Geotechnical Asset Management for Transportation Agencies in the United States

Ground Related Risk to Transportation Infrastructure
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Acknowledgements

• National Cooperative Highway Research Program (NCHRP): Project 24-46 on GAM Implementation
  – Study team of transportation and geotechnical asset management (GAM) experts
    • Shannon & Wilson, Spy Pond Partners, Iowa State University, and Missouri University

• Other GAM advocates in U.S.
  • Dave Stanley, Scott Anderson, Paul Thompson, Darren Beckstrand
Funding for Surface Transportation in U.S.

- Federal government rebates a portion of the federal gas tax revenue each year to each state

- States supplement highway budgets primarily through one or more of the following:
  - More gas taxes, vehicle license fees/taxes, wheel taxes
  - Income, property, and business taxes
  - Mineral and petroleum extraction severance taxes
  - Tolling – limited to high congestion areas with political support

- Railroad
  - Amtrak: federally funded passenger rail system
  - Private: Numerous freight rail owners who also may have occasional passenger operations
Voluntary Implementation Environment

• Currently no regulatory or legislative requirement for geotechnical asset management at Federal or State level

• Recent legislation does require asset management for bridges and pavements and encourages management for other assets

• Most work has evolved from rockfall hazard rating systems initiated state by state

Early 1990s: Rockfall Hazards – > 2015: Risk Based Geotechnical Asset Management
Early Asset Management-Safety Based Rockfall Hazard Rating Systems (RHRS)
Rockfall Hazard Rating Example

- Sum (additive) based hazard score
  - 0, 3, 9, 27, or 81 points assigned for each input category
  - Provides an indication of highest hazard and components can be used for safety risk analysis

<table>
<thead>
<tr>
<th>Slope</th>
<th>Site 6</th>
<th>Site 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope Height</td>
<td>50 to 75 feet</td>
<td>75 to 100 feet</td>
</tr>
<tr>
<td>Rockfall Frequency</td>
<td>1 to 2 years</td>
<td>Yearly, Seasonal</td>
</tr>
<tr>
<td>Average Slope Angle</td>
<td>2 to 4</td>
<td>4 to 8</td>
</tr>
<tr>
<td>Launching Features</td>
<td>Minor (&lt;2 ft. surface variation)</td>
<td>Many (2 to 6 ft. surface variation)</td>
</tr>
<tr>
<td>Ditch Catchment</td>
<td>65% to 94% / Class 2</td>
<td>30% to 64% / Class 3</td>
</tr>
<tr>
<td>Climate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Precipitation</td>
<td>10 to 20 inches</td>
<td>20 to 35 inches</td>
</tr>
<tr>
<td>Annual Freeze Thaw Cycles</td>
<td>6 to 10</td>
<td>11 to 15</td>
</tr>
<tr>
<td>Seepage/Water</td>
<td>Damp / Wet</td>
<td>Dripping</td>
</tr>
<tr>
<td>Slope Aspect</td>
<td>E, W, NE, NW</td>
<td>SE, SW</td>
</tr>
<tr>
<td>Sed Rock</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Degree of Under-Cutting</td>
<td>no value</td>
<td>no value</td>
</tr>
<tr>
<td>Jar Slake</td>
<td>no value</td>
<td>no value</td>
</tr>
<tr>
<td>Degree of Interbedding</td>
<td>no value</td>
<td>no value</td>
</tr>
<tr>
<td>Crys Rock</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rock Character</td>
<td>Small faults/ Strong Veins</td>
<td>Schist/ Shear Zones &lt; 6 in.</td>
</tr>
<tr>
<td>Degree of Overhang</td>
<td>1 to 2 ft.</td>
<td>2 to 4 ft.</td>
</tr>
<tr>
<td>Weathering Grade</td>
<td>Surface Staining</td>
<td>Slightly Altered/ Softened</td>
</tr>
<tr>
<td>Block in Matrix</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Block Size (x3)</td>
<td>no value</td>
<td>no value</td>
</tr>
<tr>
<td>Block Shape (x3)</td>
<td>no value</td>
<td>no value</td>
</tr>
<tr>
<td>Vegetation (x3)</td>
<td>no value</td>
<td>no value</td>
</tr>
<tr>
<td>Discontinuities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Block Size/Volume</td>
<td>1 to 2 ft. / 1 to 3 cy</td>
<td>2 to 5 ft. / 3 to 10 cy</td>
</tr>
<tr>
<td>Number of Sets</td>
<td>1 plus random</td>
<td>2</td>
</tr>
<tr>
<td>Persistence, Orientation</td>
<td>&gt; 10 ft. and dips into slope</td>
<td>&lt; 10 ft. and daylights out of slope</td>
</tr>
<tr>
<td>Aperture</td>
<td>0.1 to 1 mm</td>
<td>1 to 5 mm</td>
</tr>
<tr>
<td>Weathering Condition</td>
<td>Surface staining</td>
<td>Granular infilling</td>
</tr>
<tr>
<td>Friction</td>
<td>Undulating</td>
<td>Planar</td>
</tr>
<tr>
<td>Total Hazard Score</td>
<td>162</td>
<td>486</td>
</tr>
<tr>
<td>Site Distance</td>
<td>60 to 80%</td>
<td>40 to 60%</td>
</tr>
<tr>
<td>Average Vehicle Risk</td>
<td>25 to 49%</td>
<td>50 to 74%</td>
</tr>
<tr>
<td>No. of Accidents</td>
<td>3 to 5</td>
<td>6 to 8</td>
</tr>
<tr>
<td>Total Risk Score</td>
<td>27</td>
<td>81</td>
</tr>
<tr>
<td>Combined Score</td>
<td>189</td>
<td>567</td>
</tr>
</tbody>
</table>
History

