INTRODUCTION

At the request of the Highway Safety and Design Section, we have completed a rock slope stability investigation of a rock slope on VT-105 in Jay. This rock slope is located adjacent to the westbound travel lane at mile marker 3.66 (Figure 1). The existing rock cut is approximately 30 feet in height and 460 feet in length. The rock slope was identified in the VTrans Rockfall Hazard Rating Study (RHRS) as an “A” ranked rock slope (rockfall is expected to occur and reach roadway) with a total RHRS score of 361.

According to District personnel, rockfall events are common at this location. They reported that in the last three years, rock in the roadway had to be cleared at least four times.

Figure 1  Rock slope location.
Most of the rock reaching the road occurs as small to medium sized (softball to suitcase sized) pieces of rock although there have been some instances where large sheets about desk size have slid down to the roadway. The catchment ditch here is considered good although as noted, individual rocks falling from the slope face occasionally reach the roadway.

This report presents discussions of the investigation, analysis, and recommendations by the Geotechnical Engineering Section.

SITE INVESTIGATION

The slope stability investigation consisted of interviewing District 9 personnel to assess the rockfall history at this location, a review of information gathered during RHRS investigations, visual observations, photographing the slope, measuring the physical properties of the slope, evaluating kinematic slope conditions, and developing recommendations to limit the occurrence of rockfall at the site. As-built project plans from the initial construction were unavailable for review. A photo of a representative portion of the rock slope is presented Figure 2.

Figure 2  Photograph of portion of the rock cut. Notice slabby nature of the rock and the orientation of foliation planes.

SITE CONDITIONS

Vermont Route VT-105 is a 25-foot wide paved two lane highway in the project area with a 15 foot wide catchment ditch (measured from edge of pavement to the toe of slope). The roadway at this location is on a slight up-hill grade traveling westbound. The roadway is straight throughout the area of the cut. A power line crosses over the roadway and a hiking trail (Long Trail) crosses the road here as well.
The annual average daily traffic count at mile marker 5.7 east of the subject cut for the year 2012 was 680 vehicles per day. The posted speed limit is 50 miles per hour and the site distance here was measured to be 872 feet. VT-105 is the major east-west corridor in the northern part of the state. The rock slope face dips toward the southeast (120°) at angles from about 45° to 65° from horizontal. The upper slope surface (above the brow of the cut) is relatively flat lying. A very large boulder sits atop the slope at about Station 194+30 that can be seen in Figure 3.

![Figure 3 Photograph showing large boulder perched atop the crest of the slope.](image)

Recent geologic mapping performed in the area indicates that bedrock at this location consists of metamorphic rock of the Hazens Notch Formation. The rock is described as “Dark-rusty-brown graphitic biotite-muscovite-chlorite-quartz (+/-garnet) schist and gneiss”. Observations performed in the field confirms this classification.

The rock contains prominent foliation planes which dip directly toward the roadway. Two jointing plane sets are also present. These jointing planes dip toward the east-northeast and west-northwest respectively. The jointing planes act as release surfaces which allow large slabs of rock to slide down the slope along the foliation planes. Based on laboratory testing, the rock at this location has a unit weight of 165 lbs/ft³.

Trees are present above the brow of the slope and at a few locations along the rock cut, small pine and birch trees are growing out of the rock face. No significant water seepage was noted.

**ROCKFALL ANALYSIS**

Modeling of rockfall was conducted utilizing RocFall® software developed by the company Rocscience. RocFall® is a statistical analysis program designed to assist with the risk assessment of rockfalls. The program simulates the path of falling rock based on
a slope profile input and determines energy, velocity, bounce height and the location of fallen rock end points.

Cross Sections generated from MicroStation plan files were used in the program to model rockfall parameters. Based on observations of the slope, a nominal size rock block of 3,060 pounds (representative of a 1.5’ × 4’ × 3’ block of rock with a unit weight of 165 lbs/ft³) was used. For each profile, the program was run using 100 individual rocks. Figure 6 shows the trajectories of rockfall paths at Station 194+50.

Based on this analysis, it appears that rocks do not reach the roadway. It should be noted that the RocFall® computer program models rocks as individual spheres rolling down an inclined surface. The individual rock blocks falling from the subject slope are slabby in shape and tend to slide down the slope rather than roll. In addition, the modeling software only accounts for single rockfalls while in reality, the rock falling from slopes break up during rockfall events breaking into many pieces. Multiple pieces of rock bounce off of each other making rockfall modeling very difficult to produce accurate results in those instances.

