Types of slope instruments

Displacement monitoring devices
  Precise surveys
  Differential global positioning systems (DGPS)
  Space-borne and terrestrial SAR interferometry

Strain monitoring devices
  Surface extensometers
  Borehole extensometers
  Borehole inclinometers
  Tiltmeters
  Time domain reflectometry (TDR)

Pore-pressure measurements
  Piezometers and monitoring wells
  Tensiometers
  TDR moisture gauges

Microseismicity
  Geophones
Displacement monitoring

1) “Total Station”: Electronic Distance Measurement (“EDM”) + Theodolite

2) “DGPS” