Accepting Special Wastes and Maintaining Stability

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Objective

Technically speaking, the cause of this huge landslide is quite simple to calculate ... merely factor in the amount of garbage, the degree of the slope, the weather, etc. ... and you come to one conclusion ...
• Case History
• Shear Strength Specification
• Placement Specification
• Slope Stability Analyses
• Slope Monitoring
• Summary
• 7.5 M cubic yards of PCB sludge
• $450 M
• 10-year project
• Low Strength Waste (LSW) v. Direct Disposal Waste (DDW)
  • LSW ~ $20/ton more than (> ) DDW
  • ~500,000 tons
  • ~$10 M
SPECIAL WASTE

• ~3H:1V
• No slope setback
• Flatten and berms for stability
• Depth of Movement ~ 10 ft?
• Bottom Liner System
WASTE ACCEPTANCE/OPERATING PLAN

- Strength requirements
- **Interim** and Final Slopes
- Testing program
  - sampling, testing, timing, and classifying
- Slope inclination - 4H:1V
- Maximum fill height
- Slope benches
TOPICS

- Case History
- **Shear Strength Specification**
- Placement Specification
- Slope Stability Analyses
- Slope Monitoring
- Summary
• **DDW = Meet only one criterion**

  a. Minimum unconfined compressive strength of 0.8 tons per square foot; **OR**

  b. Minimum cohesive strength of 800 pounds per square foot; **OR**

  c. Minimum short term frictional strength of 25 degrees; **OR**

  d. Defined combinations of cohesive and short term frictional strength that provide a factor of safety for the landfill slopes as determined through slope stability modeling **at least equivalent to (b) or (c).**
Strength Envelopes for: (a) saturated and (b) partially saturated clayey soils (figures from Holtz and Kovacs (1981) - Figure 11.40)
• If sludge is saturated:
  c. $\phi = 0$ NOT 25 degrees
  b. $c = S_u = \frac{1}{2}qu = \frac{1}{2}a$.

a. Minimum unconfined compressive strength of 0.8 tons per square foot (1,600 psf); or

b. Minimum cohesive strength of 800 pounds per square foot; or
   (CU or UU Triaxial Compression)

If saturated: $a = b$
• 0.8 tsf = 1,600 psf

• Medium consistency - “penetrated several inches by thumb with moderate effort” – Peck et al. (1974)

• So DDW ~ weak

• LSW = weaker.........
• Blackmar and Stark (2015)

Su = 800 psf

DDW

LSW
SHEAR STRENGTH TEST RESULTS

- Blackmar and Stark (2015)

Su = 800 psf

DDW

LSW
a. Minimum unconfined compressive strength of 0.8 tons per square foot; or (viable if saturated but hard to test)

b. Minimum cohesive strength of 800 pounds per square foot; or (viable if saturated but hard to test)

c. Minimum short term frictional strength of 25 degrees; or (viable if unsaturated)

d. Defined combinations of cohesive and short term frictional strength that provide a factor of safety for the landfill slopes as determined through slope stability modeling at least equivalent to (b) or (c). ???
SHEAR STRENGTH SPEC.

• Use quantitative specification – \( q_u = 0.8 \) tsf or \( \phi' = 25^0 \)

• Qualitative spec. = ?
  - Support its weight
  - Walk on it
  - Support material placed over it
  - Capable of being worked by low ground pressure equipment
  - Ensure stable slopes
  - Maintain slope stability
  - FS > 1.5
  - Stable 3:1 slope
  - Medium consistency
<table>
<thead>
<tr>
<th>Shear Strength Test</th>
<th>Acceptance Limit</th>
<th>Lab or Field</th>
<th>Test Frequency (1st 10,000 yd$^3$)</th>
<th>Test Frequency (after 10,000 yd$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unconfined compressive strength (ASTM D2166-UC, Pocket penotrometer, or Torvane)</td>
<td>&gt; 0.8 tsf</td>
<td>Field</td>
<td>1 per 1,000 yd$^3$</td>
<td>1 per 5,000 yd$^3$</td>
</tr>
<tr>
<td>Undrained shear strength (ASTM D2573-FV or D4648-Lab Vane)</td>
<td>≥ 800 psf</td>
<td>Field</td>
<td>1 per 1,000 yd$^3$</td>
<td>1 per 5,000 yd$^3$</td>
</tr>
<tr>
<td>Undrained shear strength (ASTM D2850-UU or D4767$^1$-CU)</td>
<td>≥ 800 psf</td>
<td>Lab</td>
<td>Once</td>
<td>1 per 30,000 yd$^3$</td>
</tr>
<tr>
<td>Effective Shear Stress Strength Parameters (ASTM D4767$^1$-CU or D3080-DS)</td>
<td>≥ 25 degrees$^2$</td>
<td>Lab</td>
<td>Once</td>
<td>1 per 30,000 yd$^3$</td>
</tr>
</tbody>
</table>

**NOTES:**
1) with pore-water pressure measurement
2) or a combination of cohesive and frictional strength that provides for a factor of safety for landfill slopes of 1.2 for intermediate slopes and 1.5 for final cover slopes

- Blackmar and Stark (2015)
TOPICS

- Case History
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- Placement Specification
- Slope Stability Analyses
- Slope Monitoring
- Summary
PLACEMENT SPECIFICATION

- Correct Landfill Cell
- Slope Setback > 100 feet – increase stability & decrease leachate outbreaks
- Allow for Drying during Placement
- Compact using Lifts < 12 inches
- Mix with MSW???-next slide
- Promote Runoff – no ponding to minimize infiltration
- ~4H:1V
Rudy Bonaparte (2018) – 54th Terzaghi Lecture
• Test results show MSW/LSW mixtures become weaker at LSW mass fractions above ~40%
• At 70 to 80% LSW content, mixture behaves similarly to LSW
SLOPE PLACEMENT SPECIFICATION

