Data Acquisition for Geotechnical Analysis in Tailing Design and Survey: Approach using CPT Technique

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ABSTRACT

The use of Cone Penetration Tests (CPT), also called "Dutch Cone" - named after its country of origin, has a long history in civil engineering. It was developed and used in the last decades to provide raw data for immediate assessment of soil stratigraphy, soil classification, pore water pressure, and soil strength, among others.

Over the years, a large number of correlations for interpretation of soil parameters have been identified and are now partly considered to be "standards". There are relationships which allow the interpretation of the relative density of granular soils and the consistency of cohesive soils whilst measuring the cone penetration resistance of the cone into the ground. Thus, the bearing capacity of soils for many design situations may be assessed in a fast and reliable manner from the overseeing engineer.

Considering tailing materials (dumps and dams) as being comparable to the natural soft soils described generally by relative density and consistency, we may draw an analogy between the soil properties obtained in tailings and those obtained in natural soils with widely-used CPT-interpretation methods. Nevertheless, the peculiarities which may exist from site to site in mining must be considered.

By means of example, a mine site from the current engineering practice in Germany will be presented emphasizing special points concerning data acquisition using CPT-Testing.

INTRODUCTION

A general assessment of the demand for geotechnical expertise for existing tailings in the copper belt region of North Chiles results in the special need for a fast and reliable field investigation (FI). A fast FI means rapid and safe access to the dam crown and to the tailings storage facility areas, while reliable means accurate data collection of basic parameters on site for further characterization and dam stability calculations. This may be achieved using the technique described below [8, 9, 10].

Many successfully executed tests in mining dumps and tailings demonstrated the viability of CPT-technique for geotechnical, geochemical and environmental purposes. The performed tests also outlined the viability of the method for use in the field of rehabilitation and closing of mines [6, 12].

This study to show the potentialities of the use of CPT-Technique in tailing geotechnics, pointing out geotechnical characterization for both tasks design and survey.

CONE PENETRATION TESTS

In-situ Testing Equipment

CPT-tests are often conducted in mining using a cone apparatus mounted on crawlers with weights in a range between 15 to 30 tons providing the required reaction to penetration force. Geotechnical data is collected at each geotechnical exploration point down to penetration refusal depth. Refusal is typically encountered due to either high tip resistance, high friction along the cone rods or due to high CPT rod deviation at depth. Detailed procedures and equipment specifications on CPT operations are provided e.g. in ASTM D5778 [8] or in EN ISO 22476-1 [9] (both Electrical Cone and Piezocone Penetration Testing of Soils).

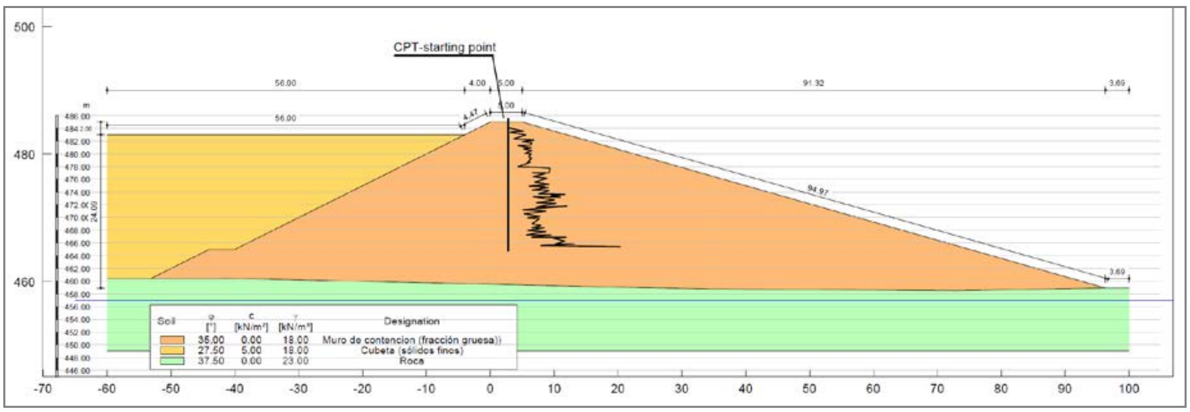

Figure 1 CPT-Sounding with starting point at the top of the dam crown of a tailing

Figure 1 schematically depicts the way to start the sounding method [7], whilst Figure 2 shows the mobilization of the crawler equipment to the site. Figure 3 shows the measuring cone itself.

Figure 2 CPT-Crawler during mobilization

Figure 3 Electrical CPT(U) probe

Figures 2 to 3 are courtesy of the Dutch CPT-equipment manufacturer GEOMIL (www.geomilcom).

CPT-Interpretation

For soil classification, different CPT based methods have been developed. One of the most representative methods is the simplified CPT chart method. According to this method the logarithm of cone tip resistance (q_t) is plotted against the friction ratio (FR) to delineate six major soil types: gravels, sands, silty sands, sandy silts, silts and clays. Figure 4 showing the relationship between cone penetration resistance (q_t) plotted against the friction ratio (FR) indicates this procedure (after MAINE, 2007 [5]):

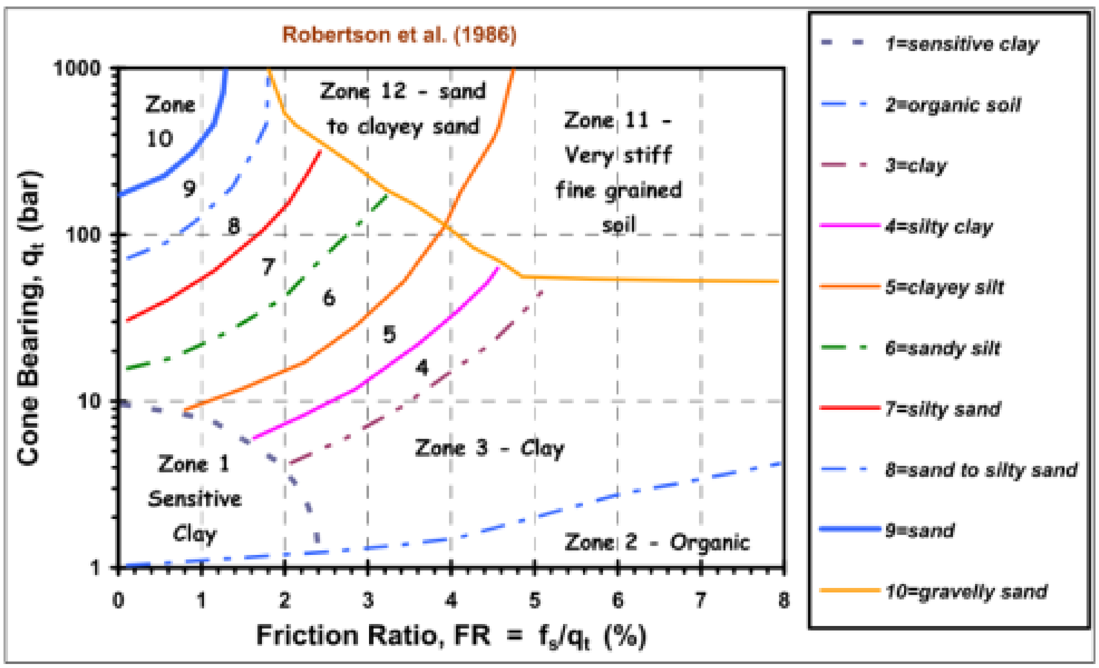

Figure 4 Relationship between cone penetration resistance q_t against the friction ratio FR [5]

The encountered materials are not natural soils but can be classified according to the particle size test, e.g. after ASTM D 422 (Particle-Size Analysis of Soils). The main components of the encountered soils belong mostly to the expected fractions (sands, silty sands, sandy silts and silts). Thus, the encountered soils may be classified under the ASTM D2487 (USCS, Unified Soil Classification System [8]).

Furthermore, ground engineering properties (such as Cu, φ, E_{oed}, E' and Dr) may be derived from the raw data obtained. Piezo-cones (CPTU) may also be used to assess hydrostatic head, consolidation and permeability characteristics [1, 2, 4, 5].

In addition, the seismic Cone Penetration Test (SCPT) is a reliable technique to determine the in situ seismic wave velocity giving an indication of ground characteristics such as low strain shear modulus and Poisson's ratio.

CPTu-Interpretation for Granular Soils

As a guidance for interpretation, the relative density of granular soils may be assessed using the relationship shown in Table 1.

