ROCK SLOPE INVESTIGATION ALONG US 340 NEAR HARPER’S FERRY, WEST VIRGINIA

Harper’s Ferry, Jefferson County, WV

18th Annual Technical Forum for Geohazards Impacting Transportation
In the Appalachian Region
August 7th – 9th, 2018
Baltimore, MD

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WV Division of Highways, Charleston, WV
SCOPE OF WORK OVERVIEW:

Phase 1 (Preliminary Engineering):
- Perform Lower and Upper Slope Investigations
- Evaluate Feasible Rockfall Protection and Stabilization Options
- Perform Preliminary Design of Options
- Develop Preliminary Cost Estimates

Phase 2 (Final Design):
- Perform Final Design of Selected Options
- Prepare Slope Remediation Plans for Construction
PHASE I DETAILED SCOPE OF WORK:

• Complete Aerial and Mobile LiDAR Mapping
• Review of Existing Geologic Information
• Complete Road-Level Field Investigation
• Complete Upper-Slope Field Investigation, Including 22-Mile Detour
• Complete Rockfall (CRSP), Kinematic, and Global Stability Analyses
• Perform Relative Risk Analyses
• Evaluate and Develop Preliminary Designs for Three (3) Feasible Rock Slope Remediation Options
• Prepare Preliminary Construction Cost Estimates (30% Design)
• Reporting
PROJECT LOCATION
PROJECT LOCATION MAP:

Hagerstown, MD

Martinsburg, WV

Frederick, MD

Harper’s Ferry

Baltimore

60 Miles

Harper’s Ferry

Baltimore

60 Miles

PROJECT LOCATION MAP:

Hagerstown, MD

Martinsburg, WV

Frederick, MD

Harper’s Ferry

Baltimore

60 Miles

Harper’s Ferry

Baltimore

60 Miles

ROCK SLOPE INVESTIGATION ALONG US 340 NEAR HARPER’S FERRY, WV

2018 Geohazards Technical Forum, Baltimore, MD, August 7th – 9th, 2018
PROJECT VICINITY MAP:

Approximate Limits of Work
PROJECT PHYSIOGRAPHY AND GEOLOGY
PROJECT PHYSIOGRAPHY AND GEOLOGY:
PROJECT PHYSIOGRAPHY AND GEOLOGY:

Weverton Formation:
- Cowo – Owen’s Creek Memb. - Quartzite and MetaSiltstone
- Cwm – Maryland Heights Memb. - Quartzite and MetaSiltstone
- Cwm – Buzzard Knob Memb. - Quartzite and Sandy MetaSiltstone
PROJECT PHYSIOGRAPHY AND GEOLOGY:

US 340 - Oblique Aerial
Write a description for your map.

Typical Conditions

Slope Area 1

Slope Area 2

Slope Area 3

Harper's Ferry Rockfall Site

Northern Limit

Begin Area 1

End Area 1

600 ft
PROJECT PHYSIOGRAPHY AND GEOLOGY:

US 340 - Oblique Aerial

Typical Conditions

Slope Area 1

Slope Area 2

Slope Area 3
ROCK SLOPE INVESTIGATION ALONG US 340 NEAR HARPER’S FERRY, WV
2018 Geohazards Technical Forum, Baltimore, MD, August 7th – 9th, 2018

PROJECT PHYSIOGRAPHY AND GEOLOGY:

Traffic Data:

Table 1: 2014 Average Annual Daily Traffic within Project Limits

<table>
<thead>
<tr>
<th>Route</th>
<th>State</th>
<th>Begin Location</th>
<th>End Location</th>
<th>2014 AADT</th>
<th>Source</th>
</tr>
</thead>
</table>

1. Traffic counts for Harper's Ferry Road (VA-671) was not readily discernible from the referenced VDOT source.
2. Traffic volume shown (30,946 vpd) is the traffic on US 340 through the study area.
PROJECT PHYSIOGRAPHY AND GEOLOGY:
PROJECT PHYSIOGRAPHY AND GEOLOGY:
PROJECT PHYSIOGRAPHY AND GEOLOGY:

Slope Area 1
PROJECT PHYSIOGRAPHY AND GEOLOGY:
PROJECT PHYSIOGRAPHY AND GEOLOGY:
PROJECT PHYSIOGRAPHY AND GEOLOGY:
PROJECT PHYSIOGRAPHY AND GEOLOGY:
PROJECT PHYSIOGRAPHY AND GEOLOGY:
PROJECT PHYSIOGRAPHY AND GEOLOGY:

Slope Area 2 (Boulder Field)
PROJECT PHYSIOGRAPHY AND GEOLOGY:
PROJECT PHYSIOGRAPHY AND GEOLOGY:

