MODULE – 4

Dynamic Soil Properties
Cyclic Stress Ratio (CSR)

- Seismic demand on a soil layer
- Equation formulated by Seed and Idriss (1971)

\[
CSR = \left( \frac{r_{av}}{\sigma'_{v0}} \right) = 0.65 \left( \frac{a_{max}}{g} \right) \left( \frac{\sigma_{v0}}{\sigma'_{v0}} \right) r_d
\]

- \( a_{max} \) = peak horizontal acceleration at the ground surface generated by the earthquake
- \( g \) = acceleration due to gravity
- \( \sigma_{v0} \) = total vertical overburden stress
- \( \sigma'_{v0} \) = effective vertical overburden stress
- \( r_d \) = stress reduction co-efficient (flexibility of the soil)

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Liquefaction (contd.)

Stress Reduction factor to estimate the variation of cyclic shear stress with depth below level or gently sloping ground surfaces.

*(after Seed and Idriss, 1971.)*
Liquefaction (contd.)

Stress Reduction Coefficient, \( r_d \)

→ For routine practice for noncritical projects, use Liao and Whitman (1986) equations,

\[
\begin{align*}
\ r_d &= 1.0 - 0.00765z \text{ for } z \leq 9.15m \\
\ r_d &= 1.174 - 0.0267z \text{ for } 9.15m < z \leq 23m
\end{align*}
\]

→ New procedures are under development and verification (Robertson and Wride 1998, Seed et al. 2003) but uncertainty remains

\[
\begin{align*}
\ r_d &= \frac{1.000 - 0.4113z^{0.5} + 0.04052z + 0.001753z^{1.5}}{1.000 - 0.41772^{0.5} + 0.05729z - 0.006205z^{1.5} + 0.001210z^{2}}
\end{align*}
\]

From Youd et al. (2001)

(Blake, 1996)
Evaluation of CRR

→ Cyclic resistance of a layer; cyclic stress required to induce liquefaction
→ Based on semi-empirical correlations from database of field experience of sites which did not liquefy; using values of SPT $N_{1,60cs}$ or CPT $q_{c1ncs}$ or $V_{s1}$
→ The charts are developed for moment magnitude 7.5, any other magnitude requires a correction
→ Corrections are also required for overburden stress and presence of a driving static shear stress (a slope)

Corrections to CRR

Regardless of the investigative method, three corrections should be applied to the CRR

- Magnitude correction, $k_M$
- Overburden correction, $k_o$
- Sloping ground (driving static shear stress) correction, $k_\alpha$

$$FS_1 = \frac{CRR}{7.5} = \frac{CRR \cdot k}{M} \cdot \frac{k}{\sigma} \cdot \frac{k}{\alpha} = \frac{CRR}{CSR} \cdot \frac{M}{CSR}$$
**SOIL DYNAMICS**

**Magnitude Correction Factor, $k_m$**

Empirical correlations are based on moment magnitude 7.5; for any other magnitude, a correction is required.

$$MSF = \frac{10^{2.24}}{M^{2.56}}$$

[After Youd et al. (2001)]

**SOIL DYNAMICS**

**Overburden Correction Factor, $k_\sigma$**

$\rightarrow$ Laboratory tests indicate that liquefaction resistance increases (nonlinearly) with increasing confining stress

$\rightarrow$ A correction for overburden stress is recommended

$$k_\sigma = (\sigma'_v)^{f-1}$$

The exponent $f$ is a function of site condition, relative density, stress history, aging.

[After Youd et al. (2001)]
**SOIL DYNAMICS**

**Overburden Correction Factor, \( k_\sigma \)**

Variation of correction factor, \( K_\sigma \), with effective overburden pressure. [After Marcuson et al. (1990)]

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**SOIL DYNAMICS**

**Sloping Ground Correction Factor, \( k_\alpha \)**

Variation of correction factor, \( K_\alpha \), with initial shear / normal stress ratio. (after Seed and Harder, 1990.)
Sloping Ground Correction Factor, $k_a$

After Youd et al. (2001)

Various Scales of Earthquake Magnitude

After Youd et al. (2001)
Use of SPT Result for Liquefaction

- Standard penetration test (SPT) consists of driving a thick-walled sampler into a granular soil deposit
- Generally, should be used only for cohesionless soils; it is not applicable for soils with plastic fines or gravels
- SPT gives a measure of in situ density
- Corrected SPT “N” values are widely used in semiempirical estimation of liquefaction

Specifications for SPT

- Sampler: Per ASTM D 1586-99 (2000), SPT sampler has an inside barrel of diameter $D = 3.81$ cm (1.5 in) and an outside diameter $F = 5.08$ cm (2 in)
- Driving hammer: 63.5 kg (140 lb) hammer falling a distance of 0.76 m (30 in)
- Driving distance and rate: total of 45 cm (18 in), with number of blows recorded for each 15 cm (6 in) interval, at a rate of 30-40 blows per minute
- Gives a measured SPT Value which is the total number of blows required to drive the hammer through the last 30 cm
SPT Sampler Tube

Corrections for SPT

A number of corrections are recommended to convert the N value measured in the field to a corrected and normalized \( (N_1)_{60} \) value

\[
(N_1)_{60} = N_M C_N C_E C_B C_R C_S
\]

where,
- \( N_M \) = measured standard penetration resistance
- \( C_N \) = depth or overburden correction factor
- \( C_E \) = hammer energy ratio (ER) correction factor
- \( C_B \) = borehole diameter correction factor
- \( C_R \) = rod length correction factor
- \( C_S \) = correction factor for samplers with or without liners

Sources: Youd and Idriss (1997), Martin and Lew (1999)
**SOIL DYNAMICS**

**Overburden Correction for SPT**

\[
(N_1)_{60} = N_M C_N C_E C_B C_R C_S
\]

\[
C_N = \left( \frac{P_a}{\sigma'_{v_0}} \right)^{0.5}
\]

\[P_a = 100 \text{ kPa} \]

\[0.4 \leq C_N \leq 1.7\]

Normalized to an effective overburden pressure of 100 kPa (1.044 tsf). This normalized blow count is designated as \( N_1 \).

