Construction over Mine Spoil Fills

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Background

- Strip mining; mountaintop and contour mining
  - Creates huge quantities of mine spoil
  - The mine spoil is placed in adjacent valleys and over previously mined benches
  - This disposal and reclamation method results in large areas of flat land
  - Flat Land in Mountainous areas would appear to be valuable???

Valley fills Sites in the Area
Construction of a valley fill slope

In the mountains???

Primary Concerns when Developing on Mine Spoil Fill Sites

- Heterogeneous mix of durable and non-durable materials
- Settlement due to reduction in void space due to self-weight
- Degradation of non-durable rock (shale) within fill
- Settlement due to water infiltration
Past Problems
Appalachian Regional Hospital, Hazard, KY

- Multi-story portion is founded on drilled shafts.
- Single story portion founded on spread footings.
- The door pad was constructed flat, now it is sloping.
Objective of Exploration Program
• Reduce the Risk of Unknowns
• Develop a Reasonable Predictive Model (site to site basis based on material composition)
• Develop an estimation of settlement based on the model

Site 1
• 386 Acres
  • Mountaintop removal mining
  • Mined in the early 1980’s
  • Mined in the late 1980’s and early 90’s
  • Reclamation in early 1990’s
  • Mine spoil placed using end dumping methods; dump trucks and D9’s
  • The fill has been in place ranging from 10 years to 25 years
  • Fill depths of 40 to 60 feet on the benches and up to 250 feet in the valleys

Site 2
• 348 acres
• Underground and Mountaintop removal
• Underground mining from 1910 to 1944
• Surface Mining ended in mid 1990’s
• Reclamation in mid 1990’s
• Mine spoil placed using end dumping; dump trucks and D10’s
Site 3

- 6000 acres total
- Still an active mine
- Area of study; mountain top removal
- Mined in the mid 1990’s
- Mine spoil placed using dragline
- Subsurface conditions consist of limestone, sandstone, siltstone and shale spoil:
  - 150 to 160 feet

Site 4

- 6500 acres total
- Still an active mine
- Area of study; mountain top removal
- Mined in the early 1980’s and in the mid 1990’s
- Mine spoil placed using Marion 8050 dragline
- Subsurface conditions consist of sandstone and shale

Site Characterization Methods

- Exploratory Borings
- Shallow Test pits
- Geophysics
  - Seismic Refraction
  - Cost effective v. numerous borings
  - Can delineate bedrock surface by measuring P-wave velocities
- Instrumentation
  - Settlement Plates
  - Extensometers

Bedrock defined as Vs > 5000 ft/sec
Interpretation of Refraction Data, Site 2

Estimate of Bench Location

Isometric Interpretation of Rock Surface

Geophysical Summary

- Seismic Refraction worked well in delineating the old mine bench
- Confirmatory borings verified the findings of the seismic refraction data

Hazard Site – Seismic Refraction
Comparison of penetration resistances from three different sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Mean N-value</th>
<th>Median N-value</th>
<th>Standard Deviation</th>
<th>Minimum N-value</th>
<th>Maximum N-value</th>
<th>Number of samples</th>
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</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>26.8</td>
<td>21</td>
<td>16.3</td>
<td>33</td>
<td>87</td>
<td>127</td>
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<tr>
<td>Site 2</td>
<td>27.5</td>
<td>22</td>
<td>18</td>
<td>2</td>
<td>70</td>
<td>237</td>
</tr>
<tr>
<td>Site 3</td>
<td>26</td>
<td>20</td>
<td>23</td>
<td>2</td>
<td>100</td>
<td>727</td>
</tr>
</tbody>
</table>

Seismic Refraction Testing

Interpretation of Seismic Refraction Velocities to Material Type (International Building Code)

<table>
<thead>
<tr>
<th>Material Description</th>
<th>Shear Wave Velocity, Vs, ft/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard Rock</td>
<td>&gt; 5000</td>
</tr>
<tr>
<td>Rock</td>
<td>2500 &lt; Vs &lt; 5000</td>
</tr>
<tr>
<td>Very Dense Soil and Soft Rock</td>
<td>1200 &lt; Vs &lt; 2500</td>
</tr>
<tr>
<td>Stiff Soil</td>
<td>600 &lt; Vs &lt; 1200</td>
</tr>
<tr>
<td>Soft Soil</td>
<td>Vs &lt; 600</td>
</tr>
</tbody>
</table>
Typical Mine Spoil parameters - Vince

<table>
<thead>
<tr>
<th>Type</th>
<th>Soil Moisture</th>
<th>Wet Unit Weight</th>
<th>Total/Effective Angle of Internal Friction</th>
<th>Total Cohesion</th>
<th>Effective Cohesion</th>
<th>Plasticity Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>13 to 37</td>
<td>86 to 109</td>
<td>0 to 10 / 24</td>
<td>100</td>
<td>200</td>
<td>20</td>
</tr>
<tr>
<td>Loam</td>
<td>12 to 30</td>
<td>96 to 105</td>
<td>5 / 19</td>
<td>800</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>Mixed</td>
<td>9 to 19</td>
<td>82 to 124</td>
<td>4 to 30 / 27</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Rock</td>
<td>5 to 15</td>
<td>90 to 119</td>
<td>27 to 32</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Typical Extensometer Data

West VA site – Inclinometer Readings
Analyses of Settlement Data

- Initial compression of unsaturated mine spoil fills occur in a similar manner to the consolidation process of clays, with an initial short term period of large settlement.

