WSDOT’s Unstable Slope Management Program
COMMON TYPES OF UNSTABLE SLOPES

Landslide
Landslide is the vertical and horizontal displacement of a soil mass, under the influence of gravity, within a slope or embankment. Generally, landslides can be divided into two categories based on failure geometry: circular and sliding-block failures. The movement of landslides can vary from a slow-moving to rapid-moving rate.

Debris flow
Debris flow is a rapidly moving fluid mass of rock fragments, soil, water, and organic material, with more than half of the particles being larger than sand size. Generally, debris flows occur on steep slopes or in gullies and can travel long distances. Typically, debris flows result from unusually high rainfall, or rain on snow events.

Rock fall
Rock fall is the fall of newly detached segments of bedrock of any size from a cliff or steep slope. The rock fall descends mostly through the air by free fall, bouncing, or rolling. Movements can be extremely rapid and might not be preceded by minor movements.
THE PROBLEM

The Washington State Department of Transportation manages 7,048 miles of highway facilities that traverse widely varying terrains with complex geologic landforms. Unstable slopes, including landslides, rock falls and debris flows of all sizes, can impact highways when they fail. An unstable slope failure can pose a potential safety risk to highway travelers and might adversely affect regional commerce, if the slope failure results in a highway closure.

HOW WE MANAGE UNSTABLE SLOPES

Prior to 1995, we stabilized unstable slopes reactively, after they had failed. To take a more proactive approach, WSDOT established a budget category in the Highway Preservation Program for unstable slopes in 1995. The target investment level for this category in the highway system was estimated at approximately $300 million over 10 biennia. WSDOT developed the Unstable Slope Management System (USMS) to provide a methodology to evaluate known unstable slopes within the WSDOT highway system. This method focuses on balancing hazard and risk when prioritizing slopes for funding of proactive stabilization efforts.

WSDOT regional offices, in collaboration with the Headquarters Geotechnical Office, did the initial identification of unstable slopes. This resulted in a baseline inventory of over 2,500 sites. These known unstable slopes are scored using a numerical rating system based on 11 criteria that identify the hazard and measure potential risk factors to the highway. Based on the numerical rating system, a site may have a score ranging from 33 (lowest) to 891 (highest), with higher numbers representing a greater risk to the highway facility at that location. Table 1 identifies the rating factors. Since the inception of the USMS, the number of slopes in the inventory has increased to about 3,400. Detailed numerical ratings have been completed for almost all known unstable slopes statewide.

Figure 1: Unstable slopes along state routes in Washington state.

Data Source: Unstable Slope Management System (USMS)
Date: 1/12/2018
Table 1: USMS rating criteria

<table>
<thead>
<tr>
<th>Category</th>
<th>Points=3</th>
<th>Points=9</th>
<th>Points=27</th>
<th>Points=81</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem Type: Soil</td>
<td>Cut or Fill Slope Erosion</td>
<td>Settlement or Piping</td>
<td>Slow moving landslides</td>
<td>Rapid Landslides or Debris Flows</td>
</tr>
<tr>
<td>Problem Type: Rock</td>
<td>Minor Rockfall Good Catchment</td>
<td>Moderate Rockfall Fair Catchment</td>
<td>Major Rockfall Limited Catchment</td>
<td>Major Rockfall No Catchment</td>
</tr>
<tr>
<td>Average Daily Traffic</td>
<td>&lt; 5,000</td>
<td>5,000 to 20,000</td>
<td>20,000 to 40,000</td>
<td>&gt;40,000</td>
</tr>
<tr>
<td>Decision Sight Distance</td>
<td>Adequate Sight Distance</td>
<td>Moderate sight distance</td>
<td>Limited Sight Distance</td>
<td>Very Limited Sight Distance</td>
</tr>
<tr>
<td>Impact of Failure on Roadway</td>
<td>&lt; 50 Feet</td>
<td>50 to 200 Feet</td>
<td>200 to 500 Feet</td>
<td>&gt;500 Feet</td>
</tr>
<tr>
<td>Roadway Impedance</td>
<td>Shoulder Only</td>
<td>½ Roadway</td>
<td>¾ Roadway</td>
<td>Full Roadway</td>
</tr>
<tr>
<td>Average Vehicle Risk</td>
<td>&lt; 25% of the time</td>
<td>25% to 50% of the time</td>
<td>50% to 75% of the time</td>
<td>&gt;75% of the time</td>
</tr>
<tr>
<td>Pavement Damage</td>
<td>Minor- Not Noticeable</td>
<td>Moderate- Driver must slow</td>
<td>Severe- Driver must stop</td>
<td>Extreme- Not traversable</td>
</tr>
<tr>
<td>Failure Frequency</td>
<td>No Failures in last 5 Years</td>
<td>One Failure in Last 5 Years</td>
<td>One Failure Each Year</td>
<td>More than one failure</td>
</tr>
<tr>
<td>Annual Maintenance Costs</td>
<td>&lt; $5,000 per year</td>
<td>$5,000 to $10,000</td>
<td>$10,000 to $50,000</td>
<td>&gt;$50,000</td>
</tr>
<tr>
<td>Economic Factor</td>
<td>No Detours Required</td>
<td>Short Detour &lt; 3 Miles</td>
<td>Long Detours &gt; 3 Miles</td>
<td>Sole access- No detours</td>
</tr>
<tr>
<td>Accidents in Last 10 Years</td>
<td>0 to 1</td>
<td>2 to 3</td>
<td>4 to 5</td>
<td>&gt;5</td>
</tr>
</tbody>
</table>