Table 1 Cone penetration resistance and relative density of soils

Cone penetration resistance q_t [MPa]	Relative density I_D	Designation	Angle of internal friction φ [°]
<2.50	<0.15	Very loose	<30
2.5 – 7.5	0.15 – 0.35	Loose	30 – 35
7.5 – 15.0	0.35 – 0.65	Medium dense	35 – 40
15.0 – 25.0	0.65 – 0.85	Dense	40 – 45
>25.0	>0.85	Very dense	>45

CPTu-Interpretation for cohesive soils

As a guidance for interpretation, the consistency of cohesive soils may be assessed using the relationship shown in Table 2.

Table 2 Cone penetration resistance and consistency of soils

Cone penetration resistance, q_t [MPa]	Consistency designation	Consistency Index, Ic	Undrained shear strength Cu	Compressive strength, UCS [kPa]
<0.50	Very soft	<0.25	<20	-
0.50 – 1.00	Soft	0.25 – 0.50	20 – 40	-
1.00 – 1.50	Firm	0.50 – 0.75	40 – 75	80 – 150
1.50 - 2.50	Stiff	0.75 – 1.00	75 – 150	150 – 300
2.50 – 5.00	Very stiff	>1.00	150 – 300	300 – 600
>5.00	Hard	>1.25	>300	>600

Relationship between cone penetration resistance q_c (10cm² cone), consistency and undrained shear strength C_u for cohesive soils (adapted from PRINZ & STRAUSS [3] and EN ISO 14688-2:2004 [10]).

CASE STUDIES

In the region of Lusatia (Lausitz, see Figure 5) in the east of Germany, brown coal was mined in opencast mining since the 19th century. The mining technology scheduled a deep groundwater lowering to access the coal layers. The overburden was dumped into the dismantled parts of the field. In the hinterland of the remaining residual holes, which are water-filled after the planned groundwater rise, huge and effectively flat inner dump areas with mostly complicated geotechnical conditions were created.

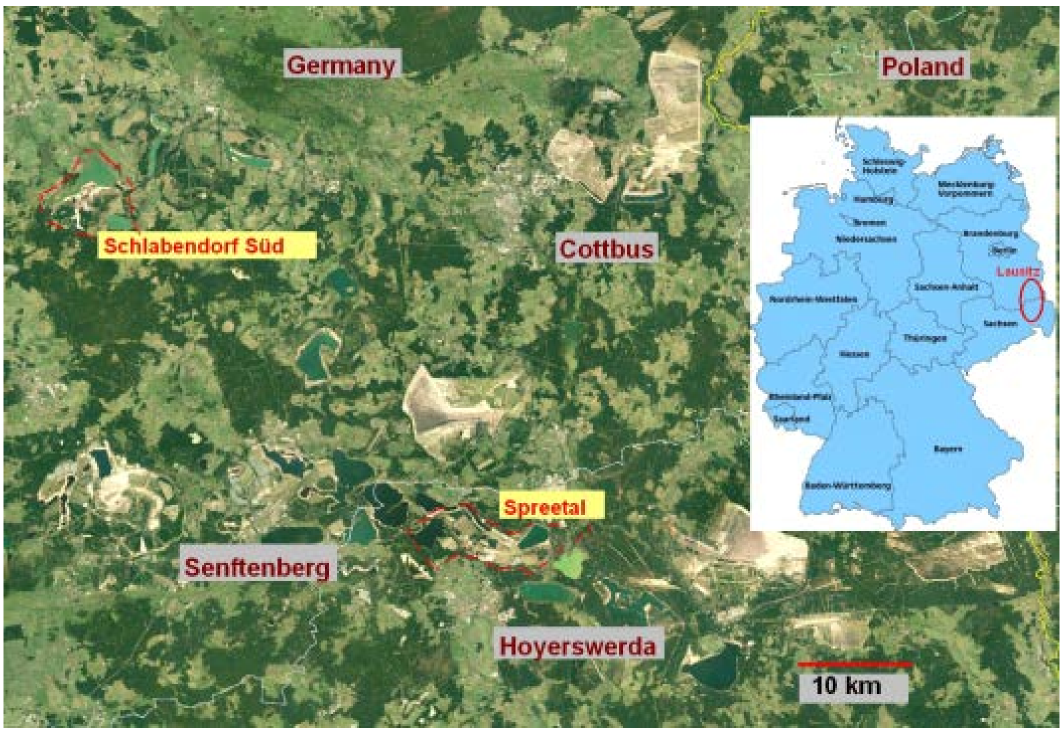

Figure 5 Germany and the Lusatia Region

Thus, the dump materials of Lusatia are characterized by water saturated mixed soils with a very low density of fine and medium sands with low amounts of silts and clays (less than 15% of fines). These soils are subject to soil liquefaction. The main reasons for liquefaction, besides the above discussed soil conditions, is understood to be the collapse of the existing grain structure after

