Slope Monitoring Methods in the Mining Industry

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Open pit mining creates the highest man-made rock faces on earth – presenting slope stability hazards.

Bingham Canyon Mine, Utah. Pit slopes up to 3,500 feet (1,100 m) high.
Slopes can present a hazards to assets (personnel, equipment, ore reserves)
Gold Mine - Montana
Coal Mine - Wyoming
Copper Mine - Arizona
Slope Monitoring

- Detect movement
- Measure displacement
- Determine displacement trend
  - Uniform
  - Decelerating
  - Accelerating
Slope Monitoring Methods
(Low to High Tech)

- Visual observation
- Crack monitors
- Wireline extensometers
- Surveying with prisms
- Slope Stability Radar
- LiDAR
- InSAR
Crack Monitoring

• Small cracks at the top of the pit or unstable area are often an early warning sign of instability.

• Crack monitoring can start with simple makeshift devices as soon as the crack is noticed.
Wireline Extensometer

End of line anchored beyond crack

Extensometer

Wireline tensioned w/weight & pullies
Surveying with Prisms

• Precise (millimeter precision) 3-axis slope movement monitoring of very large areas.
• Most widely used slope monitoring system in mining.
Slope Stability Radar
Slope Stability Radar (SSR)

- Sub-millimeter distance range measurements between antenna and continuous points on slope over a set scanned area.
- Range up to 3 ½ km.
- Rapid “tactical” deployment and setup.
SSR Data Presentation

Velocity of two selected pixels in scanned area

Critical alarm velocity

Blue is Area #2
Green is Area #7

Time of Failure
LiDAR

(Light Detection and Ranging)

• Uses speed of light to measure distance from instrument.
• Ground- or aerial-based surveys.
LiDAR Capabilities

• High precision, geo-referenced, 3-D “point cloud” data and imagery of rock faces.
  – Examine rock faces from inaccessible perspectives (drone-based systems).
  – Obtain detailed geometry of cracks, fractures, joints, and other discontinuities on the rock face.
  – Point-cloud computer analysis software can plot discontinuity data and determine potential rock slope failure modes.
LiDAR Capabilities

- Drone based 3-D point cloud image of a failing pit slope (not a photograph). Images constructed from millions of geometric data points:
LiDAR Capabilities

- 3-D point cloud image of a rock face.
- Precise geometry of the discontinuities can be extracted from the data.
LiDAR Capabilities

- LiDAR-generated data of rock face – point cloud and stereonet plots of the discontinuity orientations…
InSAR
(Interferometric Synthetic Aperture Radar)

• Various satellites in operation since 1992.
• Datasets provide 1-2 mm resolution coverage of ground movement for most of the Earth.
InSAR

Large-area application - investigating subsidence after underground coal mine pillar failure accident.
InSAR

- Surface Deformation from USGS InSAR.
- Each “fringe” depicts 5 cm of subsidence that occurred between successive satellite passes.
InSAR

Advantages:

• High precision – can detect 1 to 2 mm displacements.
• Large coverage – data is available for most of earth back to 1992.
• Remote sensing – no ground instruments or site work needed.
• Full site monitoring – can detect movements where risk was not previously suspected.

Disadvantages:

• Measurement frequency limited by satellite passes from 2 to 12 days.
• A supplement, not replacement, for local monitoring methods like prisms and SSR.
Data Interpretation

Progressive movement to failure…
Predicting Time to Failure

Inverse velocity (1/v) often used in predictive models.

Fit trend line to data (Quadratic in this case)

Predicted failure time (i.e., velocity approaches “infinity”)
Predicting Time to Failure

Inverse velocity (1/v) method – SSR data example

Predicted failure (intercept) at 2 Nov, 09:33
Predicting Time to Failure

Actual failure was on 2 November at about 1:00 p.m.
Instruments and radar detected critical wall movements. Pit evacuated prior to failure.
Radar monitoring detected critical movement. Pit evacuated ten hours before failure.