APPENDIX I
CONSTRUCTION MONITORING MEMORANDUM

Technical Memorandum

To: Norman Norrish (Wyllie & Norrish Rock Engineers)

From: Balin Strickler (Fisher & Strickler Rock Engineering)

Date: January 26, 2009

Re: Persistent Discontinuities – Interstate 90, Hyak, Washington

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During the ongoing field investigation and analyses of the East Hyak Realignment project several persistent (over 100's of feet) discontinuities and discontinuity types were observed between Milepost (MP) 56 and 61 along the Interstate 90 (I-90) project corridor. Persistent discontinuity identification and analysis is a vital component to any rock slope design and construction monitoring (CM) program. This is due to the potential adverse interaction between features and cut slope orientation, resulting in large scale instability such as that shown in the margin photograph. Rock slope stability analysis will include these features when identified during the rock mass characterization; however, there is a high probability that additional features or variability in feature orientation will be observed during rock slope excavation. This memorandum is intended to provide a descriptive approach to field identification and analysis of these features during construction and should be a helpful tool for the CM personnel.

In review of this memorandum please note the following:

1. All stationing will be from west-bound (WB) and will be approximate.
2. All orientations unless otherwise noted are in dip/dip direction.
3. All orientations have been corrected to true north using 17 degrees east.

Persistent discontinuities have been identified in several of the design sectors within the project corridor, however the example used for this memorandum is in Sector III (WB stationing 1318+00 to 1321+75).

General Geology

Detailed geologic summaries of the project area can be found in several of the Wyllie & Norrish site characterization studies (Wyllie & Norrish 2007a, 2007b). The bedrock geology of the immediate project area are Tertiary rocks from the Cascade volcanic arc including the Naches Formation and the Ohanapecosh Formation. These rocks are primarily comprised of altered pyroclastic dacite tuffs, volcanclastic deposits, andesitic and basaltic flows, and occasionally sandstone/siltstone sequences. The *Rock Cut Feasibility Investigation – Slide Curve I-90 MP 59* (W&N 2007a) noted three dominant discontinuity types along the project corridor. These include faults/shear zones, joints and flow boundaries.

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Persistent Discontinuity Types

Faults/Shears and Joints

Faults and shear zones are typically persistent over many hundreds of feet to miles with thickness ranging from a few millimeters to several tens of feet. The infilling can include comminuted rock, gouge material, mylonite and/or slicken-sided and polished surfaces. These features can either retard or act as conduits for groundwater movement. Jointing is a discontinuity without lateral or vertical displacement where the movement of the rock is primarily perpendicular to the joint plane. These features can have persistence of less than one foot to several hundred feet with varied infilling and thickness.

Flow Boundaries

While faults and joints can typically be traced linearly with some constraints for termination, offset or en echelon characteristics, flow boundaries have much greater uncertainty for interpolation between known points of intersection. This is due to their depositional nature which is influenced by 1) the pre-existing topography; 2) the duration between eruptive events (variable paleosol development); 3) the amount of native soil evacuated during the eruptive event; and 4) the degree of welding to the surface deposits. This effectively means that even in the absence of evidence from the field investigations, it is possible that unanticipated flow boundaries will be encountered during the excavation of the proposed rock cuts and that when identified their orientation, thickness and infilling will vary over distance.

Discontinuity Analysis

Detailed kinematic analysis has been completed on the available structural database for the I-90 project. This database includes traditional surface structural mapping, Sirovision surface mapping and downhole televiewer surveys all of which have provided several thousand orientations. These analyses evaluate the kinematic viability of structural failure along joint sets that intersect at adverse orientations to the proposed rock cut with reasonable reliability. Specific fault and flow boundary orientations are included within the kinematic analysis on a feature by feature and sector by sector basis for the various design sectors completed for the project.

However, during construction it is probable that unidentified flow boundaries, faults, en echelon faults or variability in fault and flow boundary orientation will be encountered. As the rock cut is advanced, detailed structural mapping of the newly exposed rock face will be crucial for identification of these structures. This data should then be integrated into the kinematic model for the Sector and compared to other available structural data in adjacent sectors. These observations may justify local modification of planned mitigation measures (ie: spot bolting, shotcrete placement) or predict potentially large scale failures between more persistent discontinuities. This type of failure could be caused by adverse intersections between flow boundaries and/or faults or in association with persistent joints. Bowel-shaped failure along an exposed flow boundary(s) is also possible.