**PROCESSES LEADING TO SLOPE INSTABILITY**

Slope instability is a category of natural hazard that refers to the movement of a soil or rock mass under the influence of gravity. Rock falls occur on both natural and excavated slopes. Causes of rock falls include a combination of natural processes and man-made influences, acting singly or in combination, to dislodge discrete blocks of rock. Usually planes of weakness termed “discontinuities” physically divide the rock mass into an assemblage of blocks.

Landslides are a category of natural hazards that involve the down-slope movement of soil materials under the influence of gravity. Soil slope failures generally fall into two categories: deep-seated rotational failures or translational slides; and, shallower debris flows and slides. Generally, deep seated slope failures occur more slowly than shallower debris flows and slides, which can occur rapidly. Failure mechanisms involve either an increase in driving forces or a reduction of resisting forces (i.e., increased water pressure or loss of shear strength of the soil).
The next step is for geotechnical specialists with expertise in slope stability to describe the slope stability problem, and then develop conceptual slope mitigation designs along with cost estimates. A simple benefit-cost analysis compares the cost of an estimated traffic delay and the maintenance costs over 20 years, to the costs for mitigating the slope hazard. Based on this approximate benefit-cost comparison, sites with a ratio of 1 or greater are placed on a prioritized list of slopes to be programmed for remediation. Currently, WSDOT prioritizes and programs remediation for unstable slopes that have a numerical rating of 300 or greater along interstate highways, principal arterials, and other highway facilities with traffic volumes of 1,000 vehicles a day or greater, and a benefit-cost ratio of 1.0 or greater. Conceptual designs and cost estimates have been completed on approximately 300 unstable slopes as part of the ongoing prioritization process.

WSDOT’s unstable slope management program is a proactive, infrastructure-preservation program. It’s intent is to cost-effectively reduce the risk of unstable slopes from adversely impacting our highest priority state highway facilities. The mitigation objective is to achieve long-term risk reduction with either a permanent solution or a reasonable performance life (>20 years).

Under the existing USMS procedures, a slope that qualifies for stabilization receives a comprehensive (i.e., 20-year design life) treatment. In other words, stabilization is all or nothing at a given site.

**Figure 2: Mitigated slopes along state routes in Washington state.**

Data Source: Unstable Slope Management System (USMS)
Date: 1/12/2018
DISTINCTION BETWEEN HAZARD AND RISK

It is important to understand the terms “hazard” and “risk.” Rock fall or soil slope failures are geologic processes categorized as natural hazards. These natural processes include landslides, debris avalanches, slope creep, soil piping, snow avalanches and so on. These events occur in nature and have done so since the geologic evolution of landforms began. In some cases, the activities of humans can influence the occurrence of natural hazard events. A reference to a high hazard means that there is a high likelihood an event will occur. 

Risk refers to the consequences of a natural hazard event if it occurs. It is easy to envision an event that has absolutely no consequence in terms of human activity, for example a snow avalanche in the remote mountains. The same natural hazard perched above a ski resort would represent a significant risk.

In 2004, WSDOT began evaluating how the highway system was performing and developed a 10-year Asset Management Plan to identify the investment levels needed for the 2005-2007 Highway Preservation Program. At that time, we estimated it would take an additional $100 million over the next 10 years to retrofit the currently identified high rated unstable slopes. Our evaluation recognized that emergency work – including slope failures – would probably continue, and WSDOT set aside state funding to match federal emergency relief dollars and state-declared emergencies. Our program’s 2017 eight-year plan has been allocated approximately $51 million of construction and design funding to cover an outstanding need of nearly $300 million.

Our history of managing risk

Between 1995 and 2017, WSDOT spent approximately $176 million on stabilizing programmed unstable slopes. In addition, the department spent another $206 million on unforeseen emergency slope corrections.

The funding of non-dedicated dollars for WSDOT’s Highway Construction Program decreased from approximately $1,400 million in 2001-2003, to $650 million in 2009-2011. This reduction in non-dedicated state and federal funds made it essential for us to evaluate the performance of the highway system and determine how that performance will change in the future as a result of different investment alternatives.

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In 2013, WSDOT began tracking the cost of repairs to unstable slope infrastructure (i.e., rock fall and debris flow fences and netting and drapery applications) not eligible for federal emergency reimbursement funds. Since 2013, WSDOT has spent approximately $2 million repairing this type of infrastructure on six different unstable slopes.