Slope Area 3
PROJECT PHYSIOGRAPHY AND GEOLOGY:
PROJECT PHYSIOGRAPHY AND GEOLOGY:
PROJECT DEVELOPMENT
LiDAR MAPPING AND PLAN DEVELOPMENT:

Approximate El. 1100

SLOPE 1 LIMITS

Approx. El. 550'

SLOPE 2 LIMITS

Approx. Roadway El. 300'

Chestnut Hill Rd

ATTACHMENT 1
PRELIMINARY
LiDAR MAPPING AND PLAN DEVELOPMENT:

Approximate El. 1100

SLOPE LIMITS

WV STATE LINE

Approx. El. 278'

Approx. El. 550'

SLOPE AREA #3

SLOPE AREA #2

Preliminary Lidar Survey

Attachment 1
LiDAR MAPPING AND PLAN DEVELOPMENT:
LiDAR MAPPING AND PLAN DEVELOPMENT:
ROAD LEVEL INVESTIGATION
FIELD “TRUTHING” OF GEOLOGIC CONDITIONS:
Preliminary Rock Slope Analysis:

LiDAR Mapping Integrated with SplitFx

Preliminary Kinematic Analysis

Preliminary CRSP Analysis
UPPER-SLOPE INVESTIGATION
PRELIMINARY TTCP DEVELOPMENT:
FINAL TTCP DEVELOPMENT:
A CLOSER LOOK WITH UAV:

UAV and Research Team from Radford University
SLOPE RAPPELLING:
SLOPE RAPPELLING:
SLOPE RAPPELLING:
SLOPE RAPPELLING:

Conditions on Upper Slope Areas
SLOPE RAPPELLING:

Conditions on Upper Slope Areas
SLOPE RAPPELLING:

Conditions on Upper Slope Areas
SLOPE RAPPELLING:

Conditions on Upper Slope Areas
SLOPE RAPPELLING:

Slope Area 1 Safety Scaling
SLOPE RAPPELLING:

Rockfall Cleanup
RELATIVE RISK ASSESSMENT
## Relative Risk Assessment:

### Table 1: Relative Rockfall Risk Assessment

<table>
<thead>
<tr>
<th>Slope</th>
<th>Slope Location / Height of Rockfall Generator (1)</th>
<th>Rockfall Risk (2)</th>
<th>Debris Channels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Road Cuts and Natural Rock Slopes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Subglobal Rockfall (3)</td>
<td>Global Rockfall (3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Subglobal Rockfall (3)</td>
<td>Global Rockfall (3)</td>
</tr>
<tr>
<td>1</td>
<td>Within DOH ROW</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Within Project Limits</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Above Project Limits</td>
<td>High (1)</td>
<td>High (1)</td>
</tr>
<tr>
<td>2</td>
<td>Within DOH ROW</td>
<td>High</td>
<td>Moderate (2)</td>
</tr>
<tr>
<td></td>
<td>Within Project Limits</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Above Project Limits</td>
<td>Low (3)</td>
<td>Low (3)</td>
</tr>
<tr>
<td>3</td>
<td>Within DOH ROW</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Within Project Limits</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Above Project Limits</td>
<td>High (4)</td>
<td>Moderate (4)</td>
</tr>
</tbody>
</table>

(1) **Slope / Rockfall Generator Location:**
- Within DOH ROW – based on 1949 plans varies from elevation 325 to 450 feet
- Within Project Limits – within ROW and up to approximate elevation 475 feet – blue clouded area on orthophotographs (DOH and NPS ROW)
- Above Project Limits – Outside ROW and Project Limits – yellow clouded area on orthophotographs (NPS ROW)

(2) **Rockfall Risk** - Likelihood of rockfall to reach roadway
- High: 68-100% Likelihood Rockfall will reach the roadway
- Moderate: 34-67%
- Low: 0-33%

(3) **Rockfall Failure Mechanisms:**
- Subglobal Rockfall – 0.5’ to 5.0’ rockfall diameter
- Global Rockfall – greater than 5.0’ diameter rockfall typically discontinuity controlled failures (planar, wedge, etc.)

(4) Slopes were not investigated for rockfall hazards. Relative rating is based on observations from lower elevations from HDR engineering geologists and potentially unknown slope conditions within NPS.