Another thing to consider is that rockfall events can involve large volumes of rock which can be enough to overwhelm the catchment ditch and as more rock falls, the filled ditch can become ineffective in stopping rocks from reaching the roadway.

KINEMATIC ANALYSIS

The Agency geologist collected measurements of the discontinuities within the rock during a site visit on November 5, 2013. A total of 119 individual discontinuity measurements were collected. Based on a stereographic analysis of this data, we have identified three discontinuity sets (see Table 1 and Figure 3). A discontinuity set is a collection of discontinuities measurements that share a common trend in dip and dip direction. In nature, discontinuities within rock are seldom orientated in exactly the same dip and dip directions. By plotting these orientations, a pattern emerges that allows...
investigators to group families of discontinuities into sets that are orientated in the same
general direction and dip. The most prevalent discontinuity in the rock is foliation. Joint
sets 1 and 2 represent jointing surfaces in the rock produced by tectonic forces during the
geological history of mountain building in the area.

Table 1 Discontinuity Sets Gathered during November 5, 2013 site visit.

<table>
<thead>
<tr>
<th>Discontinuity Set ID</th>
<th>Average Orientation - Degrees (Dip/Dip Direction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foliation</td>
<td>48/133</td>
</tr>
<tr>
<td>Joint Set J1</td>
<td>72/77</td>
</tr>
<tr>
<td>Joint Set J2</td>
<td>78/279</td>
</tr>
</tbody>
</table>

The interaction between the rock cut alignment orientation and the measured
discontinuity orientations are critical for evaluating the potential for planar, wedge or
toppling failure. By plotting the orientation of the rock slope face, assigning a friction
angle (assumed to be 30°) and plotting discontinuity orientations, the analyzer can
determine if various failure modes are kinematically possible. For the purposes of
analysis, a conservative value of 65° was used for the rock slope face angle.

The basic concept of kinematic analyses for plane failure is straightforward. Two
conditions must be met for sliding to occur. First, the discontinuity must have a dip angle
that is steeper than its friction angle of the rock. In simple terms, the friction angle is the
minimum dip angle for which sliding will occur along a discontinuity. For example, if
two saw-cut slabs of rock are placed together horizontally and slowly tilted, the top slab
will begin to slide when the sliding surface reaches the friction angle. Of course, this
description ignores some obvious factors such as cohesion and irregularities between the
surfaces, hence it is conservative. It is useful nevertheless. Friction angles for a typical
competent rock range from around 25° to 40°.

The second condition for sliding is that the discontinuity must daylight from the slope
face in a down-dip direction. This means that the discontinuity must dip in the same
general direction as the slope face, but less steeply. Sliding cannot occur if the
discontinuity dips back into the slope because it is locked in place. Sliding can only
rarely occur if the discontinuity dips in the same direction but more steeply than the slope
face, as it too is locked in.

The two conditions described above can be represented on a stereonet in the form of a
truncated pie-shaped critical zone. Discontinuity pole vectors, which lie within the
critical zone, dip more steeply than the friction angle of the rock because they are inside
the friction circle. They dip less steeply than the slope face because they lie outside the
great circle representing the slope face. It is generally true that plane failures are not likely
unless the discontinuity dips almost directly out of the slope face. The portion of the critical
zone that lies within 20° (plus or minus) of the slope face dip direction is considered most
vulnerable. Outside of that 20° zone, discontinuities disappear into the slope such that they
often lock themselves in. Figure 3 shows the stereonet pole plot for plane failure at the
subject rock cut.
Stereonet analyses for potential wedge failures is similar to stereonet analyses for plane failure. In order for a wedge failure to occur, the line made by the intersection of the planes creating the wedge must plunge more steeply than the friction angle and less steeply than the dip of the slope face and in a direction such that it daylights from the slope face.

To test for these conditions, a single great circle may be chosen and plotted on the stereonet to represent the discontinuities of each cluster. If any of the great circles representing clusters on the stereonet intersect within the truncated pie-shaped critical zone then the conditions are met and a wedge failure is kinematically possible. The intersection point provides the plunge and trend of the line of intersection and is read from a stereonet in the same manner as dip and dip direction. Figure 4 shows the stereonet pole plot for wedge failure at the subject rock cut.
Toppling failures are possible when blocks of rock, formed by steeply dipping discontinuities in the rock rotates about a fixed point along a release discontinuity. The center of gravity of the rock slab must fall outside the dimension of its base for toppling failure to occur. Figure 5 shows the stereonet pole plot for toppling failure at the subject rock cut.

