GEOTECHNICAL CHALLENGES OF THE LEWISTOWN NARROWS RECONSTRUCTION

GTS TECHNOLOGIES, INC.
BRENT J. BASOM, P.E. AND DANIEL S. RAMER, P.E.
This $104.36 million contract for Section A09 is the second largest single construction contract that PennDOT has ever awarded. Given the unique geotechnical features and traffic challenges, the project also is one of our most complex.”

George Khoury, P.E
2-0 District Engineer
PROJECT OVERVIEW

• 3 Construction Sections
  • A09 - $104.4m Narrows Reconstruction
    » 6.5 miles
    » 2 bridges, 3 culverts
    » 2 MSE walls (15,000 lf), 9 CIP walls (7500 lf)
    » 2.8m CY of earthwork
  • A10 – $12.7m Arch Rock Interchange Reconstruction
    » Full diamond construction
    » 3 bridges, 2 culverts
  • A11 – $17.7m SR 22/SR 322 Interchange
    » 1 bridge, 2 MSE walls
    » 360 rock anchors
    » 380,000 CY earthwork
GEOLOGIC CROSS SECTION
through the Lewistown Narrows
(looking east)

Legend
St - Tuscarora Formation  Ob - Beekmantown Group
Sc - Rose Hill Formation  Or - Reedsville Formation
Oj - Juniata Formation
SUBSURFACE CONDITIONS

BOR. NO. M-248
Sta. 246+00
Offset: 42' L
EL. 460.3

BOR. NO. M-249
Sta. 246+00
Offset: CL
EL. 461.5

BOR. NO. M-250
Sta. 246+00
Offset: 65' R
EL. 446.8

246+00
SUBSURFACE INVESTIGATIONS

- 850+ borings
- 35+ piezometers
- 8 inclinometers
- Geophysical investigations
  - VLF Resistivity
  - Seismic Refraction
  - Ground Penetrating Radar
- Utilized borings from previous design
SUBSURFACE INVESTIGATIONS
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GEOTECHNICAL CHALLENGES

• Stability of talus slopes
• Stability of bifurcation construction
• Talus rockfall and construction
• Reinforced soil slope design
• Instrumentation program
• Rock anchor design
TYPICAL SOIL CUT XS

532.00
CL. 2 EXC. = 64 S.F.

BLANKET DRAIN
CL. 1 EXC. = 273 S.F.

414+50

PAVT. REMOVAL = 56 S.F.
TYPICAL BIFURCATION XS

194+50
TYPICAL BIFURCATION XS

206+00

ELEV = 438.5

-0.5% --->
TALUS STABILITY
TALUS STABILITY
TALUS STABILITY

S.R. 0022, SECTION A09, STATION 254+00 PROPOSED CONDITIONS, WL#1, BLOCK SRCH B

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Soil No.</th>
<th>Total Unit Wt (pcf)</th>
<th>Saturation Unit Wt (pcf)</th>
<th>Cohesion (kPa)</th>
<th>Internal Friction Angle (deg)</th>
<th>Plotted Plane No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>FILL</td>
<td>1</td>
<td>120.0</td>
<td>125.0</td>
<td>0.0</td>
<td>32.0</td>
<td>W1</td>
</tr>
<tr>
<td>TALUS</td>
<td>2</td>
<td>140.0</td>
<td>140.0</td>
<td>0.0</td>
<td>40.0</td>
<td>W1</td>
</tr>
<tr>
<td>RESIDUAL</td>
<td>3</td>
<td>150.0</td>
<td>152.0</td>
<td>0.0</td>
<td>30.0</td>
<td>W1</td>
</tr>
<tr>
<td>SHALE</td>
<td>4</td>
<td>150.0</td>
<td>150.0</td>
<td>500.0</td>
<td>45.0</td>
<td>W1</td>
</tr>
</tbody>
</table>

Preconstruction Minimum Factor of Safety = 1.3
Post Construction Minimum Factor of Safety = 1.6

Safety Factors Are Calculated By The Modified Janbu Method
# TALUS STABILITY ANALYSES