- steady groundwater rise according to the closing of mines schedule and associated initial increase of pore water overpressure, and sometimes due to
- additional exposure to static loads (e.g. additional dumps or earthmoving), and/or
- additional exposure to dynamic loads such as heavy equipment induced vibrations, nearby deep compaction methods (e.g. vibro-displacement) or compaction blasting activity.

Summarizing, these soils lose their strength almost completely when induced by an *initial rise of pore water overpressures*. As a result, in the past and often during the ongoing mining operations, liquefaction occurred involving several million cubic meters of soil, which were thus flowed into adjacent open spaces [11, 12, 13].

In the years since 1990, the geotechnical protection of the slopes for most of the remaining lagoons in these soils was carried out using deep compaction techniques. In so doing, the risk of liquefaction for these slopes is now entirely eliminated.

For dump areas lying within mining perimeters (inner dumps), it was assumed in the past that an agricultural and forestry use with a groundwater flooring distance of more than three meters is generally possible without risk. Since 2009, however, breakings of the surfaces have occurred. The cause of this can usually not be explained considering only man-made influences.

Figure 7 Typical broken terrain

The task of the engineering companies commissioned by the concerned Mining Administration Company (LMBV) is to determine the necessity, nature and extent of pertinent remediation measures.

The necessary geotechnical model of the dump site massif is based on geological, hydrological, soil-physical and technological data. Part of this data can be determined using the Cone Penetration Test technique (CPT), measuring pore water pressure, cone resistance, skin friction and related friction ratio.

The derivation of soil-index properties and calculation parameters (soil strength and compressibility) from the obtained data is only possible if sufficient and reliable correlations for the required parameters are available. These correlations must be obtained by calibrating direct investigations with undisturbed samples. Hence, the physical laboratory examinations of the soil must correspond to the aim of the investigations.

For the assessment of the risk of soil liquefaction of a dump surface, the evaluation of the total number of CPT-Tests performed within the concerned dump region becomes essential. Due to the generally used continuous dumping technology for opencast lignite mining by means of conveyor bridges and spreaders, typically you will measure the lower limit of the cone resistance all along the vertical sounding length through dump material. For a sandy dump material with a lower proportion of particles of fines, a cone resistance characteristic close to the lower limit (ch-curve, presented as a green curve in Figure 8) signalizes a high liquefaction sensitivity of the soil.

Spreetal

For the Spreetal opencast mine, a representative one among many others, a typical curve was determined which is characterized by the fact that only 5% of the measured values of all CPT tests lie below the ch-curve mentioned above. The measured values were previously separated from values for compacted working levels and cohesive areas. The measured values are not connected as usual with lines but rather displayed as individual measuring points [13].

