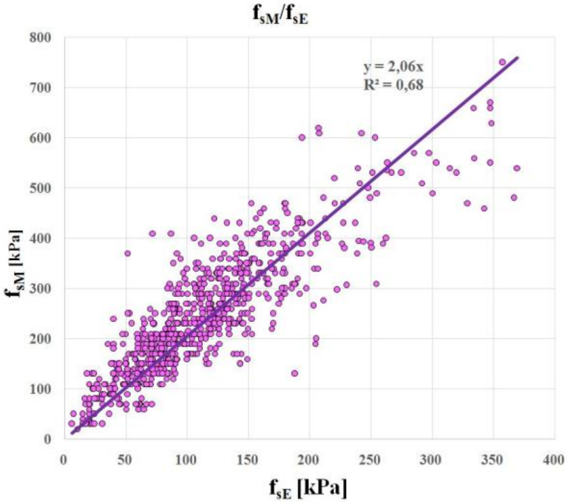

Figure 9. Comparision of the sleeve friction f_s obtained from CPT/CPTm

The following diagram (Fig. 9) presents the values of sleeve friction f_s obtained with electric (CPT) and mechanical (CPTm) cones, along with the relevant trend line. The sleeve coefficient β_f in this case amounted to 2.06, with R^2=0.68. The trend line determine sleeve coefficient β_f, with the successive dependence (2).

$$f_{s(m)} = \beta_f f_{s(e)} \tag{2}$$

Where f_s (MPa) is the electric sleeve friction, $f_{s(m)}$ (MPa) is the mechanical sleeve friction, β_f (-) is the sleeve coefficient.

The comparison shown in the study (Meisina et al. 2017) also shows that the sleeve friction values obtained with the mechanical cone were more higher than those obtained with the electric cone.

6 CONCLUSIONS

The article compares the cone penetration test results obtained with electric and mechanical cones. The values of cone resistance q_c from both tests appear similar, although the value of q_c obtained with the mechanical cone was slightly lower. Coefficient β, reflecting the transition from mechanical into electric cone, was derived, and for the Lublin unsaturated loess it was established at β =0.93. Taking into account the slight difference and the fact that it was biased towards the safer side (β<1), it should be concluded that the use of both cone types provides reliable results for loess soils and, hence, could be viewed as admissible.

The sleeve friction values obtained from the tests utilising various cone types differed significantly. The transition coefficient was β_f=2.06 which was likely to increase the material coefficient R_f by 2.22 in average terms. In consequence, different types of soils were identified by means of classification charts. As the difference was proven to be substantial, this issue needs to be borne in mind when interpreting the test data, and mechanical cones should only be used in the areas where local adjustments are made (Fellenius and Eslami 2000).

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