• 1990-2010: Rockfall Hazard Rating Systems
  – Oregon, Colorado early adoption
  – Numerous states with rockfall hazards adopt and modify RHRS’s for state specific needs

• Rockfall systems modified for all unstable slopes
  – Washington (2000’s), Alaska 2010

• 2003 - Need for geotechnical asset management first discussed in U.S. literature
History

- Retaining wall inventory and assessment early efforts
  - Cincinnati (1990s-2006) – 1800 walls
    - $170M replacement value
  - National Park Service (2005-2008) – 3,500 walls in 33 parks and monuments
    - $18.5M in deferred maintenance
    - $407M replacement value
  - Oregon, New York
History

• 2012 – first efforts towards starting geotechnical plans
  – Alaska, Colorado, Vermont
  – Geotechnical Asset Management joint committee formed within Transportation Research Board

• 2016 – Federally funded study to create geotechnical asset management implementation plan for states (current study)
Alaska Department of Transportation

• First state to complete a GAM plan through
  – GAM Champion - David Stanley

• Unstable slopes, rockfall sites, retaining walls, material sites

• Condition based inventory developed from the rockfall hazard rating methodology

• Evaluating risk to safety, mobility, and direct financial costs to department
This overview map shows the location of all assets in AKDOT&PF's Geotechnical Asset Management Program.

Please click on the appropriate tab for detailed information in the asset-specific maps.

**Route Feature March 2017**

- Retaining Wall Locations
  - Assessed Walls

- Retaining Wall Locations
  - As-Built Inventory

- Soil Slope and Embankment
  - SoilSlopes

Number of features:

- > 20
- 15
- 10
- 6
- 1
Alaska Department of Transportation

• Status:
  – Plan document complete
  – Expert judgment for deterioration models
  – Investment not occurring yet
• Several $M in needs identified but limited funds

From AKDOT&PF, 2017
Colorado Department of Transportation

• ~ 3,000 walls: condition based inventory

• Approximately 1600 geologic hazard sites: condition and event based inventory
CDOT Wall Structure Inventory
CDOT Wall Structure Inventory

Rapidly growing and relatively young asset group
Consequences and Risks

- Environment
- Safety
- Social Impacts
- Economic Vitality
- Mobility
- Geohazards in CDOT Right-of-Way
- Maintenance of System
Colorado Department of Transportation

Status:

• Reporting Measures
  – Walls: element level and wall condition
  – Walls and Geohazards: Level of Risk (LOR)

• Draft plans in development

• Annual funding of around $5M-$10M for investment in both geohazards and walls
Vermont Transportation Department

- 3,600 rock cuts in risk based program
  - 4% (121) identified as high hazard
  - Risk evaluated based on degree of customer (traffic)

<table>
<thead>
<tr>
<th>Rockfall Hazard Ranking Score</th>
<th>500+ (High Hazard)</th>
<th>300 to 500 (Medium Hazard)</th>
<th>300– (Low Hazard)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer Service Level (Exposure)</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>7</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>32</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>6</td>
<td>4</td>
</tr>
</tbody>
</table>

- High Priority
- Medium Priority
- Low Priority
Vermont Transportation Department

- Reporting measure
  - Access Sustainability Index (ASI)
    - ratio of available funds/needed funds
    - Communicates funding need of program to deliver improvements
Vermont Transportation Department

- **Status**
  - Planning a 5 year, $4.2M investment program for 9 rock slopes with State funds
  - Mitigation selected based on optimized financial analysis over life-cycle
  - Starting wall inventory
What has enabled Geotechnical Asset Management in U.S. (so far)

• Dedicated state funds, not waiting for outside funding/direction
• Recent major natural hazard event that highlighted need
• Personnel changes
  – Geotechnical staff interested in asset management
  – Planning and management staff who understand value
• Change management programs for implementing new efforts in a large agency
• Staff that can assume a proactive role versus solely being assigned to design and construction support duties
• Prior experience with early GAM (e.g. rockfall sites)
• Executive leadership that understand risk, asset management, and performance measurement
Communicating the Risk to Others

- Risk Cube
Communicating the Risk to Others

- Illustrating outcome Colorado DOT outcomes
Going Forward in U.S.