Note: use \( \sigma'_{v_0} \) at time of drilling (not as-built)

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**SOIL DYNAMICS**

**Energy Correction for SPT**

\[
(N_1)_{60} = N_M C_N C_E C_B C_R C_S
\]

\[
C_E = \frac{ER(\%)}{60}
\]

- Most important factor affecting SPT results is the ENERGY delivered to the sampler (measure it if possible)
- Depends primarily on the type of hammer/anvil system and the method of hammer release (hammer strikes rod eccentrically, lack of hammer free fall, new stiff rope, more than two turns around cathead, incomplete release of rope each drop...)
- Expressed in terms of the rod energy ratio (ER)
- ER of 60% has generally been accepted as the reference value (safety hammer, N.A. practice)
**SOIL DYNAMICS**

**Testing Procedure Corrections for SPT**

\[ (N_s)_b = N_m C_B C_R C_S C_N C_S \]

- **Borehole Diameter Correction, \( C_B \)** - larger gives lower \( N_m \)
  \( C_B = 1 \) for 65-115 mm diameter (preferred dia.)
  \( C_B = 1.05 \) for 150 mm diameter
  \( C_B = 1.15 \) for 200 mm diameter

- **Short Rod Correction, \( C_R \)** - shorter drill rods give higher \( N_m \)
  \( C_R = 0.75 \) for rod length less than 4m
  \( C_R = 0.85 \) for 4m to 6m rod length
  \( C_R = 0.95 \) for 6m to 10m rod length
  \( C_R = 1 \) for rod length between 10m and 30m

- **Missing Sampling Liner correction, \( C_S \)**
  \( C_S = 1.2 \) for sampler without liners

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**SOIL DYNAMICS**

**Summary of SPT Corrections**

*[after Youd et al. (2001)]*

<table>
<thead>
<tr>
<th>Factor</th>
<th>Equipment variable</th>
<th>Term</th>
<th>Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overburden pressure</td>
<td>—</td>
<td>( C_N )</td>
<td>((P_a / \sigma_v)^{0.5})</td>
</tr>
<tr>
<td>Overburden pressure</td>
<td>—</td>
<td>( C_N )</td>
<td>( C_N \leq 1.7)</td>
</tr>
<tr>
<td>Energy ratio</td>
<td>Donut hammer</td>
<td>( C_E )</td>
<td>0.5–1.0</td>
</tr>
<tr>
<td>Energy ratio</td>
<td>Safety hammer</td>
<td>( C_E )</td>
<td>0.7–1.2</td>
</tr>
<tr>
<td>Energy ratio</td>
<td>Automatic-trip Donut-type hammer</td>
<td>( C_E )</td>
<td>0.8–1.3</td>
</tr>
<tr>
<td>Borehole diameter</td>
<td>65–115 mm</td>
<td>( C_B )</td>
<td>1.0</td>
</tr>
<tr>
<td>Borehole diameter</td>
<td>150 mm</td>
<td>( C_B )</td>
<td>1.05</td>
</tr>
<tr>
<td>Borehole diameter</td>
<td>200 mm</td>
<td>( C_B )</td>
<td>1.15</td>
</tr>
<tr>
<td>Rod length</td>
<td>&lt;3 m</td>
<td>( C_B )</td>
<td>0.75</td>
</tr>
<tr>
<td>Rod length</td>
<td>3–4 m</td>
<td>( C_B )</td>
<td>0.8</td>
</tr>
<tr>
<td>Rod length</td>
<td>4–6 m</td>
<td>( C_B )</td>
<td>0.85</td>
</tr>
<tr>
<td>Rod length</td>
<td>6–10 m</td>
<td>( C_B )</td>
<td>0.95</td>
</tr>
<tr>
<td>Rod length</td>
<td>10–30 m</td>
<td>( C_B )</td>
<td>1.0</td>
</tr>
<tr>
<td>Sampling method</td>
<td>Standard sampler</td>
<td>( C_S )</td>
<td>1.0</td>
</tr>
<tr>
<td>Sampling method</td>
<td>Sampler without liners</td>
<td>( C_S )</td>
<td>1.1–1.3</td>
</tr>
</tbody>
</table>
SPT as per Indian Standard of Practice

- Note that the Indian Standard (IS 2131 – 1981) recommends corrections for only overburden and dilatancy (fines below the water table).

- If any deviations from the standard procedure are made, it is necessary to make the aforementioned correction, especially the energy correction and the short rod correction.

SPT Fines Correction for Liquefaction

If the SPT $(N_1)_{60}$ values are to be used in the simplified liquefaction triggering analyses, the values must be converted to equivalent clean sand values. If the fines content is greater than 5%, use the following correction

$$(N_1)_{60,CS} = (N_1)_{60} C_{\text{FINES}}$$

where,

$$C_{\text{FINES}} = (1 + 0.004FC) + 0.05 \frac{FC}{N_{1,60}}$$

which is valid for fines contents (FC) less than 35%
SPT in Gravel

- Limited effectiveness, at best, because of the large size of particles compared to size of sampler
- Often, misleadingly high values are obtained. As a general rule, any SPT N value over 50 should be thrown out (of liquefaction analysis)
- Can look at incremental (i.e., per inch blow counts), to distinguish between N values obtained in matrix material vs. those affected by large particles
- Try another method (Becker Penetrometer)