saturations increase from 50 percent to 90 percent, limiting the amount of oxygen available for further oxidation and acid generation. After the first dry period, water saturations in layer 1 decreased, and oxygen saturations increased and remained at approximately atmospheric conditions between day 300 and the end of the experiment.

Average water saturations in layer 1 are shown with average oxygen concentrations and water saturations in layers 2 and 3 in Figs. 2b and 2c, respectively (layer 4 is not shown in this extended abstract for brevity). Average water saturations in layers 2 to 4 showed a muted response to surface moisture addition (through irrigation or precipitation) and stayed below approximately 50 percent for the duration of the experiment. Water saturation data suggest that only minimal amounts of water percolated to depths between 2.0 and 3.5 m in an extremely wet year and to depths between 0.5 and 2.0 m under a year with normal precipitation and no irrigation. Average oxygen concentration behavior in layers 2 to 4 mirrored layer 1: that is, when water saturations were low in layer 1, limiting oxygen ingress, the oxygen concentration decreased in all layers. These data illustrate that comingled GeoWaste can be effective at limiting oxygen ingress, potentially reducing pyrite oxidation, but only when the tailings matrix stays sufficiently saturated with water to limit oxygen ingress.

Conclusion

During a 26-month pile experiment no leachate was observed at the bottom of the comingled GeoWaste pile, while leachate was observed from a companion waste rock pile. The results of this study suggest that GeoWaste can be effective at minimizing ARD by limiting oxygen ingress through maintaining high levels of water saturation. ARD is also minimized by reducing percolation and thus reducing the flux of water through a mine waste facility. Additional study is needed to assess the effectiveness of GeoWaste under different climatic conditions, and to fully understand the geotechnical and geochemical stability of GeoWaste. ■

Disclaimer

The opinions, findings, conclusions, or recommendations expressed herein are those of the authors and do not necessarily represent the views of the National Science Foundation or the Newmont Corporation.

References

A list of all references is available in the full-text paper.

Automated discontinuity extraction software versus manual virtual discontinuity mapping: Performance evaluation in rock mass characterization and rockfall hazard identification

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Full-text paper:

Mining, Metallurgy & Exploration (2021) 38:1383–1394, https://doi.org/10.1007/s42461-021-00416-9

Keywords: Virtual discontinuity mapping, Automated discontinuity mapping, Rock mass characterization, Hazard identification, Rockfall, Underground

To read the full text of this paper (free for SME members), see the beginning of this section for step-by-step instructions.

Special Extended Abstract

Ground control failures are one of the main causes of accidents in the underground stone mining industry. Some of the fundamental tools for rockfall hazard identification are related to rock mass characterization and geotechnical discontinuity mapping. Recent technological advances in these methods are related to remote sensing techniques and point-cloud processing software for automated discontinuity mapping. Remote sensing techniques, such as LiDAR and photogrammetry, generate multimillion-point clouds with millimetric precision, capturing the structure of the rock mass. The automated point-cloud processing tools offer alternative algorithm-based methods to characterize and map these discontinuities. However, their applicability is constrained by multiple factors, such as site-specific conditions of the rock mass and the parameters used within the mapping algorithms. This paper evaluates the performance of automated discontinuity extraction software compared with manual virtual discontinuity mapping. Sampling windows from laser-scanned sections in an underground limestone mine are defined and mapped using the Discontinuity Set Extractor (DSE) open-source software. Results from the virtual discontinuity software are compared with manually extracted fractures from I-Site based on reviewing orientation, trace length, spacing, number of extracted discontinuities, and processing time.

Background

Geomechanical failure is still one of the main causes of accidents in underground stone mines in the United States, causing 11 percent of these accidents in 2019. Ground-control best practices are shifting to risk-management-based approaches. These practices include a thorough process of geomechanical hazard identification. Rock mass characterization (RMC) is essential for identifying such hazards, provides information to perform engineering analyses to validate the stability of the excavations and allows identification of potential failure mechanisms. Laser scanning and photogrammetry technologies have recently been implemented in underground excavations to perform RMC and discontinuity mapping. Researchers have proved that RMC can be performed accurately from point clouds obtained from these two methods, yielding results that agree with observations and analyses obtained through manual RMC. Along with these remote sensing techniques, a series of processing software and algorithms have been developed to aid engineers during the discontinuity mapping process from point clouds. Different authors have developed a series of automated and semi-automated algorithms for discontinuity mapping, either from point clouds or triangular irregular networks. However, most of the case studies where these automated discontinuity extraction (ADE) algorithms are applied have very well-defined discontinuities and may not represent challenging conditions from other sites. The goal of the present work was to evaluate and compare discontinuity mapping results from an open-source ADE software (ADES) with manual virtual discontinuity mapping (MVDM) software through the comparison of orientation, trace length, spacing, number of extracted discontinuities, and processing times.

