4.9 Cone penetration tests (CPT)

An Electric Cone Penetration Test (CPT) is a geomechanical probing technique for shallow subsurface exploration. Probing through weak ground to locate firmer strata at depth has been practised since 1917, but CPT developed into its final form in the Netherlands during the 1930’s (Lunne et al. 1997). CPT combines rapid and cheap insight in the mechanical composition of the subsurface in the upper tens of meters. The widest application is currently found in geomechanical applications, i.e. surveys for road and railway constructions and the foundation of buildings and houses in areas with weak subsurface. The principles of CPT are published in Lunne et al. (1997) and Coerts (1996).

4.9.1 Principles of cone penetration tests

Cone resistance, sleeve friction and friction ratio

CPT surveying involves the penetration of a metal electrical cone with a surface of 10 cm$^2$ into the subsurface (Fig. 4.9.1). From beneath a heavy truck, the cone is penetrated at a constant rate of 1 cm/s. During penetration, a number of variables are recorded at the cone head or along the sleeve. At the cone head the cone resistance ($q_c$) is recorded (in MPa), which expresses the resistance of the sediments to penetration. Along the cone the sleeve friction ($f_s$) is recorded (also in MPa); indicative for the adhesive strength of the material.

From the cone resistance and the sleeve friction the friction ratio ($R_f$) can be calculated according:

$$R_f = \left[ \frac{f_s}{q_c} \right] \times 100$$

Numerous analyses of data have lead to an empirical relationship between $R_f$ and inferred lithology (Table 4.9.1). The friction ratio is, in combination with cone resistance, broadly used in geomechanical applications.

<table>
<thead>
<tr>
<th>Friction ratio ($R_f$)</th>
<th>Inferred lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 – 0.6</td>
<td>Gravel, coarse sand</td>
</tr>
<tr>
<td>0.6 – 1.2</td>
<td>Sand</td>
</tr>
<tr>
<td>1.2 – 4.0</td>
<td>Silt/loam</td>
</tr>
<tr>
<td>3.0 – 5.0</td>
<td>Clay</td>
</tr>
<tr>
<td>5.0 – 7.0</td>
<td>Heavy clay (incl. “pot clay”)</td>
</tr>
<tr>
<td>5.0 – 10.0</td>
<td>Peat</td>
</tr>
</tbody>
</table>

Pore water pressure

Another useful parameter that can be recorded in CPTU surveying (the so-called piezocone test) is the pore pressure ($u$) (Fig. 4.9.1). In the saturated or vadose zone increasing values occur with increasing depth, expressed in MPa. Also perched ground water tables can be detected using this technique.

4.9.2 Data interpretation

CPT interpretation mainly involves pattern analysis of the cone resistance and friction ratio curves. In common practice it is possible to define CPT “facies” for certain sedimentary deposits. In buried valley environments for example, the friction ratio curve characteristics of “pot clay” (or Lauenburger Ton) are well known. Similar typical CPT facies units can be defined for cover sands, boulder clay (till), several fluvial deposits and so forth. Figure 4.9.2 demonstrates an example of a CPT plot in which typical “pot clay” patterns can be recognized between 22 and 29 m depth. Less distinct are the clayey deposits between 0 and 22 m depth.
4.9.3 Application of CPT in the study of buried valleys

CPT is a useful, fast and cost-effective technique that can be used for the following applications related to the characterisation of buried valleys;

- the establishment of the occurrence, extent and upper boundary of “pot clay” bodies
- the establishment of protecting impermeable beds above buried valley aquifer systems (such as “pot clay”, boulder clay, etc.)
- characterisation of the upper sedimentary records outside buried valleys.

Figure 5.6.8 presents a CPT transect, combined with lithological columns of boreholes, of the Groningen Burval project area. Particularly between 2 and 4 km along the profile, a large clayey body is identified. The presence and rough outline of this unit was also demonstrated by Helicopter Electromagnetics (see Chap. 4.6). Below this unit other sediments associated with the Peelo Formation occur, while near the surface Weichselian deposits are present (Boxtel Formation). Figure 4.9.3 shows an enlarged part of Figure 5.6.8 to demonstrate the correlation more clearly.

The CPT characteristics of the “pot clay” (PENI) are clearly defined. The deeper undifferentiated deposits of the Peelo Formations are characterised by a strong lateral and vertical heterogeneity.
4.9 Cone penetration tests (CPT)

4.9.3 Fig. 4.9.3: Enlarged part of Figure 5.6.8. CPT transect with lithological columns of boreholes across unit of low-resistivity in HEM data. PE=Peelo Formation; PENI=Nieuwolda Member of the Peelo Formation, consisting of “pot clay”. BX =Boxtel Formation (Weichselian deposits).

4.9.4 Some remarks on the application of CPT

CPT can be broadly used in unconsolidated sediments; however there are certain limitations that have to be kept in mind:

1. The empirical relationship presented in Table 4.9.1 is based on observations below the ground water table. Above the ground water table a clayey bed (for example) can be partly dried out, leading to higher cone resistance and lower sleeve friction, hence lowering the friction ratio number. However in a climate with excess rainfall like that in northwestern Europe, hanging water is likely in the unsaturated zone. Hence it should be possible to discriminate clayey beds from their sand or gravelly counterparts in the unsaturated zone.

2. In buried valley environments glaciotectonized sediments can occur. The same is true for overconsolidated sediments due to glacial loading. In both situations geomechanical properties of the sedimentary record is potentially modified: sediments could respond different to CPT than expected in \textit{in situ} sedimentary sequences following the stratigraphical rule (Bakker 2004). In situations with overconsolidated clay adhesive strength is relatively high, but possibly reduced due to mechanical expel of pore water. Cone resistance is enhanced (higher compaction), leading to a reduced Rf. Hence, Rf values can differ from normal sedimentary conditions, with normal setting and compaction due to overburden.

The examples demonstrated above, attest that CPT is a powerful technique for the identification and mapping of large sedimentary units to a maximum depth of about 60 m below the surface. Combined with the low-costs CPT is a technique that is highly recommendable in environments with unconsolidated sediments such as buried valley systems.

4.9.5 References