- Secondary compression of unsaturated mine spoil consists of crushing of the rock point contacts.

- Evaluated data based on end dumped and dragline dumped.
Are we done?
• Water infiltration

Hydrocompression on Settlement
Site Preparation, extensive subsurface exploration, carefully monitored site work: undercut 10 feet and recompacted to 95% of standard Proctor using Cat 825 rollers

Building Pad
Building Information - 1

- 180,000 square feet, Spread footing foundations, steel framed metal sided, concrete slab on grade.
- Roof rain collected to gutters at front and rear of building.
- Front lawn are flat, no positive drainage.
- Construction completed in summer 2002.
- Cracking noticed in winter/spring 2003.

Settlement Crack above Doorway

Differential Level Survey of Floor Slab

- Differential settlement up to 8 inches on portions of the floor slab.
- Topo of floor slab from March 2003 to September 2004.
Water ponded next to building

Site Observations
- Area of most severe settlement grass covered and very flat with no slope for runoff
- Some areas of lawn sloped toward building
- Evidence of gutter overflow; staining on sides of building
- Small diameter conduits in the mine spoil just outside building walls
- Settlement confined to exterior walls
- Less than 1 inch of settlement observed from extensometers
- Borings drilled to confirm the presence of the bench as determined by the seismic refraction data.
- Found generally uniform thickness of mine spoil over the bench
Findings
• Settlement essentially stopped by the March 2004 survey
• Based on the area of flat lawn, about 2 million gallons of water infiltrated the mine spoil fill adjacent to the building
• Borings found the top 10 feet of mine spoil soft and wet
• Water flow through mine spoil considered pseudokarst.
• Slaking of the shale portion of the spoil creates a “crusting” of the surface over time.
• Construction/site development destroys this crust allowing water infiltration

Building 2 – Theater in WV

Observations and Findings
• Site was relatively flat
• Site drainage to the rear of building along ditch at base of mountain
• Spring at various locations
• Storm Drainage not sloped enough
• Water entered subsurface through inadequate storm drains
• (18 inch diameter culvert v. 3 – 6 inch culverts)
Site 3 – Coal Processing Facility

Site 3 – loading tower

Relationship between unit weight and Hydrocompression - Laboratory
Proposed Hydrocompression Testing (I want to do this)

- Excavate and recompact area to a depth
- Install extensometers
- Construct footings
- Flood site
- Measure movement

Factors Affecting the Magnitudes of Settlement

- Based on the results of this research the following factors affect settlement
- Placement methods
- Age of fill
- Composition of fill
- Thickness of fill
- Water infiltration/hydroconsolidation

Site Development/Remediation Methods

- Past failures resulted in very conservative site remediation methods
- Most common methods
  - Mass undercut and replacement
  - Dynamic Compaction
  - Deep Foundations
  - Surcharge/Preloading
Dynamic Compaction
  • Deep Dynamic Compaction

Mine Spoil Fill
  • Pipe pile installation

Mine Spoil Fill – Coal Fields
  • Rebar in Mat Foundation at Call Facility
Comparing Costs of Options including using the Reasonable Predictive Model

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option 1</td>
<td>Deep Dynamic Compaction</td>
<td>$1,928,750</td>
</tr>
<tr>
<td>Option 2</td>
<td>Undercut 10 feet and Replace</td>
<td>$1,577,500</td>
</tr>
<tr>
<td>Option 3</td>
<td>Deep Foundations</td>
<td>$2,768,800</td>
</tr>
<tr>
<td>Option 4</td>
<td>Preloading</td>
<td>$3,340,700</td>
</tr>
<tr>
<td>Option 5</td>
<td>Enhanced Undercut and Replacement</td>
<td>$1,185,500</td>
</tr>
</tbody>
</table>

Benefit of Using Exploration Program

- Savings for site development costs without increasing level of risk
- However, predictive model does not account for hydrocompression.

Summary – if you feel lucky

- Settlement of end dumped mine spoil fills of less than 100 feet can be within tolerable ranges about 10 years after placement (reclamation)
- The depth of fill beneath the development can vary up to 20% without additional risk
- Positive drainage to prevent hydrocompression is critical to minimizing detrimental settlement