• Implementation Manual Completion in 2018
  – Apply lessons learned from state interviews and established asset management programs
  – Propose simple maturity approach with options for more complexity if desired
What do State DOTs Suggest for Enabling

• Training on implementation for geotechnical staff
  – data awareness and management
  – financial planning
  – and life-cycle analysis

• Training on applying risk management in financial and life-cycle scenarios

• Dedicated staff resources to implement and maintain the program
Concepts and Frameworks for U.S. Implementation

• Models to emulate
  – Network Rail
    • Mature risk-based GAM program
  – Switzerland PLANAT program
    • Functioning life-cycle cost-benefit process for natural hazard mitigation among multiple funding partners
  – Infrastructure Maintenance Management Manual
  – USACE Water Infrastructure
    • Aggregation of risk and conventional software usage
  – Vermont, Colorado, Alaska DOTs
    • Lessons learned in early GAM implementation experience
Challenges for U.S. Implementation

• **No regulatory requirement** expected in near term
  • States must fund and Federal funds are limited

• **Geotechnical asset management** will need to **compete** on measurable risk and cost benefit
  • Improve performance for the same cost; or,
  • maintain current performance at a lower cost

• **While most see need, there is reluctance due to:**
  • Absence of Federal or other requirement for GAM; or
  • Potential liability associated with adverse reporting to public or FHWA (may do GAM but not report)
Challenges for U.S. Implementation

– Staffing for implementation
  • Geo-professionals and resources to develop plans (e.g. Executives and TAM staff aren’t going to start)

– Data for tracking and measurement
  • Department costs
  • Delay and safety performance

– Differentiating between natural hazard and physical failure – not a routine process or data point yet
Important Distinction for GAM: Physical Failure vs. Natural Hazards
Important Distinction for GAM: Physical Failure vs. Natural Hazards

Funding opportunity?
Assets Beyond Right-of-Way (ROW)

• Current U.S. practice
  – DOTs often include hazardous assets beyond ROW in inventory
  – Typically responsible for first (and only) response and funding
    • More likely to recover costs from private owners
    • Adjacent public lands usually don’t have funds for assistance

Funding opportunity?
U.S. Implementation Guidance

• Overcoming barriers
  – Communicate performance/exposure to executives in absence of top down objectives. Inform the level of risk acceptance.
  – Make the business case for voluntary investment

• Slope sites and walls have done well in inventory and assessment steps, but difficult to complete the management cycle
  – Start simple with continuous improvement
  – Common definitions and terminology between agencies
U.S. Implementation Guidance

• Measuring Performance
  – Performance measures need to connect to broader agency goals such as investment, risk exposure, and performance (Outward Measures)
  – Condition data more applicable internal to program (Inward Measures)
  – Need flexibility to connect to variable strategic goals

• Risk and Risk Management
  – Direct risk analysis at performance of asset rather than value
U.S. Implementation Guidance

• Return on Investment
  – Tools to show benefit from reduction in future adverse situations/events
  – Adaptable ROI analysis frameworks for a geo-professional

<table>
<thead>
<tr>
<th>Existing/Baseline GAM Risk Exposure</th>
<th>Annual Risk Exposures</th>
<th>Expected Annual Risk Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Safety</td>
<td>Mobility</td>
</tr>
<tr>
<td></td>
<td>$ 5,000</td>
<td>$ 50,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Proposed Risk Management Treatment Option 1 (e.g. Instrumentation)</th>
<th>Probability of Improvement to Safety Exposure</th>
<th>Probability of Improvement to Mobility Exposure</th>
<th>Probability of Improvement to Maintenance Exposure</th>
<th>Option Initial Investment Cost</th>
<th>Option Annual Cost</th>
<th>Net Benefit/Year</th>
<th>5 Year Expected Net Present Value</th>
<th>5 Year Expected Present Value Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.05</td>
<td>0.25</td>
<td>0</td>
<td>$ 67,250</td>
<td>$ 50,000</td>
<td>$ 2,500</td>
<td>$ 10,250</td>
<td>$ (1,827)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Proposed Risk Management Treatment Option 2 (e.g. scaling)</th>
<th>Probability of Improvement to Safety Exposure</th>
<th>Probability of Improvement to Mobility Exposure</th>
<th>Probability of Improvement to Maintenance Exposure</th>
<th>Option Initial Investment Cost</th>
<th>Option Annual Cost</th>
<th>Net Benefit/Year</th>
<th>5 Year Expected Net Present Value</th>
<th>5 Year Expected Present Value Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.25</td>
<td>0.5</td>
<td>0.5</td>
<td>$ 41,250</td>
<td>$ 50,000</td>
<td>$ 1,000</td>
<td>$ 37,750</td>
<td>$ 127,418</td>
</tr>
</tbody>
</table>

Assumes 2.1% annual inflation rate