Using Lichenometry to Evaluate Rockfall Recurrence Interval and Talus Fan Behavior, Glenwood Canyon, Colorado

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Lichenometry, a Quaternary age dating technique that uses lichen sizes to estimate surface age, is used to evaluate rockfall recurrence interval in Glenwood Canyon, CO. Glenwood Canyon hosts a stretch of Interstate-70, which has a history of severe rockfall problems. Previous rockfall incidents in Glenwood Canyon have resulted in injuries, fatalities, and lengthy road closures for making repairs. Rockfall recurrence interval has the potential to aid in prediction of future events, allowing mitigation to be completed proactively, rather than reactively. This research seeks to estimate recurrence intervals for individual talus fans, to evaluate talus accretionary behavior, and to compare talus behavior across multiple fans. Calibration curves were locally prepared for two lichen species, *Lecidea Atrobrunnea* and *Lecanora Novomexicana*. In total, 654 *L. Atrobrunnea* and 595 *L. Novomexicana* lichens were measured on boulders larger than 0.5m on the long axis from six talus fans: three in Glenwood Canyon and three in a connected canyon along Grizzly Creek. Only largest lichens were measured. GPS coordinates, boulder size, and lithology were also collected for each boulder on which lichens were measured. Lichen sizes were converted to dates using the calibration curves, and the dates were used to estimate recurrence intervals for each fan. Lichen dates were also plotted spatially to observe accretionary trends. Observations during data collection and processing suggest that
the accuracy of lichenometry used to evaluate rockfall recurrence is limited by unpredictable lichen colonization and inheritance of lichens that began growing on boulders before they fell from the source zone. Calibration is also difficult in the vicinity of Glenwood Canyon because of the small number of lichens available for calibration on local surfaces of known age, the relatively short history of settled human habitation, and the limited number of previous geochronology studies in the region. These problems must be resolved for effective application of lichenometry to rockfall recurrence studies. Therefore, several potential solutions are considered, including calibration curve matching, modeling of growth and mortality in whole lichen communities, and evaluation of lichen areal coverage.

Automation of Photogrammetry and Slope Deformation Change Detection

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Monitoring of rock slopes is critical to ensure safety of people and infrastructure that could be affected by slope deformation events, such as rock fall. Photogrammetry is a relatively low cost, compact, and non-invasive method of 3D-imaging and modelling surfaces, such as cliffs and slopes. With repeated modelling, comparison algorithms can detect changes between these models, allowing for evaluation of rock fall and debris hazards. The purpose of this research is to develop optimal automation procedures for the generation of 3D slope models and detection of slope deformation processes, such as rock fall. This research could increase the practicality of photogrammetric remote sensing techniques in geoscience and maximize budgeting of resources for risk evaluation of rock slopes.

A fixed photogrammetric system consisting of five cameras with solar chargers was constructed to analyze a rock slope along Highway I-70, near Idaho Springs. Images were collected for nine months, twice daily, to construct photogrammetric models. Models were constructed with Agisoft Photoscan software and aligned to a LiDAR data set via CloudCompare using a best fit algorithm. Several methodologies of construction and alignment of the point clouds were developed and analyzed to determine the optimal method to minimize change detection error.

Initial results indicate the optimal method of point cloud construction for the purpose of volumetric change detection is alignment of an initial point cloud to a high accuracy LiDAR data set, and align each future model to the preceding. Additionally, most optimal results were obtained by treating each image as a separate camera for purposes of parameter calibration during point cloud construction. Further analysis of this data remains to be completed regarding impacts of weather and lighting, seasonal influences, and most significantly, the examination of pre-failure deformation rates to produce predictive indicators of rock fall prior to events.
Landslide Mechanics Evaluation of the Roaring Judy Landslide, Almont, Colorado

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This study is a landslide mechanics evaluation of the Roaring Judy Landslide which is located between mile marker 12 and 13 on the northbound side of Highway 135 just outside of Almont, Colorado. The slide is in a road cut and is a northwest facing aspect. Evidence of previous movement is indicated by the main scarp, and two minor scarps below. The toe of the slide is at or below the road surface. The study will be composed of mapping of the landslide through aerial photographs as well as field work; soil sampling for use in soil saturation calculations, Atterburg limits, cohesion calculations and soil strengths. The study will also institute a simple piezometer and extensometers to determine the water table level and rate of movement, respectively. The goal of this study is to model the landslide and determine the amount of water or natural forces needed to cause failure of the landslide surface. This small landslide is of interest because of the rotational blocks that exist on the face of the slide, and its potential to impact highway 135, if it does fail.

A Demonstration of Uncertainty Assessment for Fault Networks in 3D Geologic Models of Mountain Tunnels

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In engineering, uncertainty is traditionally treated in an objective sense where a given model’s uncertainty is evaluated based on the uncertainty of the observations from which it is made, and the inherent spatial variability of the natural phenomena observed. When considering a 3D geologic model, observations are typically sparse (e.g., surface mapping and drillholes) and prior geologic knowledge must be used to interpret how the geology is expected to vary in the subsurface. This prior knowledge, and the interpretations made from it, contribute their own, subjective uncertainty to the resulting model. To arrive at a realistic assessment of the geologic model’s uncertainty, both the objective and subjective uncertainty should be evaluated.