![Figure 6 Stereonet Pole Plot showing potential toppling failure.](image)

Each kinematic analysis was plotted electronically using the software Dips® developed by Rocscience of Toronto, Canada. Dips® estimates of "probability of failure" with respect to all planes, and with respect to all planes in individual sets. The number of poles within the critical zone are then counted and the results are expressed as a percentage of all poles, and as a percentage of poles within individual discontinuity set.

Attachment 1 presents an excerpt from the Dips® help file detailing methods for plane, wedge and toppling failure analysis.

Based on this analysis, plane and wedge failures were identified as possible modes of failure on this slope. Forty-six percent of dipping planes are susceptible to plane failures and fifty-six percent of the intersections of planes are susceptible to wedge failures. Less than one percent of the planes plot in the critical zone for toppling failure.

**MITIGATION ALTERNATIVES**

Rockfall hazard mitigation techniques can be used separately or in combination to eliminate or significantly reduce the potential for rockfall hazards. The selection of a preferred technique or combination of techniques must consider the project’s complexity, constructability, traffic control limitations, environmental constraints, aesthetic impacts, cost, and future maintenance requirements. One must also consider the durability and effectiveness of chosen techniques.

We have evaluated common rock slope mitigation techniques currently in use in the industry and evaluated the considerations mentioned above in order to provide the
Agency with a preferred technique(s) so that the ultimate mitigation applied is designable, biddable and constructible.

Based on our evaluation, it appears that the rock is susceptible to plane and wedge sliding. Our evaluation of each of the mitigation techniques discussed below has taken this into consideration. Descriptions of each technique are attached as Attachment 2. A discussion of each mitigation method and our recommendations follows:

**Excavation:**

In order to reduce the potential for future plane and wedge failures, the slope face would need to be reduced so that most of the planes and plane intersections plot outside the critical zone on the plots. Based on our evaluation of available mitigation techniques, we have determined that excavating the slope back on a 4V:1H slope (45°) would be the most appropriate course of action. The rock here naturally wants to break along the foliation planes which dip at this angle. Excavation can be accomplished utilizing either blasting or mechanical scaling techniques. Figure 6 shows the proposed cut line at Station 195+50.

![Proposed Cut Line](image)

**Figure 7** Section at Station 195+50 showing proposed cut line.

We estimated that approximately 3,500yd³ of material would need to be removed. A gross estimate of cost would be $80,000 for blasting or $50,000 for machine scaling.
Hand Scaling:

Hand scaling is not recommended on this project. Scaling individual loose blocks off of the slope face will remove the immediate potential for falling rock, however this type of scaling is considered a temporary solution as continued weathering along foliation and jointing in the rock will lead to future instability.

Secured Netting:

This technique is best used on slopes where there may be a thin layer of surficial unstable rock fragments. The secured netting helps to tie together the loose masses of rock into a cohesive mass that improves the rock face stability. Secured netting is not an appropriate technique for this slope.

Wire or Cable Draped Netting:

Netting works best on much smaller blocks of rock. The use of this technique is not appropriate for this slope as large slabs of rock can break free and slide along the foliation planes. Netting would not be able to hold back these large masses of rock and therefore is not recommended for this slope.

Catchment Ditch Improvement:

The existing catchment ditch measures 15 from edge of pavement to toe of slope, however a portion of this ditch located immediately adjacent to the roadway is relatively flat lying reducing the effectiveness of the ditch. We recommend constructing a ditch in general conformance with design guidance presented in FHWA-OR-RD-02-04, Rockfall Catchment Area Design Guide and current VTrans design standards. This will allow for adequate fallout for any possible rockfalls in the future.

Flexible Rockfall Barrier at Roadway Level:

Due to the nature of sliding on this slope, flexible rockfall barriers would not be appropriate as other mitigation techniques could easily remove or secure the potential threat. Flexible barriers require maintenance and would impede on the ability to throw snow from the roadway.

