Slope Stability Evaluation of a Wet MSW Landfill Utilizing Cone Penetrometer Testing

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35-Acre Active Municipal Solid Waste (MSW) Landfill (10-Acres Previously Closed)

Approximately 650 tpd MSW and 80 to 100 tpd Municipal Sludge (±7:1 MSW to Sludge Ratio)
PROJECT BACKGROUND

- Lime-Stabilized High Water-Content Municipal Sludge
- Physically Mixed on the Working Face
- Not Deposited in Separate Layers or Trenches
- Sludge Represents a Significant Revenue Source for the Landfill
Gas Well Drilling:
The High Sludge Content Led to Seeps and Fluid Accumulating in Landfill Gas Wells…

- Reduced Recovery of LFG from Active Collection System (Issue for Developer)
- Observation of Fluid Levels in LFG Wells Over Time Showed Levels to Be Fairly Consistent
PROJECT CONCERNS

1) The Possibility of a Phreatic Surface Forming in the Waste Mass was a Concern for Slope Stability

2) How to Remove Waste Fluid to Enhance Gas Extraction Efficiency?
INITIAL OBSERVATIONS

• Measured Leachate Flow (Gravity) Suggested Collection System was Functioning as Designed (Some Flow from Seep Collection)

• Attempt to Camera-Inspect Leachate Lines for Excess Head was Limited by Configuration of Cleanouts

• No Visual Evidence of Instability Noted (Toe Bulging, Cracking Near Top of Slope, and/or Sloughing)

Landfill Thus Continued to Operate During Evaluation
Evaluation Tasks Included:

1) Initial Slope Stability Analysis

2) CPT Investigation in Waste Mass (Primarily to Evaluate Pore Pressures)

3) Final Slope Stability Analysis

4) Consideration of Dewatering Options
1) INITIAL SLOPE STABILITY ANALYSIS

• Completed Using STABL5M for Deep-Seated Failure Surfaces Through Waste Mass
  ▪ Block (Translation Along Liner)
  ▪ Circular

• Existing and Final Slopes Evaluated

• Phreatic Surface Assumed Based on Observations from LFG Wells
1) INITIAL SLOPE STABILITY ANALYSIS

### Material Properties:

<table>
<thead>
<tr>
<th></th>
<th>Perimeter Berms/Subgrade</th>
<th>Waste</th>
<th>Liner System</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unit Weight:</strong></td>
<td>100 pcf (moist); 110 pcf (saturated)</td>
<td>90 pcf (moist &amp; saturated)</td>
<td>100 pcf (moist &amp; saturated)</td>
</tr>
<tr>
<td><strong>Cohesion:</strong></td>
<td>100 psf</td>
<td>200 psf</td>
<td>0 psf</td>
</tr>
<tr>
<td><strong>Friction Angle (phi):</strong></td>
<td>25 degrees</td>
<td>25 degrees</td>
<td>21 degrees</td>
</tr>
</tbody>
</table>

**Assumptions**

<table>
<thead>
<tr>
<th></th>
<th>Perimeter Berms/Subgrade</th>
<th>Waste</th>
<th>Liner System</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unit Weight:</strong></td>
<td>Well compacted materials.</td>
<td>Wet MSW</td>
<td>Not critical; thin plane</td>
</tr>
<tr>
<td><strong>Shear Strength:</strong></td>
<td>Failure surfaces evaluated within the waste mass, these values are not critical to the evaluation</td>
<td>Weak Sludge Mixed with MSW</td>
<td>Conservative for geosynthetic / soil and geosynthetic / geosynthetic</td>
</tr>
</tbody>
</table>
1) INITIAL SLOPE STABILITY ANALYSIS

- Shear Strength ($\tau$) of Waste Mass is Related to 1) Normal Stress acting on Waste ($\sigma$), and 2) Strength parameters of Waste (friction angle $\phi$ and cohesion $c$):
  \[ \tau = (\sigma - \mu) \tan \phi + c \]

- As Pore Pressure ($\mu$) Increases, the Effect of Normal Stress ($\sigma$) is Reduced - Shear Strength Reduced
1) INITIAL SLOPE STABILITY ANALYSIS

Failures Elsewhere (Due to Pore Pressures):
In-Situ Soil Testing LC

1) INITIAL SLOPE STABILITY ANALYSIS - 2 SECTIONS

Figure 1 – Sections A and B

Slope Stability Cross Sections (Base Grades):

NOTES:
1. Grades shown represent Top of Soil Liner.