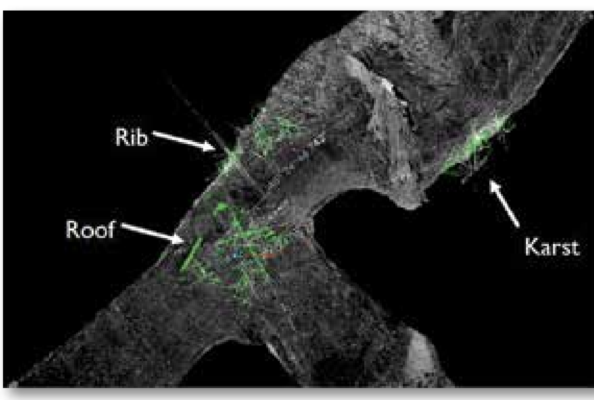

Fig. 1 Case study mine — section of interest referenced point cloud indicating mapping windows.

Methods

The comparison between ADES and MVDM was performed in an underground limestone operation. A study area was defined and scanned using a FARO Focus 3D LiDAR system. Three 12 m by 12 m squared mapping windows were defined in the resulting point cloud to perform the discontinuity mapping process with both methods under a controlled environment. The mapping windows were selected on different areas of the tunnel, the rib, the roof and a karst-laden pillar area (Fig. 1).

The MVDM process was performed using Maptek's I-site Studio software, where each discontinuity was individually identified and manually mapped for each window. The ADE process was carried out using the DSE open-source software. DSE uses a series of algorithms that yield point clouds containing the coplanar points that represent each defined discontinuity set. The Cloud Compare software was used to visualize the DSE results and to convert automated extracted discontinuity point clouds into plane elements defined as facets. Facet elements contain automatically extracted discontinuities that are comparable to manually mapped discontinuities using I-Site.

Once all discontinuities were mapped with a consistent data structure for each method, a database was compiled containing the x, y and z coordinates of the centroid of each discontinuity element, dip, dip direction, and strike, length and area of the mapped plane, mapping window, and mapping method (ADES or MVDM). This data set was used to define the main discontinuity sets through stereographic analy-

