Scour in Cohesive Soils

presented by

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Outline

- Background
- Ex Situ Scour Testing Device
- Flow Condition: Log-law Velocity Profile
- Soil Preparation & Geotechnical Tests
- Erosion Results
- Conclusions
Hydraulic Loading Decay Function and Critical Soil Resistance

**Hydraulic Loading Decay Function and Critical Soil Resistance**

- $P_{L0,i} > < P_{C_{R1,i}}$
- $P_{L1,i} > < P_{C_{R2,i}}$
- $P_{L2,i} > < P_{C_{R3,i}}$
- $P_{L3,i} > < P_{C_{R4,i}}$

$P_{L,i} =$ HYDRAULIC LOAD BASED ON $Q_{100}$

$P_{C_{R,i}} =$ CRITICAL SOIL RESISTANCE

$y_S =$ SCOUR DEPTH

$y_{S\text{ MAX}} \rightarrow P_{Lj,i} < P_{C_{Rj+1,i}}$
Ex situ Scour Testing Device
Flow Condition: Log-law Velocity Profile

[Graph showing a log-law velocity profile with different pressure levels indicated.

- 2.7 Pa
- 3.6 Pa
- 4.9 Pa
- 7.2 Pa
- 10 Pa
- 13.1 Pa
- 15 Pa

The graph plots y (mm) against V (cm/s).]
Pugger Mixer: Preparing Slaking-free Soils

7 mins

25 mins
### Tested Soil Characteristics

<table>
<thead>
<tr>
<th>Index</th>
<th>Soil type</th>
<th>Materials (%)</th>
<th>SG</th>
<th>PL</th>
<th>LL</th>
<th>PI</th>
<th>F(&lt;75 µm)</th>
<th># of WC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CL-ML: sandy silty clay</td>
<td>20 40 40</td>
<td>2.69</td>
<td>16.7</td>
<td>21.0</td>
<td>4.3</td>
<td>60.6</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>CL: sandy lean clay</td>
<td>30 20 50</td>
<td>2.71</td>
<td>14.3</td>
<td>21.3</td>
<td>7.0</td>
<td>50.7</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>CL: sandy lean clay</td>
<td>40 10 50</td>
<td>2.73</td>
<td>14.4</td>
<td>21.1</td>
<td>6.7</td>
<td>50.7</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>CL-ML: Silty clay with sand</td>
<td>25 45 30</td>
<td>2.72</td>
<td>17.4</td>
<td>22.5</td>
<td>5.1</td>
<td>70.4</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>CL: Lean clay with sand</td>
<td>40 40 20</td>
<td>2.69</td>
<td>17.7</td>
<td>26.4</td>
<td>8.7</td>
<td>80.3</td>
<td>3</td>
</tr>
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<td>3</td>
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</table>
Geotechnical Tests

1. Slaking test

2. Unconfined compression test (q_u) / Field vane tester

3. WC, SG and bulk density

4. Particle size distribution

5. Atterberg limits

6. Direct shear
Soil Erosion Video

Soil 4, WC=19.8%

CL-ML: silty clay
25% clay + 45% silt + 30% sands
PI=5%, q_u=1242 lbf (59 KPa)
## Erosion Curve of Tested Soils

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<tr>
<th>Index</th>
<th>Soil type</th>
<th>Materials (%)</th>
<th>SG</th>
<th>PL</th>
<th>LL</th>
<th>PI</th>
<th>&gt;75 µm</th>
<th>WC (%)</th>
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<td>20 40 40</td>
<td>2.69</td>
<td>16.7</td>
<td>21.0</td>
<td>4.3</td>
<td>39.4</td>
<td>3: 15.6, 16.5, <strong>18.1</strong></td>
</tr>
<tr>
<td>2</td>
<td>CL-sandy lean clay</td>
<td>30 20 50</td>
<td>2.71</td>
<td>14.3</td>
<td>21.3</td>
<td>7.0</td>
<td>49.3</td>
<td>3: 14.7, <strong>16.7</strong>, 17.7</td>
</tr>
<tr>
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<td>CL-sandy lean clay</td>
<td>40 10 50</td>
<td>2.73</td>
<td>14.4</td>
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<td>2: 16.0, <strong>18.0</strong></td>
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<td>17.4</td>
<td>22.5</td>
<td>5.1</td>
<td>29.6</td>
<td>3: 18.9, <strong>19.8</strong>, 21.7</td>
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<td>17.7</td>
<td>26.4</td>
<td>8.7</td>
<td>19.7</td>
<td>3: 21.5, 23.1, <strong>24.8</strong></td>
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<td>16.6</td>
<td>25.5</td>
<td>8.9</td>
<td>29.6</td>
<td>3: 19.2, 20.0, <strong>23.1</strong></td>
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</table>
Erosion Curve of Tested Soils

Estimated critical shear stress deduced by fitting data:

\[ \dot{Z} = C_1 (\tau - \tau_c)^{C_2} \]
Proposed Models for Critical Shear Stress

For best fit, $\alpha_1 = 0.1$

\[ \tau_c = \alpha_1 \left( \frac{W}{F} \right)^{-2.0} PI^{1.3} q_u^{0.4} \]
Proposed Models for Critical Shear Stress

\[ \tau_c = \alpha_1 \left( \frac{W}{F} \right)^{2.0} \Pi^{1.3} q_u^{0.4} \]

For design, \( \alpha_1 = 0.07 \)

\[
\begin{array}{|c|c|c|}
\hline
\text{Predicted Critical Shear Stress (Pa)} & \text{Estimated Critical Shear Stress (Pa)} \\
\hline
\text{FHWA} & \text{1:1} & \text{Illinois*} \\
\hline
\end{array}
\]

Proposed Models for Erosion Rate

\[ \dot{z} = C_1 (\tau - \tau_c)^{1.8} \]

\[ C_1 = \alpha_2 q_u^{-1.0} P I^{-1.1} \]

For best fit, \( \alpha_2 = 680 \)

\[ R^2 = 0.61 \]
Proposed Models for Erosion Rate

\[
\dot{z} = C_1 (\tau - \tau_c)^{1.8}
\]

\[
C_1 = \alpha_2 q_u^{-1.0} \text{PI}^{-1.1}
\]

For design, \( \alpha_2 = 1100 \)
Conclusions

• ESTD mimics erosion in open channel flows
• The shear sensor directly measure the shear stress
• Critical shear stress is formulated with soil properties
• Erosion rate is a function of soil properties and excess shear stress
• Slaking should be excluded from an erosion test