A Cost Effective and Context Sensitive Design for Stabilization of a 40-Years-Old Landslide

KHALID T. MOHAMED, P.E., PMP
FHWA, WASHINGTON, DC

BRIAN LAWRENCE, P.E.
FHWA, AUGUSTA, ME

THOMAS SHIFFLET, P.E., LS, PMP
FHWA, STERLING, VA
OUTLINE

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• Landslide History
• Site Geologic Settings
• Subsurface Field Exploration
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• Slide Repair Options *(Value Analysis)*
• Design Analysis
• Construction
• Performance
INTRODUCTION

• Project is Located at MP 270.3 on the Blue Ridge Parkway in Wilkes County, NC

• The Blue Ridge Pkwy is 469-mile Long National Scenic By-way Along the Crests of The Southern Appalachians

• Parkway Construction Started in 1935 and Completed in 1987
LANDSLIDE HISTORY

• A Landslide at MP 270.3 was First Reported in the Early 1970s By NPS Maintenance Staff.

• It is Possible that the Slide Movement Started Years Earlier.

• The Settled Section of the Parkway was Initially Overlaid with AC to Bring The Roadway Back Up to Grade.
LANDSLIDE HISTORY

• **1978** - First Round of Corrective Measures Consisted of Installing 17 *Horizontal Drain* Pipes and Removing the Upper 3 to 4 Feet.

• **1981** - After Observing Continued Slide Movement Additional *Horizontal Drains (5)* were Installed.

• **1983** – Movement was Observed and **18 Horizontal Drains** 60 to 150 ft long were Installed
LANDSLIDE HISTORY

• 1988/89 – Slide Was Reactivated and a series of Vertical Rock-filled Drainage Columns were Installed.

• 1991 – Stabilization Measure consisted of **Installing 3 ft diameter Draw Down Wells** filled with No. 5 and 57 Stone to a maximum depth of approximately 65 ft.
LANDSLIDE HISTORY

• 1988/89 – Slide Was Reactivated and a series of Vertical Rock-filled Drainage Columns were Installed.

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3 ft. Dia Draw Down Wells

Horizontal Drain Pipes
## Blue Ridge Parkway Milepost 270.3

### Slope Indicator Results

- **1988/89** – Slide Was Reactivated and a series of Vertical Rock-filled Drainage Columns were Installed.
- **1991** – Stabilization Measure consisted of Installing 3 ft diameter Draw Down Wells filled with No. 5 and 57 Stone to a maximum depth of approximately 65 ft.

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**Indicator Pipe #1**  
Station 10+75  
18' Right of Centerline

**Indicator Pipe #2**  
Station 10+75  
14' Left of Centerline
LANDSLIDE HISTORY

• **1995** – Slide was Reactivated With Additional Settlement of up to *5 Inches in 2 Years* were Measured.

• **1997-2000** – Monitoring of Slide Continued. Consistent Water Flow Observed from 4 of the 16 Horizontal Drains
SITE GEOLOGIC SETTINGS

• The Landslide Site is Located within the Blue Ridge Belt.

• The Project Site is Predominantly Underlain by Finely Laminated to Thinly-layered Gneiss of the Alligator Back Formation.

• This Deposit Locally Contains Massive Gneiss and Micaceous Granule Conglomeration, Including Schist, Phyllite and Amphibolite.

“Geologic Map of North Carolina (1985)”
The Subsurface Exploration Program at the Landslide Site Consisted of the following:

- Subsurface Investigation Records **Prior to 1990** were **Not Available**

- **C-Series** Borings (5 Borings) Drilled During July 1990 by EFLHD.

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- Subsurface Investigation Records *Prior to 1990* were not available.
- **C-Series** Borings (5 Borings) Drilled During July 1990 by EFLHD.
- **FD-Series** Borings (12 Borings) Drilled During February 1991 by Froeling & Robertson, Inc.
SUBSURFACE FIELD EXPLORATION

- **B270-Series** Borings (4 Borings) Drilled During July 1997 by EFLHD.
- **B-Series** Borings (3 Borings) Drilled During May 2003 by EFLHD.
- **Seismic Survey** Several Lines were surveyed.
SUBSURFACE FIELD

- **B270-Series** Borings (4 Borings) Drilled During July 1997 by EFLHD.
- **B-Series** Borings (3 Borings) Drilled During May 2003 by EFLHD.
- **Seismic Survey** Several Lines were surveyed.
SUBSURFACE FINDINGS

(0-20) **Fill** – Very loose to medium dense, brown fine sand with silt and traces gravel and boulders

(20-35) **Colluvium** – Loose to dense, light brown sand, some weathered rock fragments, trace mica

(35-40) **Silt & Sand** – Very Loose to very dense, brown silt and sand with traces mica
SUBSURFACE FINDINGS

(40-44) *Highly Weathered Rock* – Medium dense to dense, light gray and brown, Schist and sandstone.