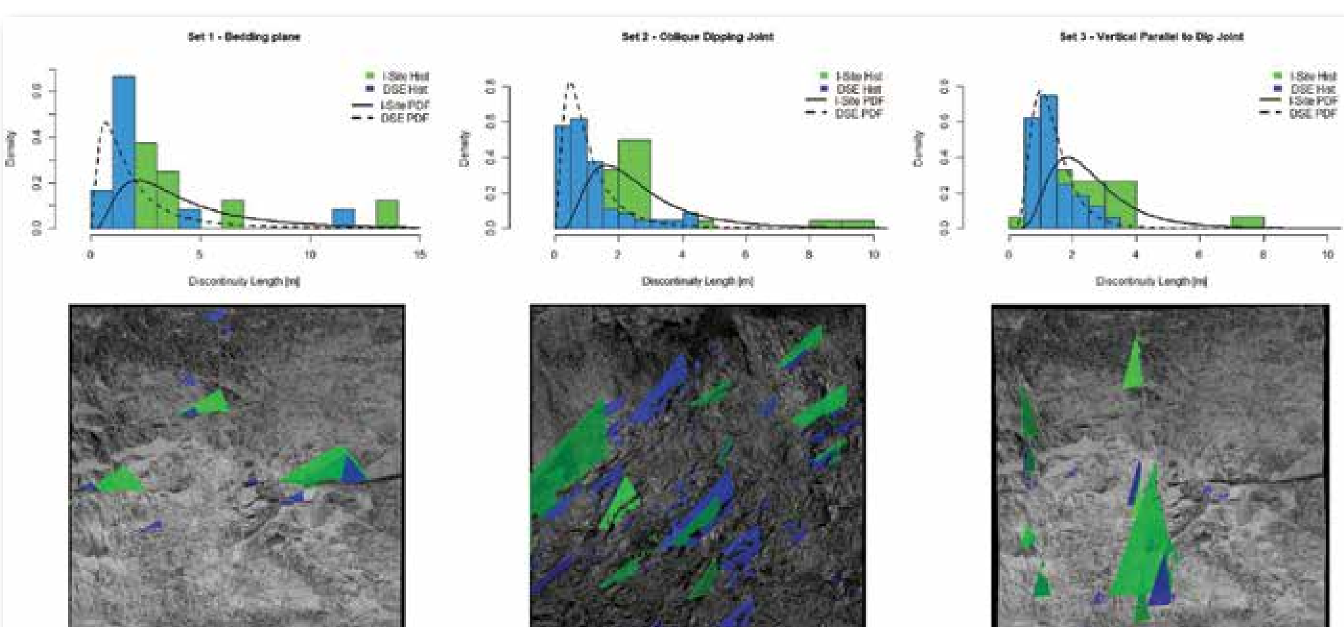

Fig. 2 Statistical summary of comparison between trace length of discontinuity sets obtained with DSE and I-Site.

sis. Trace length and spacing between discontinuities for each discontinuity set were compared between methods. For this, probability density functions were fitted for each parameter and sub-dataset using the fitdistrplus package on RStudio. The statistical distributions for each mapping method and each discontinuity set were compared using hypothesis testing to evaluate if both mapping methods yielded similar results.

Results and discussion

The stereographic analysis showed that discontinuity orientations clustered in three main areas of the stereographic net, indicating that the discontinuity orientation results obtained from both mapping methods were similar. Figure 2 summarizes the results for the discontinuity trace length comparison for each mapping method and discontinuity set. At the top of the figure one can observe the comparison between the PDFs obtained from both mapping methods for each discontinuity set. The mapping windows beneath each of the PDFs correlate with their respective discontinuity set, showing the automatically extracted discontinuities in blue and the manually mapped fractures in green. It is possible to observe for each of the three discontinuity sets that the distribution parameters for both I-Site and DSE-extracted discontinuities have a log-normal distribution. In all three cases, the distribution obtained from DSE is skewed to the left, indicating that the ADES depicted smaller-sized discontinuities. This can also be visually seen in the mapping windows where some discontinuities seem to be mapped exactly the same from both methods, while smaller fractures were mapped in blue. These results were also statistically supported by the previously mentioned hypothesis tests. For the three discontinuity sets, results indicate that the mean trace length values were significantly different between the I-Site and DSE-extracted discontinuities. However, trace length variances were statistically similar for both methods in all discontinuity sets. On the other hand, the discontinuity spacing analysis yielded results indicating the spacing measurements obtained from DSE are statistically the same as the ones obtained from I-Site for sets 1 and 2, while the set 3 results indicate that DSE-extracted discontinuities did not present the same spacing distribution. With regard to processing time, it took 3.75 hours longer to process the point clouds on DSE than directly manually mapping the discontinuities on I-Site.

Conclusions

Results from this work indicate that even though the automatically extracted fractures were not statistically identical in comparison to the manually mapped discontinuities, both results were comparable and yielded significant information useful for further engineering analysis. It is also concluded that it is essential to have input from an experienced person while using automated discontinuity extraction algorithms to avoid the extraction of features that do not correspond to real geological features in the field. Finally, this work validates the DSE open-source software as an alternative that could be used in place of commercial software. ■

References

A list of all references is available in the full-text paper.

Controlling coal spontaneous combustion fire in longwall gob using comprehensive methods — A case study

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Full-text paper:
Mining, Metallurgy & Exploration (2021) 38:1801–1816, https://doi.org/10.1007/s42461-021-00427-6

Keywords: Longwall working face, Coal spontaneous combustion, Closed, Fire extinguishing, Fire area management

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Special Extended Abstract

Coal spontaneous combustion is one of the major disasters in coal mines, and it can have devastating effects on the normal mining and production activities of mines. This paper presents the field investigation, field measurement, data analy-

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