Rigid Rockfall Barrier:

As with the Flexible rockfall barriers, rigid rockfall barriers would present similar restrictions. We do not recommend placing a rigid rockfall barrier on this project.

Shotcrete:

Shotcrete is meant to be used sparingly to shore up small portions of slopes. Because of the slabby nature of this slope, shotcrete would not be effective and therefore we do not recommend using this technique.
Buttress:

Buttressing might be effective in some areas of the slope to stabilize some of the large rock slabs. However, this technique would not be appropriate in other areas. Aside from pouring large concrete buttresses across much of the slope, this technique would not provide a cost effective solution for falling rock at this slope and therefore we are not recommending the installation of buttresses.

Rock Doweling/Bolting:

Rock doweling is a valid mitigation technique for this slope. Pattern doweling could be performed to secure exposed slabs. For purposes of this recommendations report, we could assume approximately 85 rock dowels on 10-foot spacing totaling 1,020 linear feet of rock dowels. The length of the dowels should be on the order of 10 to 15 feet in length and the dowels should be made of threaded 1” diameter galvanized steel bar manufactured specifically for the purposes of rock slope stability.

Vegetation Removal:

If blasting is performed, all vegetation removal should be conducted consistent with current Agency specifications. If blasting is not performed as the chosen mitigation technique, all vegetation (including stumps and roots) should be removed from the face of the slope. In addition, clearing and grubbing shall be performed from the slope brow to a point 20 feet back from the slope crest. If blasting is not performed and an alternative mitigation method is employed, we estimate that approximately 1/4- acres of vegetation will need to be removed from the brow of the slope extending 20 feet beyond the crest and about 30 small trees (including roots) will need to be removed from the slope face.

Drainage:

Free flowing water was not noted on this slope and as such, we see no need to install rock drains.

Cable Lashing

There were no areas on the slope that would require cable lashing techniques and therefore is not recommended.

Rock Mass Bonding

Rock mass bonding techniques are not appropriate for this slope and therefore is not recommended.
CONCLUSIONS AND RECOMMENDATIONS

Based on work performed by the VTrans geologist, the Geotechnical Engineering Section has identified the potential for plane and wedge failures at the subject site. Rockfalls are frequent events at this location according to District personnel. We have evaluated various mitigation strategies and have determined that the best course of action would be to cut the slope back on a 1V:1H slope. This could be accomplished using drilling and blasting or mechanical scaling methods. In addition to cutting the slope back, a more effective catchment ditch should be constructed. We assume there is enough right-of-way available to construct such a slope. Although rock doweling was considered a viable mitigation alternative, we feel that the advantages of eliminating the potential for further rockfall by excavation outweigh the future maintenance issues rock doweling would require.

All vegetation shall be removed and all material shall be cleared and grubbed twenty feet back from the slope crest.

VTrans had developed Special Provisions for drilling and blasting and machine scaling for recent rock slope mitigation projects. These Special Provisions should be reviewed for their completeness and appropriateness for this project and project specific Special Provisions should be developed.

The following additional construction recommendations are provided for your consideration:

Pre-bid meeting - A pre-bid meeting will be required on this project. The pre-bid meeting should be attended by the contracting team, design team, construction team, and contractor. If the bidder has a preferred sub-contractor in mind for the project, they should also attend.

Pre-blasting meeting - The Agency should require the contractor and blasting sub-contractor to attend a pre-blast meeting with the engineer and geologist. Local authorities (fire department or utility representatives) may also be invited to the pre-blast meeting. The pre-blast meeting must occur prior to any drilling or blasting activities and is intended to initiate open communications with the contractor and blasting sub-contractor. The blast plan submitted by the blaster will be reviewed and any modifications can be addressed at this time.

Construction monitoring - We recommend that a geotechnical specialist from our office be on-site periodically to assess and direct blasting activities.

Traffic Control – Mitigation work will require the closure of the westbound lane while maintaining traffic on the eastbound lane. During each blast, traffic will need to be stopped and the contractor shall muck any rock out of the travel lanes in a timely manner.
We hope this report provides the Highway Safety and Design Section with information and recommendations that will advance this project in a sound engineering and cost effective manner. Please feel free to contact us at 828-6916 to discuss the contents of this report or to answer any questions you may have.

ATTACHMENTS:

Attachment 1 - Excerpt from the Dips® help file, Failure Analysis
Attachment 2 - Rock Slope Mitigation Techniques

C: File
Operations