<table>
<thead>
<tr>
<th>Station</th>
<th>SF&lt;sub&gt;existing&lt;/sub&gt;</th>
<th>SF&lt;sub&gt;proposed&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>188+00</td>
<td>1.2</td>
<td>1.4</td>
</tr>
<tr>
<td>192+00</td>
<td>1.1</td>
<td>1.7</td>
</tr>
<tr>
<td>196+00</td>
<td>1.3</td>
<td>1.6</td>
</tr>
<tr>
<td>212+00</td>
<td>1.8</td>
<td>1.9</td>
</tr>
<tr>
<td>238+00</td>
<td>1.2</td>
<td>1.3</td>
</tr>
<tr>
<td>254+00</td>
<td>1.3</td>
<td>1.6</td>
</tr>
<tr>
<td>274+00</td>
<td>1.3</td>
<td>1.7</td>
</tr>
</tbody>
</table>
TALUS STABILITY CONCLUSIONS

• Proposed construction increases SF, with overall SF>1.3.
• No recorded slides or slope movement, through flood events and excavations into talus.
• Based on recent history the talus is in a state of equilibrium.
• No economically feasible methods exist to stabilize the mountain slopes. Therefore SF = 1.3 is acceptable.
• Do not allow excavations into talus slopes.
BIFURCATION CONSTRUCTION
PHASING

PHASE 2

PHASE 3

PHASE 1

194+00
BIFURCATION FAILURE MODES

- Shallow Circle
- MSE Circle
- Deep Circle
- Eastbound Block
- Sliver Block
- MSE Block
- Full Block
• Target safety factor
  • Phase 1 and 2, SF = 1.3
  • Phase 3 SF = 1.5
• Water Levels – No water and critical flood elevation
• Traffic surcharge iterations
• Soil vertically supported by wall footing does not contribute to driving or resistance of failure mass
## REJECTED REMEDIATION OPTIONS

### REDUCE DRIVING FORCES

<table>
<thead>
<tr>
<th>Option</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construct median northbound lanes of bifurcation with lightweight fill.</td>
<td>Rejected due to cost of fill and also stability concerns still existed.</td>
</tr>
<tr>
<td>Lower westbound grades to improve stability.</td>
<td>Performed to the extent possible.</td>
</tr>
<tr>
<td>Support westbound lanes on viaduct.</td>
<td>Rejected due to cost, schedule and also stability concerns still existed to some extent.</td>
</tr>
</tbody>
</table>
# REJECTED REMEDIATION OPTIONS

## INCREASE RESISTING FORCES

<table>
<thead>
<tr>
<th>Option</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construct MSE river wall to increase resisting force.</td>
<td>Rejected due to scour and erosion concerns of wall adjacent to river.</td>
</tr>
<tr>
<td>Utilize tiebacks to provide resisting forces.</td>
<td>Rejected as tiebacks will extend though and be bonded in questionable material. Concerns with longevity.</td>
</tr>
<tr>
<td>Use rear row of retaining wall piles to provide resistance.</td>
<td>Would need to predrill and socket all piles. Could only provide 30 k/lf resistance. Don’t allow global stability loads to reach walls.</td>
</tr>
</tbody>
</table>
REMEDIATION TS&L

- System of discrete vertical elements designed to resist the driving forces through bending and shear of the element.
  - Steel H-piles socketed into bedrock
  - Micro-piles drilled into bedrock
  - Drilled Shafts socketed into bedrock
- Piles located 5 feet behind the heel of the retaining wall. Will not allow loads to transfer to wall.
### SELECTED REMEDIATION OPTION

<table>
<thead>
<tr>
<th>Option</th>
<th>Structural Resistance (k/lf)</th>
<th>Total Cost</th>
<th>Production Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>14” H-piles</td>
<td>200</td>
<td>$20 m</td>
<td>2/day</td>
</tr>
<tr>
<td>7” Micro-piles</td>
<td>100</td>
<td>$14 m</td>
<td>8/day</td>
</tr>
</tbody>
</table>
• Retaining wall does not contribute to the stability of the slope (i.e. neglect all soil in front of the wall).
• Model the necessary resisting force as a 1 foot wide cohesive strip extending through bedrock.
• Adjust the cohesion of the strip to obtain the target safety factor.
## ANALYSIS RESULTS

<table>
<thead>
<tr>
<th>Failure Surface</th>
<th>Critical WSEL</th>
<th>Original F.S.</th>
<th>Pile Location from CL</th>
<th>Required Remediation Pile Force (kfl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow Circle</td>
<td>Normal</td>
<td>1.17</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>BFE</td>
<td>1.13</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Block</td>
<td>Normal</td>
<td>1.53</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>BFE</td>
<td>1.56</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

