The Use of LiDAR for Evaluating Geologic Structure Related to Rock Slope Safety and Stability

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Geohazards Impacting Transportation in Appalachia - 13th Annual Technical Forum
Harrisonburg, VA - August 1, 2013
Types of rock slope failures

Failure Types based on geologic structure

- Circular
- Planar
- Wedge
- Toppling

Different types of slope failures plot differently on dip-vector stereonets. Some examples are shown here.
**Discontinuity**: a weakness in a rock mass along which sliding may occur or water might flow.

Also defined at a break in the continuity of a rock mass...

- bedding planes
- foliations
- faults
- joints
- fractures

Stability analyses begin with the mapping of geologic structures to determine their orientations in space...
Characteristics: dip, dip direction, structure, roughness, water, continuity, infilling material…
Orientation: strike, dip, dip direction...
Detailed line mapping...
Window Mapping

Traditional Brunton compass
The Clar compass is a geological compass designed and manufactured by F.W. Breithaupt, Kassel 3500, West Germany. It is used for aligning with the direction of the Earth's magnetic field.

**Figure 22:** Geological compass designed and manufactured by F.W. Breithaupt, Kassel 3500, West Germany.

**Instructions:**
- Level compass, release clamp and turn compass until needle points north. Clamp needle.
- Use coin to turn adjusting screw to correct magnetic deviation. Zero on scale now reads true north.
- Place measuring plate against rock face and level compass. Release needle clamp and re-clamp after needle has settled.

**Readings:**
- Read dip of plane. In this example, dip is 35 degrees.
- Read dip direction of plane. In this case, dip direction is...
Latest Brunton compass

TruPulse 360b Laser
Now there’s even...

“an app for that...”
Virtual Data Acquisition Systems

• Laser scanning
  – Optec
  – Leica Geosystems
  – Split-FX software

• Terrestrial photogrammetry
  – Sirovision
  – Adam Technology
  – 3G Joint Metrix
• Laser scanning
  – Optec scanner
  – Split-FX software
New software is available to automatically perform rock mass fracture characterization on exposed rock faces.

The Split-FX™ software can analyze rock slopes, underground excavations, dam and bridge foundations, and other rock engineering sites of interest.

Utilizing ground-based 3D LIDAR point clouds (LIDAR: Laser Imaging Detection and Ranging) and Digital Image Processing, the Split-FX software first requires a field survey, which can take as little as 10 minutes. The results of the field survey are then automatically processed with the Split-FX software, resulting in three-dimensional information about the rock mass, including stereo nets of fracture orientation, distributions of fracture size and a roughness estimation. From start to finish, you can accurately characterize the rock mass at a field site in less time than it takes to make a few strike and dip measurements manually!
WHY USE SPLIT-FX?

- Perform rock mass site characterization in a safe and timely manner.
- Conduct analysis at significant distance from the rock face where access to the face is not possible due to safety or other concerns.
- Produce a database of thousands of fractures for a rock site in less time than just a few fractures could be characterized using traditional techniques.
- Eliminates human bias by automating the process of collecting and processing rock mass data.
Sirovision is a complete rock mass structure mapping and analysis system

Sirovision is a completely new technology for mapping the geological features and interpreting the geotechnical characteristics of exposed mining faces using digital photography.

Using images taken with a commercially available digital camera, the Sirovision Siro3D system uses sophisticated image processing algorithms to generate an accurate, detailed 3D model of the rock face. This 3D model is then itself analyzed using the robust computational geometry in SiroJoint to extract un-biased and accurate geotechnical data.
FUNCTIONS

Create 3D models
- Import digital images
- Manage survey data
- Select mapping areas
- Create 3D models

View and Edit 3D models
- Extract measurements
  e.g. vectors from 3D models.
- Map single points or line strings etc.

Export 3D model data
- Data export formats are compatible with software such as Microsoft Excel® and mine design packages allowing easy input and use of 3D model data in these packages.

Structural and Geotechnical Analysis
- Mapping of trace location and orientation
- Mapping location and orientation of discontinuity planes – dip direction etc
- Analysis and display of joint set statistics
- Visualisation of structure
- Data export in a range of formats including DXF, and Dips.

Check out our websites: www.datamine.co.uk   www.sirovision.com
Contact free acquisition and assessment of rock and terrain surfaces by metric 3D images

1/25/2011
Visit us during the ISEE 2011 in San Diego, USA. more...