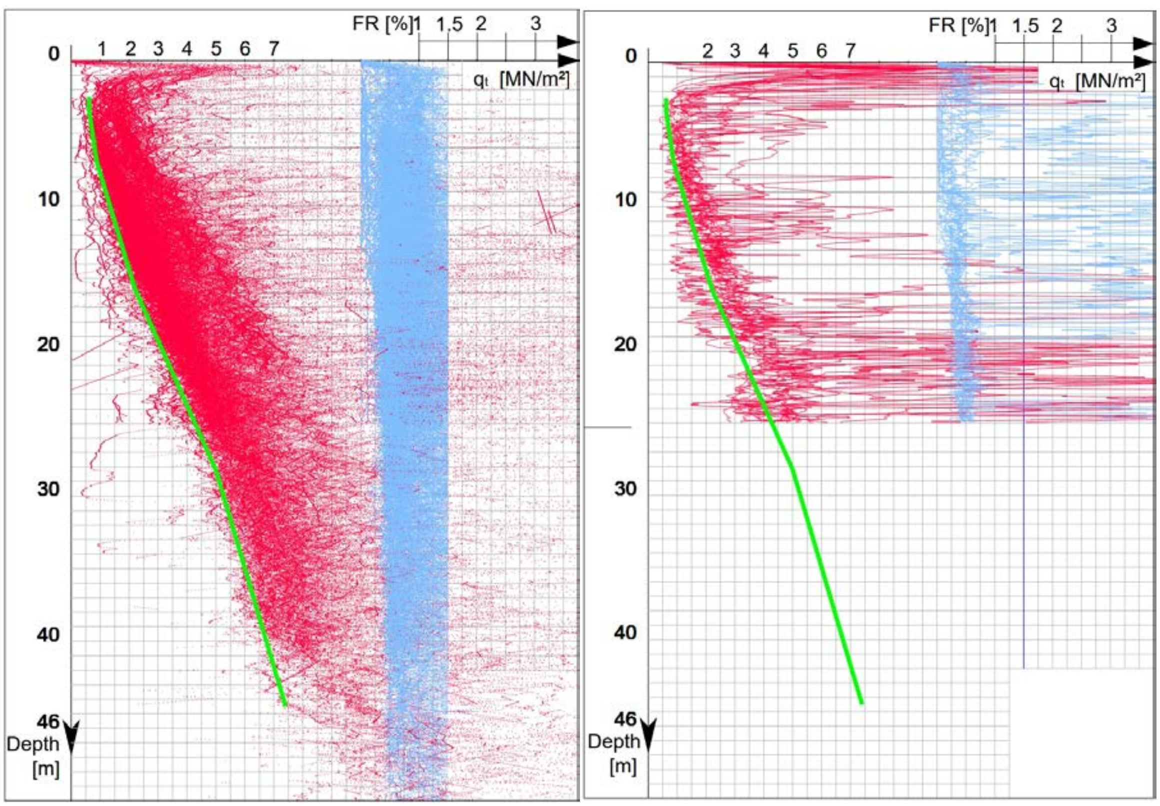

Figure 8 Typical Spreetal ch-curve and CPT tests for the low-level areas A, B and C

By comparing the measured values from CPT tests with the above mentioned ch-curve and while considering the friction ratio, it is possible to determine dump regions in which a liquefaction sensitivity is either not given or of lesser extent.

This task is to be solved on the dump sites of the former opencast mine Spreetal, for example on slopes of low height, but with very low groundwater floor distances at the foot of the embankments at the low-level areas A, B and C (see Figure 9). Here, light weight sounding techniques were applied to the upper edge of the embankment and the foot of the embankment to underline the differentiation of the soils.

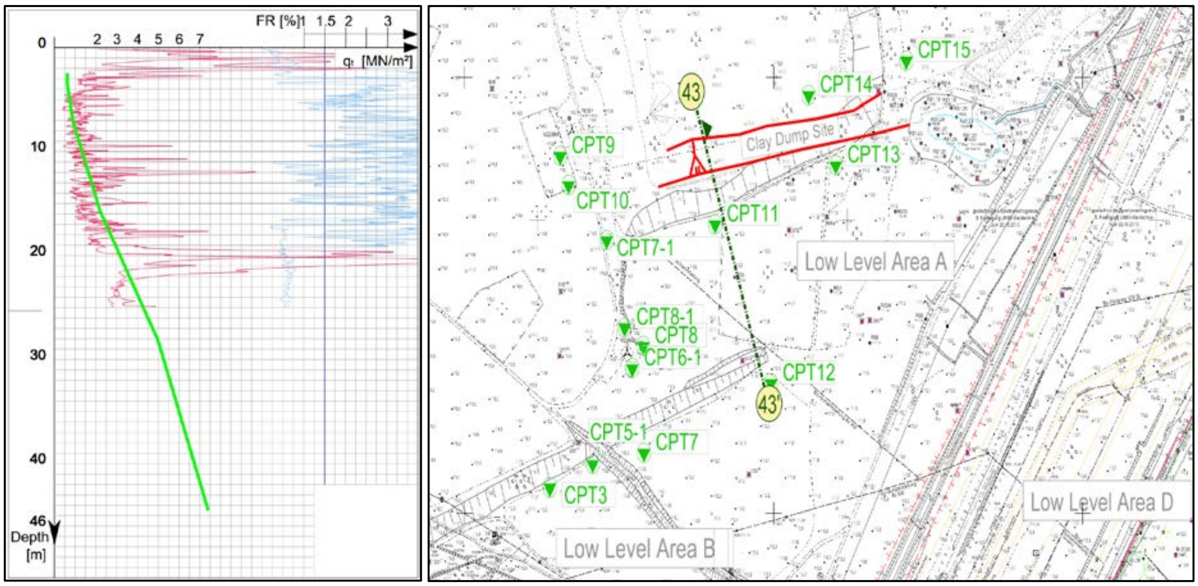

Figure 9 Soundings CPT 11 and CPT 12 with geotechnical profile 43, showing a clay dump site