### STA 266 Phase 2 - Target F.S. = 1.3

<table>
<thead>
<tr>
<th>Failure Surface</th>
<th>Critical WSEL</th>
<th>Original F.S.</th>
<th>Pile-1 Location from CL</th>
<th>Required Pile-1 Force (kfl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow Circle</td>
<td>intermed.</td>
<td>0.91</td>
<td>34'R</td>
<td>11.3</td>
</tr>
<tr>
<td></td>
<td>No Water</td>
<td>1.46</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>MSE Circle</td>
<td>100 YR</td>
<td>1.33*</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>No Water</td>
<td>1.43</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Deep Circle</td>
<td>intermed.</td>
<td>1.22</td>
<td>34'R</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>No Water</td>
<td>1.64</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Block</td>
<td>intermed.</td>
<td>1.13</td>
<td>34'R</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>No Water</td>
<td>1.41</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

### STA 266 Phase 3 - Target F.S. = 1.6

<table>
<thead>
<tr>
<th>Failure Surface</th>
<th>Critical WSEL</th>
<th>Original F.S.</th>
<th>Pile-1 Location from CL</th>
<th>Required Pile-1 Force (kfl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow Circle</td>
<td>intermed.</td>
<td>0.84</td>
<td>34'R</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>No Water</td>
<td>1.18</td>
<td>34'R</td>
<td>22</td>
</tr>
<tr>
<td>&quot;Artificial&quot; Shallow Circle</td>
<td>intermed.</td>
<td>0.83</td>
<td>34'R</td>
<td>14.5</td>
</tr>
<tr>
<td></td>
<td>No Water</td>
<td>1.18</td>
<td>N/A</td>
<td>13</td>
</tr>
<tr>
<td>MSE Circle</td>
<td>100 YR</td>
<td>1.91</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>No Water</td>
<td>2.18</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Deep Circle</td>
<td>100 YR</td>
<td>1.33</td>
<td>34'R</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>No Water</td>
<td>1.57</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>&quot;Artificial&quot; Deep Circle</td>
<td>100 YR</td>
<td>1.32</td>
<td>34'R</td>
<td>18</td>
</tr>
<tr>
<td>East Bound Block</td>
<td>intermed.</td>
<td>1.14</td>
<td>34'R</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>No Water</td>
<td>1.60</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Block</td>
<td>intermed.</td>
<td>1.11</td>
<td>34'R</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>No Water</td>
<td>1.38</td>
<td>N/A</td>
<td>44</td>
</tr>
</tbody>
</table>

1) Artificial Shallow and Deep Circles were analyzed to force critical and/or L2M material.
N/A - Not Applicable

*= Strap lengths were extended 2’ to provide appropriate F.S.*
### ANALYSIS RESULTS

#### Table: Unit Weights (pcf) and Subgrade Modulus (pci)

<table>
<thead>
<tr>
<th>Soil Properties</th>
<th>Dry</th>
<th>Sat.</th>
<th>Friction Angle</th>
<th>Dry</th>
<th>Sat.</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMB FILL</td>
<td>120</td>
<td>125</td>
<td>32</td>
<td>130</td>
<td>90</td>
</tr>
<tr>
<td>SFT PCKT</td>
<td>110</td>
<td>115</td>
<td>26</td>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>L2M COLL</td>
<td>120</td>
<td>125</td>
<td>30</td>
<td>120</td>
<td>80</td>
</tr>
<tr>
<td>M2D COLL</td>
<td>125</td>
<td>130</td>
<td>38</td>
<td>275</td>
<td>175</td>
</tr>
<tr>
<td>SH ROCK</td>
<td>140</td>
<td>145</td>
<td>45</td>
<td>600</td>
<td>500</td>
</tr>
</tbody>
</table>

---

Phase No.: 3

**Pile-1 (37’ R of CL)**
- 35’ from Sub to TOR

**Pile-2 (5’ R of CL)**
- 26’ from Sub to TOR

- EMB Fill
- L2M Coll
- M2D Coll
- SH Rock

**Notes:****
- Forced Shallow Circle Failure Surface (WL=26’)
- Forced Deep Circle Failure Surface (WL=35’)
- Shallow Circle Failure Surface 2’ above TOR (WL=26’)
- Deep Circle Failure Surface 1’ above TOR (WL=26’)
- Block Failure Surface (WL=26’)