RISK REDUCTION ROCK SLOPE SCALING

In some cases, a minimal amount of treatment slope work can reduce a large component of the risk at an unstable slope site; for example, hand scaling of a rock slope. As part of its unstable slope management program, WSDOT has also developed a risk-reduction strategy that complements the full-slope stabilization program. This risk-reduction scaling program was initiated in 2007. On an annual basis, WSDOT’s Geotechnical Office and regional staff jointly determine the sites that will be included in this risk-reduction strategy. An allocation of approximately $2 million has been made available for risk reduction for each biennium since 2007. This is in addition to the funding earmarked each biennium for programmed sites on the comprehensive slopes stabilization program.

The intent of this program is to reduce risk of rock fall along state highways. Risk-reduction rock-slope scaling entails removing loose, unstable rock from a rock slope with the use of hand tools, such as scaling bars, hydraulic wedges, air pillows and, in some cases, with the use of mechanical equipment.

In areas where geologic site conditions make this work feasible, these techniques can significantly reduce the likelihood of rock fall reaching the highway. Typically, these slopes have chronic rock fall problems with rocks reaching the highway numerous times during the year and requiring multiple maintenance callouts to clear the highway of rockfall debris. These
efforts have resulted in an extensive statewide list of candidate rock slopes that would benefit from rock-slope scaling.

WSDOT engineering geologists assess the site conditions at each of the candidate slopes and determine the feasibility of rock-slope scaling and whether or not rock-slope scaling can effectively reduce the rock fall risk. These slopes are then rated utilizing a simple rating system based on eight criteria as shown in Table 2.

**Table 2: Risk reduction rating criteria**

<table>
<thead>
<tr>
<th>Category</th>
<th>Slope Height</th>
<th>Ditch Effectiveness</th>
<th>Total Roadway Width</th>
<th>Rockfall History</th>
<th>Number of Maintenance Calls per Year</th>
<th>Rockfall Block Size</th>
<th>Volume of Rockfall per Year</th>
<th>Average Daily Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 25 ft</td>
<td>Good Catchment</td>
<td>&gt; 40 ft.</td>
<td>Few Falls</td>
<td>&lt; 1</td>
<td>&lt; 1 ft.</td>
<td>&lt; 3 cyd.</td>
<td>&lt; 500</td>
</tr>
<tr>
<td></td>
<td>25 to 50 ft.</td>
<td>Moderate Catchment</td>
<td>32 ft.</td>
<td>Occasional Falls</td>
<td>1 to 3</td>
<td>1 to 2 ft.</td>
<td>3 to 6 cyd.</td>
<td>500 to 2,750</td>
</tr>
<tr>
<td></td>
<td>50 to 75 ft.</td>
<td>Limited Catchment</td>
<td>24 ft.</td>
<td>Many Falls</td>
<td>4 to 5</td>
<td>2 to 3 ft.</td>
<td>6 to 10 cyd.</td>
<td>2,751 – 5,000</td>
</tr>
<tr>
<td></td>
<td>&gt; 75 ft.</td>
<td>No Catchment</td>
<td>&lt; 24 ft.</td>
<td>Constant Falls</td>
<td>&gt; 5</td>
<td>&gt; 3 ft.</td>
<td>&gt; 10 cyd.</td>
<td>&gt; 5,000</td>
</tr>
</tbody>
</table>

Based on a biennial budget of approximately $2 million, 26 slopes on US 2, SR 7, SR 17, US 97A, and SR 971 are programmed to be scaled during the next eight years.

**SOLUTIONS TO MEET THE CURRENT NEED TO REDUCE PUBLIC RISK**

Current funding is $51 million during the next eight years for planned work in the unstable slope management program. In preparing for the biennial budget development process, WSDOT reviews its current Asset Management Plan for unstable slope needs, adjusting it for the accomplishments of the past two years, adding any new needs, and evaluating the benefits of accelerating the rate for addressing unstable slope risks.

Some factors we include in this evaluation are hardships for the public with travel delays, detours, and potential affect to local businesses. We also assess the availability of qualified contractors and workers to perform the work. WSDOT has identified the projects for the 17-19 biennium, and has developed the preliminary program through the 23-25 biennium. We will continue scoping to identify needs and projects for the future biennia.

**FUTURE NEEDS**

WSDOT has successfully mitigated more than 300 unstable slopes, investing nearly $150 million over the last 23 years. However, more work remains to be done. Our goal is to mitigate all identified unstable slopes on interstate highways, principal arterials and other roadways with moderate to high traffic volumes before they exhibit high to very high risk. At the same time, we will continue to conduct rock slope scaling as an interim measure on highway corridors with a high incidence of rock fall.

Geotechnical analysis and design of mitigation measures for 35 more unstable slopes is currently under way. We have began preliminary engineering to develop conceptual mitigation proposals and cost estimates for an additional 75 unstable slopes in 2017. Additional engineering work to refine mitigation designs and improve cost estimates for these unstable slopes is needed to ensure that we can continue to manage risk through an aggressive construction program. A biennial investment of approximately $30 million is needed for unstable slope mitigation and risk reduction rock slope scaling to ensure that these goals can be met.
FOR MORE INFORMATION

GEOTECHNICAL OFFICE / CONSTRUCTION DIVISION / MULTIMODAL DEVELOPMENT AND DELIVERY

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