Discontinuity Typical Analysis

Sector III has identified a flow boundary that may daylight near the toe of the final excavated slope. Table 1 provides the available information from the boreholes drilled and orientation data obtained from the downhole televiewer surveys.

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Table 1 – Sector III Flow Boundary Summary Table

Borehole	Collar Coordinates			Significant Clay Filled Discontinuity		Downhole Televiewer Orientation
	Northing	Easting	Elevation	Depth feet bgs	Elevation	
RKS-02-07	1070080	1752509	2595.4	61.2	2534.2	29/193; 20/164
RKS-34-08	1070078	1752568	2613.9	69.2	2544.7	30/ 248; 42/190
RKS-35-08	1069942	1752489	2600.0	57.4	2542.6	37/ 061; 29/059

Notes:
1. X, Y coordinates based on local survey datum.
2. bgs = below ground surface
3. Orientations show upper (1st orientation) and lower mapped values
4. Depths are shown from borehole log and do not necessarily match depths obtained from televiewer data due to differences in recovery and ground surface demarcation.

A three-point solution (Vacheer, H.L., 2000) was completed on the coordinate intersections of the clay filled discontinuity from which the orientation of the plane that passes through all three points was calculated to be 11/296 (low dip out of slope). Additionally, along the face of the existing outcrop a persistent discontinuity was identified that could likely represent the southerly dipping 'arm' of this flow boundary. While a true orientation was not accurately recorded the apparent dip of the plane was calculated at 26/195 which suggests the inferred southerly dip to this arm of the boundary in exposure.

During excavation of Sector III, intersection of the northern and southern arms of this boundary is highly probable. Initially, the lateral arms will appear to be independent, persistent, and possibly adverse features with no apparent complementing feature to form a large wedge or bowl shaped failure when compared to the sector joint sets and discontinuity database (Figure 1). Therefore, likely mitigation measures for one of the arms would only address small scale block or wedge failure associated with the joint sets previously identified and spot bolting and possibly shotcreting at select locations. Additionally, in the case of this flow boundary the first exposure of the lateral arms could place them a few hundred feet apart. Without geologic and structural correlation between the two persistent features it is likely that the mitigation measures implemented would not be adequate for the size and persistence of the structure.

Conclusions and Recommendations

Persistent discontinuities as faults and flow boundaries will be encountered during the construction of the rock cuts for the I-90 realignment project. Several of these features have been identified during the field investigation and have been included within the Wyllie & Norrish reports. However, during construction it is probable that either additional features will be identified or the features observed to date will display variable orientation over the scale of the proposed rock cuts. To assist the field geologist/engineer(s) in proper identification and correlation of structures during the project the following recommendations are offered.

Geologic Interpretation

Construction monitoring should be completed by an experienced engineering geologist both familiar with the project setting and volcanic/vocaniclastic rocks. Geologic variability between deposits and types of discontinuities will require detailed mapping. Key observations during construction should include:

1. Discontinuity orientation, thickness, type of infilling and surface condition.
2. Rock types on hanging and footwall side of feature.
3. Feature specific observations:

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a. Faults: Evidence of movement along discontinuity including slicken-sided and/or polished surfaces, mylonite, fault gouge or comminuted rock, fault zones or splays, type of comminuted lithic fragments.
b. Flow boundaries: Thermally 'baked' zones above or below boundary, carbonized material, ash deposits, various types of lithic fragments within in-filled material, presence of columnar structures proximal in hanging wall, grading or sorting of vesicles or lithic fragments in hanging wall, irregular surface and thickness.
c. Joints: Absence of evidence for movement, hackles or ribs along surfaces, rock types on either side and within feature, correlation between feature and other structure observed at the outcrop and along the project corridor.

4. Observations of flow boundaries should include consideration of subsequent faulting that could have occurred along flow boundaries and evidence for both could be observed in the field along the same discontinuity.

<u>Structural Interpretation</u>
Detailed structural mapping of the newly exposed rock cuts should be completed on each lift as soon after the blasting and mucking sequence as possible. Key observations and methods to be utilized for interpretation should include:

1. Feature orientation comparison to regional orientations for similarity between joint sets and other mapped structures observed along the project corridor.
2. Survey the location of suspect persistent features.
3. Analysis between persistent features for identification of potential larger scale failure modes. This should include interaction of various types of discontinuities. For example, a wedge failure could be viable between an adverse flow boundary and a fault intersection.
4. Methods of data analysis should include stereonet analysis, 3-D modeling and feature projection, comparison between mapped data and available data from the site characterization (ie: televiewer surveys or Sirovision mapping) and three-point analysis based on survey coordinates.
5. If slope displacements are detected by the monitoring system, they should be analyzed with respect to the local structural geology to determine the failure mechanism.

