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Technical Note

Integrating discontinuity trace and facet orientation Measurements for improved discontinuity data analysis

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1. Introduction

Discontinuities, which are ubiquitous in most rock masses, influence the engineering properties and behaviors of all but the weakest of rock types [1–5]. Thus, the properties of the discontinuities become of prime importance when dealing with rock masses [6]. The orientation of the discontinuities is arguably the most important property in many instances.

The analysis of discontinuity data basically involves building models that represent the discontinuities. These models are in most cases based on the fact that geological processes usually generate one or more (typically at least three) clusters of nearly parallel discontinuities in a rock mass. Discontinuities manifest themselves in rock cuts and outcropping as fracture surfaces 'facets' that can be measured by LiDAR (Light Detecting and Ranging) or fracture 'traces' that can be measured from optical imaging methods (Fig. 1; [7–10]). Measurements of the orientation of facets are recorded in terms of dip direction and dip angle. Traces, however, are recorded with trend and plunge, which unlike facet measurement, are a two dimensional measurement that represents the intersection of the fracture surface with a rock cut/outcrop surface.

This paper presents geometrical methods of integrating facet orientations measured from LiDAR point cloud data and trace orientations measured from optical images for better characterization of systematic discontinuity orientations.

2. LiDAR and optical imaging of discontinuities

Facets can be detected using LiDAR techniques. The point cloud produced by a laser scanner is searched for a region of co-planar points, and using any three non-linear points from this region one can determine the orientation solving the classic three-point problem [10]. Thus, a geometric plane can be fitted to the entire section of the point cloud that comprises that region [7]. Alternatively, several three-point orientations can be calculated to reduce or assess uncertainty.

The assemblage of fracture traces can be optically imaged, and their (2-D) orientation can be measured by optically imaging the rock cut, using appropriate image processing filters like a canny edge detector [11] to isolate the lines of intersection, and measuring their orientation. Photogrammetry software, including Sirovision, ShapeMatrix3D, and AdamTech, allows users to measure orientations of traces [12–16].

3. Combining LiDAR and optical imaging measurements

The general principle behind combining facet 3-D orientations and trace 2-D orientations on a vertical rock cut is based on the fact that both 3-D facet orientations (LiDAR measured) and 2-D trace orientations (optically measured) can be clustered into their respective sets with mean orientations (dip direction/dip angle, and azimuth/plunge). Additionally all 2-D traces lie on, and define, the intersection of two planar discontinuities (the plane of the rock cut face and the discontinuity plane associated with that trace). While we do not know what that 3-D orientation of the discontinuity represented by a particular trace is, we can test geometrically if a given trace vector is parallel to a given

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discontinuity surface (set). If so, it belongs to the same set, and vice versa.

This methodology is inconclusive in situations where traces belong to a set or sets of unexposed facets.

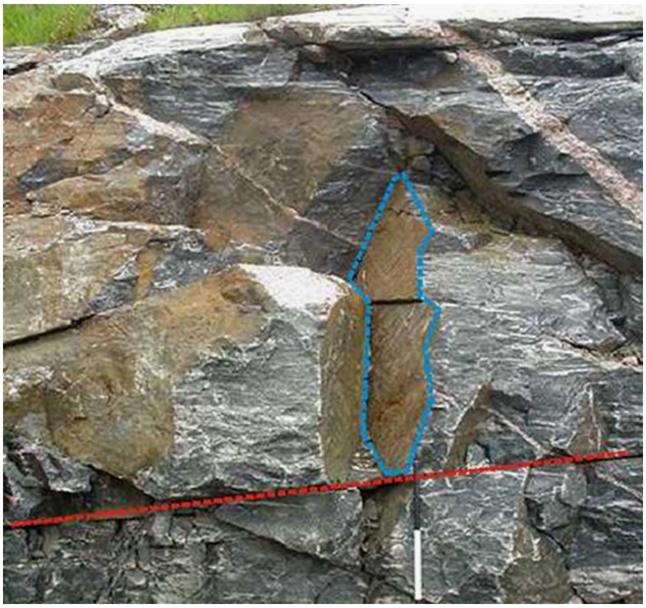

Fig. 1. Rock cut showing both fracture trace (red line) and facet (cyan polygon) [7].