The deviating curves for the friction ratio can be seen in two CPT tests. The localization in the map shows that both findings are in the area of the "Mittelmassenkippe", where it was assumed that cohesive soils were dumped. With the high friction ratio (FR) of the probes, which is measured only in clay and silt, the evidence is given. For example, a geotechnical profile can be created with the aid of old opencast situations, which clarifies the zone without a liquefaction danger in its position relative to the slope as shown in profile 43, Figure 10 [12].

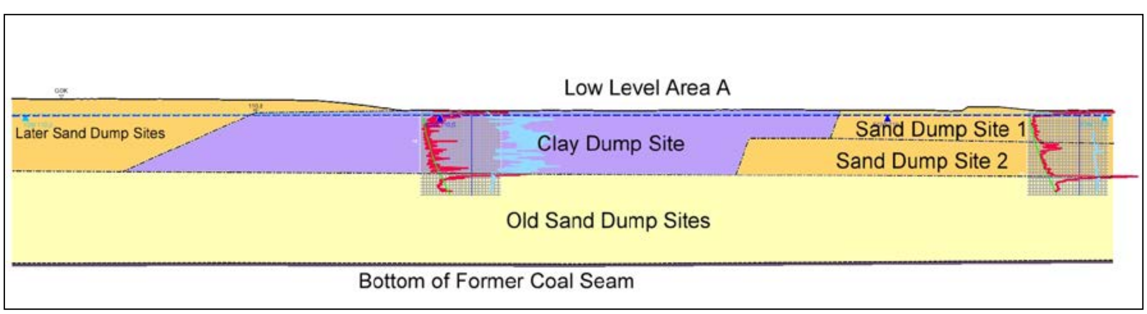

Figure 10 Geotechnical profile 43

Despite the high groundwater level, the stability of this slope can be demonstrated by means of proven stability analysis methods and using soil parameters also obtained thanks to correlations derived from CPT-Tests.

CONCLUSION

Generally, CPT-Technique is a fast, reliable, and cost effective means to evaluate the soil conditions (soil profile, geotechnical parameters, groundwater conditions) for preliminary geotechnical design, but also for ground control during construction or for proof of safety after construction and later during operations, delivering high quality information from the site. It is suitable for a wide range of soils, except for dense gravels, cobbles/boulders and hard rock.

For tailing projects in the Andes region, which is often subject to seismic activity, SCPT (seismic CPT) and CPTU (Piezo-CPT for pore pressure measurement) should in any case be used.

The main difference between the dumps of the lignite mining in Lusatia and tailings in Chile is the fact that dumps are initially just dumped without any compaction. The compaction (e.g. using vibro-flotation) follows time after, if required. Tailings by contrast represents a dam embankment which may be engineered during construction.

In both cases, the geotechnical investigation is dealing with non-native (remolded) soils. Thus, for every single site, qualified and experienced personnel in the interpretation of CPT-soundings for tailings should:

- consider the encountered soil stratigraphy, soil classification and soil properties,
- identify zones of poor stability, e.g. introducing an adapted ch-curve, after increasing frequency of soundings in identified liquefaction threatened zones, moreover
- conventional soil investigation (laboratory tests to undisturbed samples) should be carried out as they are necessary for the purpose to confirm or to calibrate existing correlations.

The complex evaluation of CPT tests permits conclusions to be drawn about specific dangers, the causes of which are however to be determined by detailed investigations.

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NOMENCLATURE

qc	measured cone tip resistance (load/πr^2; with r = cone radius)
qt	corrected total cone resistance, qt = qc + u2(1-a)
u2	measured pore pressure
a	a = An/Ac ≈ 0,80 (An = cross-sectional area of load cell; Ac = cross-sectional area of cone)
fs	cone sleeve friction (fs = load/2πrh; with r = cone radius and h = friction sleeve high)
FR	friction ratio, FR = f_s/q_t (%)
[x]	Listed references

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