12/07/2010
New distributor in India more...

› 2011 exhibitions....
› BMX BlastPlanner Demo more...
› JMX Analyst Demo more...
› Free 3D image viewer more...

Complete systems:

**JointMetriX™**

**ShapeMetriX™**

**BlastMetriX™**

Applications:

- Bench face surveying
- Tunnelling
- Mining
- Stability
- Monitoring
- Documentation
Equatorial stereonet projection
STEREONET ANALYSES

Orientations of planes in space

A

B

Stereonet representations of a plane having dip direction & dip of 090/28
STEREONET PROJECTION
DIRECTIONS

- Equatorial:
  - Dip Vectors
  - Poles
  - Great Circles

- Polar:
  - Dip Vectors
  - Poles
Polar stereonet projection
I-77 southwest
Virginia
Montana
Two structural domains, three failure modes
The Smart Road
An excellent example of structural control of stability
MARKLAND TEST PLOT: c:\rkpk2-04\data\a207
Friction Angle = 25 degrees
Slope dip direction = 38 degrees, Dip =
Number of Stations = 21

MARKLAND TEST PLOT: c:\rkpk2-04\data\a20714.DAT
Friction Angle = 25 degrees
Slope dip direction = 38 degrees, Dip = 90 degrees
Number of Stations = 21
Graduate research by Robin Reed
The design dilemma:

- vertical slopes are **not** usually the best, thanks to discontinuities
- work with the geologic structures first to eliminate rockslides
- then mitigate falling and rolling rock with barriers & mesh

Colorado Rockfall Simulation Program
CRSP
A limestone quarry in Pennsylvania...

Our first attempt to use LiDAR in a rock slope investigation
MSHA Mandated Board of Review
Following a rockslide of 600,000 cubic yards…

February 2007
Geometries for back calculations
Interpretation by CFW
Pre-slide geometries

Discontinuities can both transmit water & develop destabilizing water pressures!
Post-slide Geometry

Remaining pinnacle a safety concern?
LIDAR points of interest in remaining rock mass
Drilled & blasted by Janod
Remaining adjacent slab - Safety Concern? – Role of Water?
3d Rendering of the Auxiliary Spillway and Folsom Bridge Road
Model and Animation
Structure exposed during construction of spillway

2011 - 2012

Skip Watts & Dick Goodman
Structure exposed during construction of spillway
Field Trip Site
Rt 629, Deerfield, VA
before failure
Dr. Andrew Foy & George Stephenson of Radford University, Leica C10

VDOT’s Brian Bruckno tells all
Various steps in the processing of the LiDAR data to obtain stereonets
LiDAR Point Cloud - Stereonet stability analyses
Rt 629 Deerfield, VA

Plotted in Dips

Plotted in RockPack III
Yosemite National Park

Aerial LiDAR shaded relief image overlain in Google Earth
1996 – 2008
Each rockfall has its own story
All except the ‘96–’99 rockfalls had obvious weather related triggers.
Unfortunately, the rockfall timing in 1996, 1998-1999 matched periods of wastewater discharge from visitors’ facilities on top of Glacier Point.

Rockfall events compared to tank overflow (top). Rockfalls & rockfall sounds compared to tank overflow, event data from Snyder 1999, Report to Chief Ranger Andrew (bottom).
Yosemite rockslides:
The July 10, 1996
Happy Isles event

[photos by David F. Walter]
Happy Isles effects...

USGS photos
Wastewater management above the slide area...

1996 leach field area (in August 1997)
1996 Rockslide Area

1996 Wastewater Line

Leach field

Dominant Discontinuity Orientations

Most Probable Groundwater Flow Paths

1996 Rockslide Area

[USGS photo]
Seepage points at the release area, 1996
Geologic structure shapes the cliffs & guides the water.
Groundwater Flow Paths

Drainage area

Apparent dips, not true dips

J2 fractures

Groundwater Flow Paths

1998-99 Release Area

Glacier Point, Yosemite National Park (modified from USGS Photo)
1998-99 rockfall source

Tebush Discontinuity
CONCLUSION

LiDAR is one of several tools that can be extremely useful under the right circumstances for obtaining geologic structure orientation data useful for evaluating the safety and stability of rock slopes.
Fracture Permeameter

Parallel plates of Plexiglas

• Variable aperture & dip angle
• Variable head
• Variable infilling materials
• Piezometer tube array in top plate for measuring pressure distribution