(5) Slope 2 is significantly shorter with less exposed natural rock slopes compared to Slopes 1 and 3. Relative rating is based on observations from HDR engineering geologists.
**RELATIVE RISK ASSESSMENT:**

**Table 2: HDR Importance Factors**

<table>
<thead>
<tr>
<th>Driver</th>
<th>Importance Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction Cost</td>
<td>9</td>
</tr>
<tr>
<td>Effectiveness within Project</td>
<td>10</td>
</tr>
<tr>
<td>Limits</td>
<td></td>
</tr>
<tr>
<td>Effectiveness above Project</td>
<td>5</td>
</tr>
<tr>
<td>Limits</td>
<td></td>
</tr>
<tr>
<td>Construction Complexity</td>
<td>5</td>
</tr>
<tr>
<td>Traffic Impacts</td>
<td>9</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>2</td>
</tr>
<tr>
<td>Rockfall Maintenance</td>
<td>5</td>
</tr>
<tr>
<td>System Maintenance</td>
<td>8</td>
</tr>
</tbody>
</table>

10 = Most Important  
1 = Least Important
## RELATIVE RISK ASSESSMENT:

Table 3: Driver, Description, Score, and Relative Assessment Rating

<table>
<thead>
<tr>
<th>Driver</th>
<th>Description</th>
<th>Score</th>
<th>Relative Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction Cost</td>
<td>Construction costs includes all items necessary to install rockfall protection or mitigation measure. Items include traffic control, safety scaling, equipment, materials, utility maintenance, protection of utilities, etc.</td>
<td>5</td>
<td>Low Cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Moderate Cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>High Cost</td>
</tr>
<tr>
<td>Effectiveness (within Project Limits)</td>
<td>Effectiveness refers to the ability of rockfall protection or mitigation measure to perform for the service life (50 to 75 years) of the project within the project limits. For example, scaling would have a lower effectiveness over the service life as compared to a rockfall barrier. The scaling effectiveness can be related to how fast a rock slope weathers or how fractured a slope is, which can reduce the service life of a scaling alternative. Scaling service life is typically 5 to 20 years, but is highly dependent on the site and geologic conditions.</td>
<td>5</td>
<td>High Effectiveness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Moderate Effectiveness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>Low Effectiveness</td>
</tr>
<tr>
<td>Effectiveness (NPS ROW)</td>
<td>Effectiveness refers to the ability of rockfall protection or mitigation measure to perform for the service life (50 to 75 years) of the project from higher rockfall generators outside of the project limits. Rockfall generators exist outside the project limits which if a rockfall occurs from the higher elevation will impact the effectiveness of the designed system based on the slopes within the project. Rockfall could still impact the roadway with the system in place. However, some systems will offer some improved protection from the higher rockfall generators over other options.</td>
<td>5</td>
<td>High Effectiveness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Moderate Effectiveness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>Low Effectiveness</td>
</tr>
<tr>
<td>Construction Complexity</td>
<td>Construction complexity refers to constructability of a rockfall protection or mitigation measure relative to site constraints and access. The measure may require a specialty contractor.</td>
<td>5</td>
<td>Low Complexity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Moderate Complexity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>High Complexity</td>
</tr>
<tr>
<td>Traffic Impacts</td>
<td>Traffic impacts include all impacts to SB and/or NB traffic during construction of a rockfall protection or mitigation measure such as shoulder closure, lane closure, detour, slow roll during blasting, etc.</td>
<td>5</td>
<td>Low Impact</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Moderate Impact</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>High Impact</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>Aesthetics refers to any potential impact to the natural/existing scenery and historical setting.</td>
<td>5</td>
<td>Low Impact</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Moderate Impact</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>High Impact</td>
</tr>
<tr>
<td>Rockfall Maintenance</td>
<td>Rockfall Maintenance refers to relative cost, traffic impact, and overall complexity involved in long-term clean-up of rockfall activity associated with a particular rockfall protection or mitigation measure to maintain its effectiveness. For example, periodic catchment ditch clean-out behind rockfall barrier or removal of any accumulated material suspended in a mesh or on the slope.</td>
<td>5</td>
<td>Low Maintenance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Moderate Maintenance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>High Maintenance</td>
</tr>
<tr>
<td>System Maintenance</td>
<td>System Maintenance refers to relative cost, traffic impact, and overall complexity involved in repair or replacement of damaged rockfall protection or mitigation measure due to rockfall activity to maintain its effectiveness. For example, repair or replacement of rockfall barrier or mesh due to rockfall activity.</td>
<td>5</td>
<td>Low Maintenance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Moderate Maintenance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>High Maintenance</td>
</tr>
</tbody>
</table>
**RELATIVE RISK ASSESSMENT:**

Table 4: Feasible Options for Subglobal Rockfall and Global Rockfall for Natural Rock Slopes and Roadway Cuts

