Correlations with CPT qc Value

Attempts also have been made to correlate \( C_c \) with the cone tip resistance, as described by Sangerer (12). However, these correlations have not proved to be useful to date. For example, they show that for \( q_c/p_a > 20 \), \( C_c \) is likely to be between 0.05 and 0.2. For \( q_c/p_a < 10 \), \( C_c \) could be nearly any value above 0.1.

**CONSTRANDED MODULUS FOR COHESIVE SOILS**

**Typical Values**

As described previously, the constrained modulus (M) is an alternative to \( C_c \). Early work on this subject by Janbu (14) demonstrated that the drained secant constrained modulus \( (M_{ds}) \) is a function of the vertical effective stress \( (\sigma_v) \) and a modulus number (m). For NC clays, \( M_{ds} \) is given by:

\[
M_{ds} = m \sigma_v
\]  
(6-10)

For NC silts and sands, \( M \) is given by:

\[
M_{ds}/p_a = m (\sigma_v/p_a)^{0.5}
\]  
(6-11)

Figure 6-7 shows the general trend in \( M \) as a function of porosity for a variety of NC soils and rocks.

Since the constrained modulus is defined as \( d\sigma/\sigma \) for one-dimensional compression, it can be shown simply that:

\[
M_{ds} = \sigma_v \left( \frac{1 + e_0}{C_c} \right) \ln 10 = m \sigma_v
\]  
(6-12)

Therefore, the modulus number for clays is simply 2.3/CR, where CR = compression ratio. Figure 6-8 shows that the trend for \( M \) with water content for NC clays is consistent with the previous correlation for CR and water content (Figure 6-6). For OC clays, the modulus number is 5 to 10 times that for the NC range.

**Correlations with SPT N Value**

The constrained modulus from oedometer tests on clay also has been correlated by Stroud (16) with N values obtained from the standard penetration test (SPT). This relationship is given by:

---

6-7
Figure 6-7. General Relationship Between Modulus Number and Porosity for NC Soils

Source: Janbu (14), p. 20.

Figure 6-8. Modulus Number for NC Clay


\[ \frac{M_{ds}}{P_a} = f N \]  

(6-13)

in which the empirical coefficient, \( f \), has been related to PI, as shown in Figure 6-8.
6-9. This correlation is not very strong and should be used with caution.

Correlations with CPT Results

Numerous correlations have been suggested to relate the cone penetration test (CPT) $q_c$ value to the constrained modulus of cohesive soils. All generally take the form below:

\[ \frac{M_{ds}}{q_c} = \alpha \]  \hspace{1cm} (6-14)

in which $\alpha$ = empirical coefficient. Compilations of $\alpha$ (e.g., \textit{A}) have shown suggested values ranging from 0.4 to 8, with the majority of values between 1 and 3. However, most of these values have been obtained using a variety of mechanical and electric cones of different geometries and test procedures.

Figure 6-10 shows the variation of $M_{ds}$ with high quality cone tip resistance data from 12 sites tested by piezocone. This figure provides a more useful estimator for $M$ in clays.

Correlations with DMT Results

The dilatometer test (DMT) provides an estimate of $M_{ds}$ through an empirical relationship between the dilatometer parameters $E_D$ and $K_D$, as shown in Figure 6-11. The effect of the dilatometer parameter $I_D$ on this relationship is given in explicit equations by Marchetti (19).

![Graph](image)

Figure 6-9. SPT Constrained Modulus Coefficient $f$ versus PI

Source: Stroud (16), p. 373.
Figure 6-10. Constrained Modulus versus $q_T$ from CPTU for Clays

Source: Database from Hayne, et al. (18).

Figure 6-11. Constrained Modulus from DMT Parameters


COMPRESSION INDEX FOR COHESIONLESS SOILS

For the predominant quartz-type cohesionless soils found throughout the world, the compressibility characteristics are much less than for cohesive soils. Exceptions to this observation could include micaceous sands and the calcareous sands.
associated with coralline deposits, which show significant compressibility compared with the more prevalent silica sands. The compression index of cohesionless soils is somewhat stress-dependent, indicating that e-log $\bar{\sigma}_v$ plots are perhaps not the most appropriate means of presenting one-dimensional compression data. Typical values for the compression index and unload-reload index of six different sands are given in Table 6-2.

The effect of grain size distribution on sand compressibility is illustrated in Figure 6-12 at a reference relative density of 40 percent. The effect of relative density on sand compressibility is given in Figure 6-13. In both of these figures, the notation used is defined in Table 2-7.

CONSTRANDED MODULUS FOR COHESIONLESS SOILS

Typical Values

The stress-dependency effect on sand compressibility may be taken into account more directly by using the constrained modulus ($M_{con}$):

Table 6-2

<table>
<thead>
<tr>
<th>Sand</th>
<th>$e_0$</th>
<th>$\bar{\sigma}_v/\bar{P}_a = 1$ to 3</th>
<th>$\bar{\sigma}_v/\bar{P}_a = 20$ to 30</th>
<th>$C_{ur}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monterey</td>
<td>0.854</td>
<td>0.021</td>
<td>0.085</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td>0.782</td>
<td>0.018</td>
<td>0.090</td>
<td>0.007</td>
</tr>
<tr>
<td>Ticino</td>
<td>0.917</td>
<td>0.025</td>
<td>0.130</td>
<td>0.007</td>
</tr>
<tr>
<td></td>
<td>0.827</td>
<td>0.026</td>
<td>0.085</td>
<td>0.006</td>
</tr>
<tr>
<td>Hokksund</td>
<td>0.870</td>
<td>0.024</td>
<td>0.095</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td>0.790</td>
<td>0.018</td>
<td>0.056</td>
<td>0.005</td>
</tr>
<tr>
<td>Ottawa</td>
<td>0.760</td>
<td>0.025</td>
<td>0.030</td>
<td>0.007</td>
</tr>
<tr>
<td></td>
<td>0.560</td>
<td>0.005</td>
<td>0.100</td>
<td>0.003</td>
</tr>
<tr>
<td>Reid-Bedford</td>
<td>0.900</td>
<td>0.011</td>
<td>0.090</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td>0.650</td>
<td>0.005</td>
<td>0.019</td>
<td>0.003</td>
</tr>
<tr>
<td>Hilton Mines</td>
<td>0.950</td>
<td>0.038</td>
<td>0.210</td>
<td>0.009</td>
</tr>
<tr>
<td></td>
<td>0.732</td>
<td>0.022</td>
<td>0.100</td>
<td>0.006</td>
</tr>
</tbody>
</table>

Note: Details on these sands are given in Appendix H.
Source: Been, et al. (6), p. 295.