Disclaimer

This memorandum has been developed as a supporting document to the project construction monitoring activities. It has not been written nor should it be used as a comprehensive review of the project. The information provided herein should complement a full understanding of the project through review of the feasibility and design rock slopes reports, general rock mechanics and geologic principles and practical field experience providing construction monitoring support to rock slope excavations.

References

Vacher, H.L., 2000. *Cramer's rule and the three-point problem*. Journal of Geoscience Education v. 48 n. 4, p. 522-532.

Wyllie & Norrish Rock Engineers Inc., 2007a. FINAL REPORT: *Rock Cut Feasibility Investigation – Slide Curve I-90 MP 59*. February 12, 2007.

Wyllie & Norrish Rock Engineers Inc., 2007b. FINAL REPORT: *Rock Cut Feasibility Investigation – Jenkin's Knob MP 57.5*. February 12, 2007.

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Explanation

= General Discontinuity

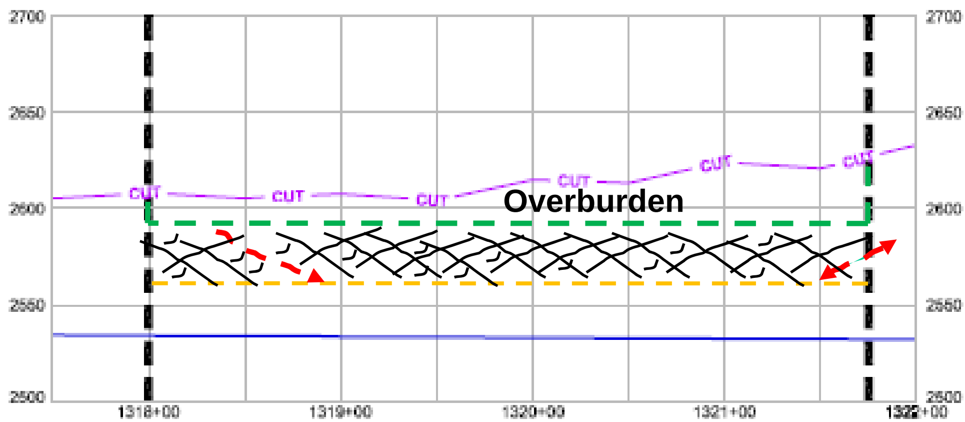
= Significant Discontinuity

= Bottom of lift

= Bottom of overburden

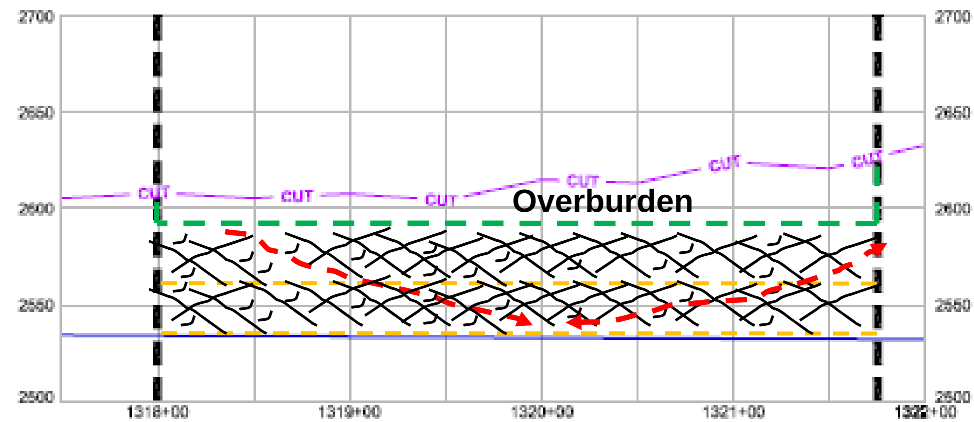
This figure is based on general geology for Sector III but should not be considered design information. The images and discontinuity orientations are for illustration only.

First Lift



PROFILE

Second Lift



PROFILE

Note the red discontinuity lines in both profiles. Absence of early detection and mitigation design (during the first lift) could result in an unstable slope with potential for large scale failure.

Figure 1

Project No: 104AZ Date: January 2009

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I-90 to Snoqualmie Pass East
Hyak to Keechelus Dam