<table>
<thead>
<tr>
<th>Driver</th>
<th>Subglobal Rockfall</th>
<th>Global Rockfall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maintenance Scaling</td>
<td>Maintenance Scaling Score</td>
</tr>
<tr>
<td>Construction Cost</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Effectiveness (within project)</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Effectiveness (NPS)</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Construction Complexity</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Traffic Impacts</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Rockfall Maintenance</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>System Maintenance</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>185</td>
<td>153</td>
</tr>
</tbody>
</table>

**Slope 1 and 3:**
- Maintenance Scaling - 185
- Attenuator Barrier - 150
- Localize Road Shift - Flexible Rockfall Barrier - 149
- Rock Bolting - 190

**Slope 2:**
- Maintenance Scaling - 185
- Rock Bolting - 190
- Rock Slope Drape - 153

1. Slope 2 has lower rockfall generators and less exposed rock face in close proximity to the roadway and a lower likelihood of rockfall from above the project limits. Therefore, the attenuator barrier and localized road shift were not considered for Slope 2.
### Table 1-3: Slope 3 Cost Summary of Remediation Options

<table>
<thead>
<tr>
<th>Slope Condition</th>
<th>Option</th>
<th>OPTION DESCRIPTION</th>
<th>DOH ROW</th>
<th>NPS ROW within Project Limits</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rockfall Remediation Cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROW</td>
<td>Project Limits</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$52,675</td>
<td>$35,521</td>
<td>$88,217</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$58,250</td>
<td>$37,190</td>
<td>$95,440</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>$65,825</td>
<td>$41,160</td>
<td>$107,085</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$73,400</td>
<td>$45,640</td>
<td>$119,040</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 1-2: Slope 2 Cost Summary of Remediation Options

<table>
<thead>
<tr>
<th>Slope Condition</th>
<th>Option</th>
<th>OPTION DESCRIPTION</th>
<th>DOH ROW</th>
<th>NPS ROW within Project Limits</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rockfall Remediation Cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROW</td>
<td>Project Limits</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>$55,289</td>
<td>$36,807</td>
<td>$92,096</td>
<td></td>
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<tr>
<td>$60,864</td>
<td>$40,383</td>
<td>$101,247</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>$66,439</td>
<td>$43,960</td>
<td>$110,400</td>
<td></td>
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</tr>
<tr>
<td>$72,014</td>
<td>$47,437</td>
<td>$119,451</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 1-1: Slope 1 Cost Summary of Remediation Options

<table>
<thead>
<tr>
<th>Slope Condition</th>
<th>Option</th>
<th>OPTION DESCRIPTION</th>
<th>DOH ROW</th>
<th>NPS ROW within Project Limits</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rockfall Remediation Cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROW</td>
<td>Project Limits</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$57,881</td>
<td>$39,500</td>
<td>$97,381</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$63,456</td>
<td>$43,000</td>
<td>$106,456</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$69,031</td>
<td>$46,500</td>
<td>$115,531</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>$74,606</td>
<td>$49,999</td>
<td>$124,605</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Probable Construction Cost Estimate

The probable construction cost estimate for the Rock Slope Investigation along US 340 near Harper’s Ferry, WV, for the years 2018-2019 is as follows:

- **Slope 1**: $124,605
- **Slope 2**: $115,531
- **Slope 3**: $119,040

Total estimated construction cost: $359,176.
PRELIMINARY SLOPE REMEDIATION PLANS
PRELIMINARY SLOPE REMEDIATION PLANS:
PRELIMINARY SLOPE REMEDIATION PLANS:

**NOTES:**
1. Locations of attenuator barrier and drains are approximate only.
2. The recommendations shown on the typical section are best estimates.
   Some modifications will be made during final design.
3. The type, size, and depth of barrier, post, and other important features will be determined
   during final design.

**TYPICAL SECTION**
SLOPE 1
ATTENUATOR BARRIER
STATION 97+50 TO 100+00
STATION 101+00 TO 102+50
PRELIMINARY SLOPE REMEDIATION PLANS:
ACKNOWLEDGEMENTS:

- WVDOH - Joe Carte, Chris Francis, Aaron Wentz, Lee Thorne, District 5 Engineering and Maintenance
- HDR - Amy Balmer-Staud, Lori Smith-Hall, John Candal
- VDOT and MDSHA
- National Park Service - Andrew Lee
- Alpha Associates, Inc. (Surveying)
- Rice Associates, Inc. (LiDAR Mapping)
- Ameritech Constructors (Slope Rappelling) - Bob Forbes, Jeff Boone
- RoadSafe (Traffic Control)
- Geotechnics (Lab Testing)
- Dr. David Brezinski (MD Geological Survey)
- Dr. Skip Watts and George “Paki” Stephenson (Radford University)
THANK YOU!