BFE: 19’
BIFURCATION STABILITY

CONCLUSIONS

• Eastbound and Full Block failures typically resulted in a load of 60 to 100 k/lf.
• Shallow circles and full circles typically resulted in a load of 20 to 40 k/lf.
• MSE circles and MSE Blocks occurred in isolated areas (10 to 20 k/lf) requiring an occasional second row of piles at the median.
MICRO-PILE DESIGN

- Designed as a shear pin, holding a block on an inclined plane. Considered shear and deflection in design.
- Limited deflection to 1”.
- Used 7” pipe due to availability.
- Analyses showed a 4 foot embedment into rock was required, specified 6 feet due to variable nature of rock.
- Typical spacing of piles was 1’ to 2’, constructed in a staggered (sawtooth) pattern.
- Final plans included 230,000 lf (42 miles) of micro-piles, bid at $19,000,000 for the entire project.
STABILITY ANALYSIS FAST FACTS

• (7 failure types) x (2 phases) x (2 water levels) x (2 pile options) 
  = 56 possible failure analyses per station.
• (2 failure types) x (2 water levels) x (2 pile options) 
  = 8 possible phase 1 analyses per station.
• Analyzed 84 stations for walls only (100 to 200 foot intervals)
• Estimated total number of stability runs performed over the life of the project????

450,000?
TALUS CONSIDERATIONS

- Phase 1 - Remediation of talus rockfall during construction.
- Phase 2 - Construction of embankment over talus.
- Phase 2 and 3 - Permanent talus rockfall protection.
PHASE 1 REMEDIATION

• Pre-Construction Remediation
  • Removal
  • Buttressing
  • Flowable fill

• Phase 1 Temporary Rockfall Protection
  • Protect traffic during phase 1.
  • Fence to be designed by contractor to withstand force of 10,000 ft lbs, with a height of 10 feet.
  • Vibration monitoring to ensure no vibration induced rockfall.
EMBANKMENT OVER TALUS

- 32" double faced jersey barrier
- Proposed grade
- Flowable backfill and choking aggregate
- Open talus slope
- Existing ground

TALUS CHOKING
NOT TO SCALE
PHASE 2 REMEDIATION

• Traffic will be protected by the buffer zone created by the WB lanes and the MSE wall.
• Permanent remediation of all talus problems.
  • Removal
  • Buttressing
  • Flowable Fill
  • Rock bolts and anchors
  • Netting and tiedowns
PERMANENT ROCKFALL PROTECTION

- Required for slopes steeper than 1.5:1.
- Combination design using CRSP and Ritchie ditch design.
- 9’ deep by 20’ wide V-ditch.
- 8’ high soldier beam rockfall fence where ditch is inadequate.
TEMPORARY REINFORCED SOIL SLOPE (RSS)
RSS DESIGN

- Global Stability
  - External
  - Internal
  - Compound
- Include contribution of MSE wall as a surcharge.
- Iterate geogrid strength to achieve target safety factor.
RSS DESIGN

- Sliding stability
- Excavation stability
  - Placement length of straps.
  - Do not allow excavations.
- Remediation – extend straps or provide piles
- Construction traffic and damage
- Piezometers
- Inclinometers
  - In-Place
  - Standard
- Strain Gauges
- Real time monitoring and remote processing
VIBRATION MONITORING

• Reduce vibration induced rockfall
• Origin of vibrations
  • Micro-piles
  • H-piles and predrilling
  • Embankment placement
• Preliminary threshold
• Remedial actions
ROCK ANCHORS

BEGIN 6" PAVT, BASE DRAIN, RT.
AT STA. 25+11.00 RT., OUTLET TO INLET
DRAIN OUTLET 16 LF.

BOR. NO. M-52
Sto. 25+06 (RAMP B)
Offset=6' R
587.9

BOR. NO. M-53
Sto. 25+03 (RAMP B)
Offset=8' R
568.7

STA. 25+00, RT.
TYPE D ENOWALL
INV. ELEV.=667.5

3' ROUNING

TOR

APPROXIMATE
BEDROCK DIP

25+00
ROCK ANCHOR DESIGN

• Design cut slopes up to 1H:1V
• Design loading = 240 k
• 360 anchors
  • 10’ c/c grid pattern
  • 2 to 4 rows of anchors
• Temporary excavations in rock for abutment and temporary roadway
ROCK ANCHORS
ROCK ANCHORS