3.1. *Principle demonstration*

A simple demonstration of the principle is presented using Fig. 2(a) and (b). Fig. 2(a) highlights the facet measurements, and Fig. 2(b) adds the trace measurements. Both the facets and traces are identified with a set number. In this case the set numbers of the facets and set numbers of the traces were made to correspond with each other for the purposes of this demonstration.

3.2. *Combining trace and facet measurements*

The two methods by which 3-D facets orientations can be combined to yield 2-D trace orientation are the stereonet and the vector dot product approaches.

3.2.1. *Stereonet approach*

A stereonet can be used to determine which facet and trace orientations go together by plotting the great circle of the facet orientation and the vector of the trace orientation. If the trace belongs to the same set as the facet, i.e. the trace sits on the same plane as that of the facet, then the trace vector will fall on the great circle of the facet (give or take measurement error and natural orientation variability) on a stereonet. If the vector terminates on the great circle then the trace and the facet are co-planar, and belong to the same set (Fig. 3). Using all of the trace and facet information in Fig. 3, it can be established for the case of all four sets that the trace vectors terminate on the great circle of the facet for each set (Fig. 4).

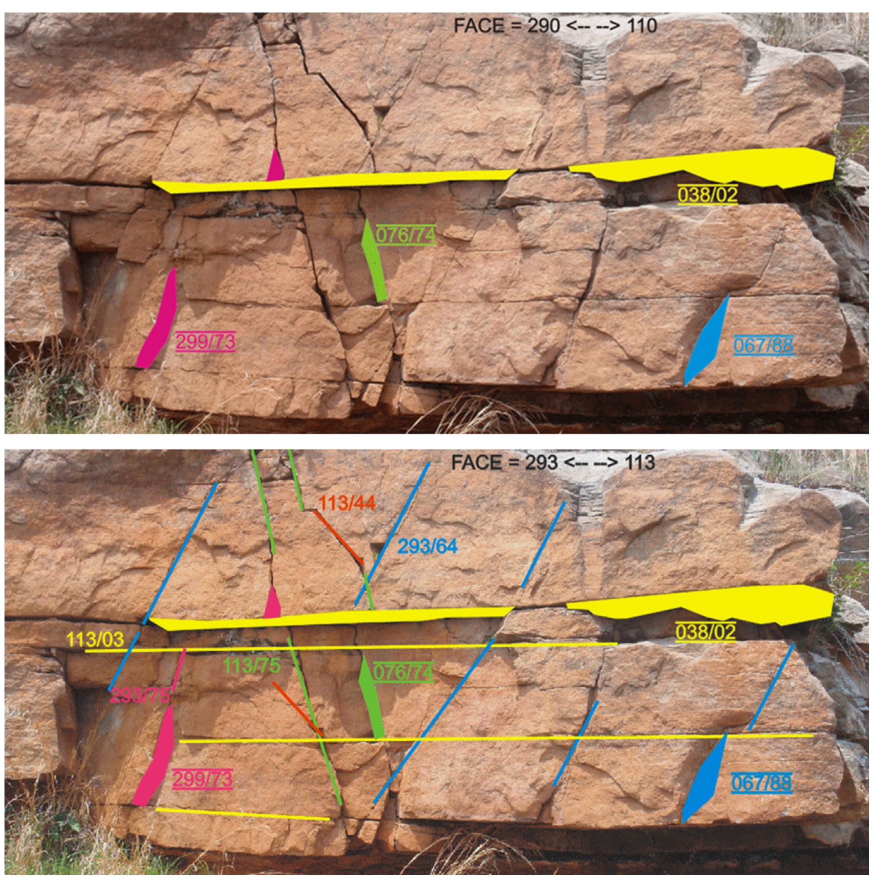

Fig. 2. (a) Test rock cut with facets measured in terms of dip direction/dip angle. Each color represents a different set (Magenta set 1, Green set 2, Yellow set 3, Blue set 4). (b) Test rock cut with both traces and facets, traces were measured in terms of dip azimuth and plunge. The colors of the traces correspond to the colors of the facets (Magenta set 1, Green set 2, Yellow set 3, Blue set 4). The red colored traces do not have a corresponding facet.