REFERENCES:
1. Site Topography Outside of Phase Limits provided by Draper Aden Associates, Date Unknown.
2. Topography Inside of Phase Limits (active areas) from Aerial Survey dated October 20, 2010 by Louisa Aerial Surveys, Inc., Mineral, VA.
Slope Stability
Cross Sections
(Final Grades):

Figure 1 – Sections A and B

Slope Stability Cross Sections
(Final Grades):
1) INITIAL SLOPE STABILITY ANALYSIS

Results:

- Factor of Safety (FS) ~ 1.0 with Phreatic Surface Modeled For Both Existing and Final Grades (Static Conditions) (Well Below Desired FS of 1.5) (Failure Potentially Imminent)

- CPT Needed to Verify if Phreatic Surface is Occurring in Waste Mass
2) CONE PENETROMETER TESTING (CPT)

1. Installation of Cone Tip Cavities and Placement of Pre-Saturated Porous Filter Element.
2. Obtain Baseline Readings for Tip, Sleeve, Porewater Transducer, & inclinometer Channels.

Cone Penetration Test (CPT) per ASTM D 5743 procedures

- $f_s = \text{sleeve friction}$
- $u_b = \text{porewater pressure}$
- $q_t = \text{measured tip stress or cone resistance}$
- $q_{t1} = \text{corrected tip stress} = q_t + (1-a_d)u_b$
- Continuous hydraulic push at 20 in/min; Add rod every 1 m

Electric Cone Penetrometer with 60° Apex
- $d = 38 \text{ mm} (10 \text{ cm})$
- $d = 44 \text{ mm} (15 \text{ cm})$

Cable to Cone Packer
In-Situ Soil Testing LC

2) CONE PENETROMETER TESTING (CPT)
2) CONE PENETROMETER TESTING (CPT)

- Six (6) Locations Selected Near Critical Cross Section from Initial Stability Analysis
- Survey Performed to Ensure that Probes Didn’t go Too Deep
- Probes Often Encountered Obstructions; Required Moving Probe and Re-testing
In-Situ Soil Testing LC

2) CONE PENETROMETER TESTING (CPT)

CPT DATA

DEPTH (ft)

0 10 20 30 40 50 60 70 80 90

TIP TSF 800 0

F s/Qr %

PRESSURE U2 F-I H2O 700 0

TEMP C

SOIL BEHAVIOR TYPE

Draper Aden Associates
Engineering • Surveying • Environmental Services
2) CONE PENETROMETER TESTING (CPT)

CPT Results:

- Pore Pressure does not Increase with Depth
- Phreatic Surface Not Identified
- Thin, Discrete Fluid Zones
- High Thermal Gradient Suggests Microbial Activity is High Supporting Gas Production
3) FINAL SLOPE STABILITY ANALYSIS

Using CPT Results:

- Initial Slope Stability Analysis Revisited – Removing the Phreatic Surface
- Desired Minimum FS:
  - 1.5 for Static Conditions
  - 1.0 for Seismic Conditions
Section A - Block Static

Safety Factors Are Calculated By The Modified Janbu Method
Section A - Circular Static

Safety Factors Are Calculated By The Modified Bishop Method
3) FINAL SLOPE STABILITY ANALYSIS

Results:

<table>
<thead>
<tr>
<th>Cross Section Analyzed (Condition)</th>
<th>Failure Type</th>
<th>Method of Analysis</th>
<th>Factor of Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Block Along Liner</td>
<td>Modified Janbu</td>
<td>1.51</td>
</tr>
<tr>
<td>A</td>
<td>Circular</td>
<td>Modified Bishop</td>
<td>1.63</td>
</tr>
<tr>
<td>B</td>
<td>Block Along Liner</td>
<td>Modified Janbu</td>
<td>1.76</td>
</tr>
<tr>
<td>B</td>
<td>Circular</td>
<td>Modified Bishop</td>
<td>1.96</td>
</tr>
</tbody>
</table>

Seismic coefficient = 0.5 x 0.09g = 0.05g
CONCLUSIONS

• Based on CPT Results – No Phreatic Surface in Waste

• Waste Mass Appears to be Stable

• Wet Conditions will Continue with Sludge Disposal

• Several Options Presented to Dewater Waste Mass (Pneumatic Pumps for LFG Wells; Drains for Seeps)
RECOMMENDATIONS
(For Landfills Accepting Sludge)

• Limit Proportion of Sludge (if Possible) (10:1 Ratio or More Should Minimize Potential Problems)

• Try to Mix Sludge with Waste as Much as Possible

• Exclude Sludge from Initial 1-2 Lifts in New Cells

• If Expecting Significant Sludge – Carefully Design Leachate Collection System (High Capacity, Cleanouts/Etc.)
THANK YOU!

For More Information:

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