For mountain tunnels, faults are typically of primary concern to construction as they introduce zones of weakness into the surrounding rockmass. In the subsurface, these deformational structures create a fault network with complex 3D geometry describing both the individual structures and their interactions with each other. The fault network intersecting two different transportation tunnels is being investigated in the context of a 3D geologic model. The MuZhaiLing tunnel in Gansu, China passes through the deformed metasedimentary rocks of the West Qinling orogen; the Eisenhower tunnel in Colorado passes through the highly faulted crystalline rocks of the Rocky Mountains.

Faults are projected into the subsurface using an implicit 3D geologic modeling algorithm. Structural traces and orientations observed at the surface provide the basis for the 3D structural geologic modeling. The geometry of individual structures is subject to objective uncertainty stemming from variability in these observations. Subjective uncertainty arises from the
interactions of structures within the fault network, which is interpreted based on a prior understanding of the site’s tectonic history by constructing a fault chronology and series of terminations (e.g., major and minor faults). In this presentation, an input-based, model discrepancy approach is applied to demonstrate the assessment of subjective and objective fault network uncertainty in 3D geologic models of two tunnel localities. The approach can be applied to a wide range of 3D geologic models in structurally-controlled hard rock settings for a realistic assessment and visualization of uncertainty.

Time-Lapse Seismic Imaging of Induced Hydraulic Fractures at Sanford Underground Research Facility Using Continuous Active Source Seismic (CASSM) Techniques

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In recent years, the surge in renewable and non-renewable energy production has highlighted the need for new methods and techniques to more efficiently extract energy from the subsurface. Enhanced geothermal systems (EGS) and unconventional oil and gas have become hot topics for research because of their vast potential as a resource and the uncertainty in the techniques used to extract them. Subsurface resources present many challenges, particularly related to creating properly designed fractures (size and position) to enhance reservoir properties (permeability, connectivity, etc.). A cross-hole seismic survey was performed at Sanford Underground Research Facility (SURF) before, during, and after six fracture stimulation tests in an environment resembling established EGS sites. The six tests were completed to initiate and propagate an emplaced fracture using low flow rates. One technique used for monitoring was continuous active source seismic monitoring (CASSM), which is a technique created by researchers at Lawrence Berkeley National Lab (LBNL) that increases the temporal resolution of a survey by fixing source and receiver positions. CASSM data were analyzed for changes in velocity and amplitude of the direct P- and S-waves. The results indicate that CASSM not only delineated the fractured zone, but also provided information about the processes occurring during and after pressurization.

Characterization and Analysis of the Cedar Pass Landslide Complex, Badlands National Park, South Dakota

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The purpose of this research is to characterize and analyze the Cedar Pass Landslide Complex located in Badlands National Park, South Dakota. Over the last three decades, the Park Service has had to regularly maintain the approximately 1.25-mile section of Badlands Loop Road (South Dakota Hwy–240) which travels through the landslide complex. Road surface distress caused by slope movement and other natural processes in the Cedar Pass area have created a financial burden for the park. While there has been successful mitigation work completed to stabilize portions of the road, stability and erosion problems have persisted. Maintenance and mitigation work completed to this date include the construction of two large earth buttresses,
roadway resurfacing, regular crack sealing and asphalt patching or grinding to smooth surface offsets, and the installation of a new stormwater collection and conveyance system. Various geotechnical investigations have been conducted to analyze parts of the complex, but detailed field mapping of landslide features and slope stability modelling of several untreated landslides has not been completed. This project aims to produce detailed maps of the various landslides in the complex, focusing on specific landslide-induced geomorphic features to identify the lateral extent of earth movement. In addition to mapping, we will complete laboratory testing and slope stability modelling. The modelling outcomes will be used as a basis to test the effectiveness of a variety of remedial measures the park may implement to increase the overall stability of the landslides and to reduce the required maintenance of the roadway. The results of mapping and modelling will be shared with Park Service staff to help them make future management decisions regarding the highway.

Automated machine learning methods for continuous rock slope monitoring

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Lidar and photogrammetry methods have increasingly been utilized in rockfall monitoring applications. Advances in field setups now allow for near-real-time monitoring at weekly, daily, and even sub-daily time intervals, presenting a major data management problem. An operational rockfall monitoring system must be able to very quickly and robustly generate information meaningful to decision-makers, but a large amount of manual interpretation is required, especially when the scene contains vegetation, talus slopes, and other features not relevant to the rockfall processes of interest. The current study investigates the use of machine learning algorithms to adaptively analyze rock slope point cloud data, including change data. A case study is presented on a rock slope adjacent to Interstate-70 in Glenwood Springs, Colorado. For lidar systems, our proposed workflow consists of two modules. First, the slope is automatically classified into one of four material types: bedrock, talus, vegetation, and snow. Slope material classification was accomplished using a Random Forest algorithm trained with multi-scale neighborhood-based geometry, slope, and return intensity statistics as features. Features derived from slope change data were also investigated. Initial validation tests indicate very good classification performance, with F scores of up to around 95% for bedrock, 92% for vegetation, 85% for talus, and up to 90% for snow. Second, significant change is to be extracted and analyzed to determine rockfall volumes and identify potential pre-failure deformation, providing information easily interpretable by Department of Transportation personnel. Our method shows significant improvement over results from the commonly used CANUPO software. The proposed framework is valuable in part because it can be taught to handle slope changes, such as seasonal variation in vegetation and weather. It is natively multi-class and can easily be modified to incorporate new data types and classes that may be useful in special cases. Ongoing research seeks to employ transfer learning approaches to generalize the algorithm to other sites, and a modified version of this framework is under development for a photogrammetric system.