- Slope Setback reduces area for LSW Placement
- LSW creates low Hydraulic Conductivity Zone
  - horizontal drains
  - accelerate consolidation
- Excess Pore and Gas Pressures can develop when Filled Over – Example below
- Hard to Mix with MSW
TOPICS

• Case History
• Shear Strength Specification
• Placement Specification
• Slope Stability Analyses
• Slope Monitoring
• Summary
• Eid et al. (2000)

• $\phi' = 35^\circ$ & $c' = 25$ kPa
Stark et al. (2008)

- Stress dependent strength envelope
- $\phi' = 35^\circ$ & $c' = 6$ kPa ($\sigma' < 200$ kPa)
- $\phi' = 30^\circ$ & $c' = 30$ kPa ($\sigma' \geq 200$ kPa)

**Low Stresses**

- Normal Stress (kPa)
- Shear Stress (kPa)

<table>
<thead>
<tr>
<th>Normal Stress (kPa)</th>
<th>Shear Stress (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>200</td>
<td>146</td>
</tr>
<tr>
<td>500</td>
<td>319</td>
</tr>
</tbody>
</table>

**High Stresses**

- Recommended:
- $\sigma' < 200$ kPa, $c' = 6$ kPa, $\phi' = 35^\circ$
- $\sigma' = 200$ kPa, $c' = 30$ kPa, $\phi' = 30^\circ$

- Eid et al. (2000)
- Zekkos (2005)
• Stark et al. (2008)

Fresh MSW
- $c' = 6$ kPa, $\phi' = 35^\circ$ \hspace{1cm} $\sigma'_v < 200$ kPa
- $c' = 30$ kPa, $\phi' = 30^\circ$ \hspace{1cm} $\sigma'_v \geq 200$ kPa

After Recirculation
- $c' = 0$ kPa, $\phi' = 32^\circ$

After Thermal Degradation
- $c' = 0$ kPa, $\phi' = 20^\circ$
• Non-Circular Failure Surfaces
• 100 ft setback
Perched Leachate over LSW Zone

\[ F = \frac{c + \sigma_n'(\tan \phi)}{W \sin \beta} \]

\[ \sigma_n' = \sigma_n - u \]

\[ \sigma_n = (\gamma H)_{\text{waste}} \]

\[ u = \gamma_w H_w \]

\[ H_w = \text{Height of leachate} \]

\[ u = \gamma_{\text{gas}}^* H_{\text{gas}} = \text{Gas Pressure} \]
• Two Liquid Levels
• Two Liquid Levels
• As-Built Conditions
• Gas Pressure
• Convert gas pressure head to gas pressure
  \[ u = \gamma_{\text{gas}} \cdot H_{\text{gas}} \]
• \( \gamma_{\text{gas}} = 12.8 \text{ N/m}^3 \) (Thiel 1998)
• Apply constant pore pressure for gas
Stability Example with Liquid & Gas Pressures

- Stark et al. (2010)
- 3H:1V
- Slip surfaces through waste above perimeter berm
- Liner system assumed intact
- Berm shear strength: $\phi'=35^\circ$ and $c'=0$ kPa
Stability Example with Low Liquid Pressure

- Stark et al. (2010)
- Liquid level = Initial leachate level
- Computed FS
  - Eid et al. (2000) parameters - 3.3
  - Stark et al. (2008) parameters - 2.75
- Effect of stress dependent envelope ~ 0.55
• High leachate level
• Measured gas pressure head = 3 to 70 ft (21 m)
• Constant gas pressure = 12.8 N/m$^3$ *21 m ~ 270 N/m$^2$
• Computed FS
  • Eid et al. (2000) parameters - 1.5
  • Stark et al. (2008) parameters - 0.9
### Stability Example Summary

<table>
<thead>
<tr>
<th>MSW Strength</th>
<th>Liquid Level</th>
<th>Gas Pressure</th>
<th>Calculated Factor of Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(N/m²)</td>
<td>(Eid et al. 2000)</td>
</tr>
<tr>
<td>Not degraded</td>
<td>El. 327 m</td>
<td>0.0</td>
<td>3.3</td>
</tr>
<tr>
<td>Not degraded</td>
<td>El. 364 m</td>
<td>270</td>
<td>1.5</td>
</tr>
<tr>
<td>Thermally Degraded</td>
<td>Gas Wells</td>
<td>270</td>
<td>0.6</td>
</tr>
</tbody>
</table>

- Increased leachate and gas pressure can decrease stability
- Use stress dependent strength envelopes
• Case History
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TENSION CRACKS

Stark et al. (1998)
TENSION CRACKS

Stark et al. (1998)
Stark et al. (1998)
LINER SYSTEM MOVEMENT

Stark et al. (1998)
Observed cracking at slope crest on 5 August 1996

Stark et al. (1998)
MONITORING SUMMARY

- Settlement v. Tension cracks
  - Gas Well Equipment

- If cracks reappear, install:
  - tell-tales across cracks
  - survey monuments – include vertical

- Evaluate movement magnitude & rate
TOPICS

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INTERIM & FINAL SLOPES

- MAJORITY OF LANDFILLS ARE CONSTRUCTED AND OPERATED SAFELY
- Increased leachate and gas pressure can decrease stability


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With Australian Chapter of the Intl. Geosynthetics Society (ACIGS)

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