(44-75) *Bedrock* – Fine to medium textured mica Schist or Sandstone, highly jointed to sound. (RQD = 50% to 100%)
SEISMIC SURVEY RESULTS

- **3D Tomography** shows a valley into the bottom bedrock filled with soft material that deepens towards the southern end of the slide.
GROUND WATER

- Groundwater was encountered in a number of borings at depths varying from 15 to 59.5 feet.

- Drainage system appears to have lowered groundwater, but site continued to collect water.

- The site topography and subsurface soil and rock conditions appear to have contributed to concentration of water at this location.
Wet, Very loose to Loose Material was Encountered at the Interface Between Overburden Material and Bedrock
Wet Zone

Wet, Very loose to Loose Material was Encountered at the Interface Between Overburden Material and Bedrock.
**LABORATORY TESTING**

<table>
<thead>
<tr>
<th>Boring No.</th>
<th>Sample Depth (ft)</th>
<th>Unconfined Compressive Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-1</td>
<td>44.0</td>
<td>6220</td>
</tr>
<tr>
<td>B-1</td>
<td>46.3</td>
<td>2770</td>
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<tr>
<td>B-2</td>
<td>50.2</td>
<td>5180</td>
</tr>
<tr>
<td>B-2</td>
<td>53.6</td>
<td>4980</td>
</tr>
<tr>
<td>B-2</td>
<td>57.6</td>
<td>1560</td>
</tr>
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</table>
## SLIDE REPAIR OPTIONS (Value Analysis Study, (VA))

<table>
<thead>
<tr>
<th>Option</th>
<th>Disturbance Area</th>
<th>Lane Closure</th>
<th>Construction Cost</th>
<th>Construction Seasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Realignment with Retaining Walls</td>
<td>0.64 Acre</td>
<td>1</td>
<td>$5.9 millions</td>
<td>1</td>
</tr>
<tr>
<td>Anchors with Blocks</td>
<td>0.78 Acre</td>
<td>2 (full)</td>
<td>$2.5 millions</td>
<td>1</td>
</tr>
<tr>
<td>Bridge</td>
<td>0.33 Acre</td>
<td>1</td>
<td>$4.0 millions</td>
<td>2</td>
</tr>
</tbody>
</table>
## DESIGN ANALYSIS

<table>
<thead>
<tr>
<th>Material type</th>
<th>Unit Weight, $\Gamma$ (lb/ft$^3$)</th>
<th>Friction Angle, $\phi$</th>
<th>Cohesion, $C$ (lb/ft$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FILL</td>
<td>115</td>
<td>30</td>
<td>--</td>
</tr>
<tr>
<td>Colluvium</td>
<td>120</td>
<td>32</td>
<td>--</td>
</tr>
<tr>
<td>Saprolite</td>
<td>125</td>
<td>25</td>
<td>00</td>
</tr>
<tr>
<td>Weathered rock</td>
<td>130</td>
<td>36</td>
<td>--</td>
</tr>
<tr>
<td>Bedrock</td>
<td>145</td>
<td>30</td>
<td>80,000</td>
</tr>
</tbody>
</table>
DESIGN ANALYSIS

- Soil and Rock Strength Properties were Developed Based on Correlations with SPT Values, laboratory test results and seismic survey results.

- Back Analyses (Pending Failure) were Performed to Confirm and Refine developed strength properties.
A Design Anchor Grid Pattern was Developed with Anchors at 20 ft c/c.

Site was Divided into Zones to Optimize Design (Anchor Length) and Reduce Cost.

Anchor Bond Length was 27 ft. Total Length varied from 55 to 110 ft Depending on Zone.

Total Contracted Anchors Length was 8,000 LNFT.

Calculated Safety Factor (1.46) Improvement For This Zone Based on Anchor Installation
A Design Anchor Grid Pattern was Developed with Anchors at 20 ft. The site was divided into zones to optimize design (anchor length) and reduce cost. The anchor bond length was 27 ft. The total length varied from 55 to 110 ft depending on the zone. The total contracted anchors length was 8,000 LNFT. Calculated safety factor (1.46) for this zone based on anchor installation.
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Calculated Safety Factor (1.46) Improvement For This Zone Based on Anchor Installation.
CONSTRUCTION PROGRESS AND CONCERNS

- Initial Site Stabilization and Access.
- New slide Movement and Cracks Developed Near Embankment Top at Beginning of Construction!
- Artesian Water Flow During Drilling for Anchors.
- Piezometers and Inclinometers were Installed for Monitoring Of Slide During and After Construction.
CONSTRUCTION PROGRESS AND CONCERNS

- Anchor Installation; Top and Bottom Rows
- Performance Tests
EMBANKMENT PERFORMANCE

2 Years After End of Construction

Looking North

* Looking South
CONCLUSION

- Careful Evaluation of Site topography, subsurface conditions, and ground and surface water Conditions is Essential for Successful Performance

✓ (Subsurface Drainage for Slope Stabilization Webinars (WA-RD 787.1)).

- This Site Can be Considered as an Asset for the National Parks Service (NPS) Along This Corridor?

- Elements of a Geohazards Program?
Thank You

Questions?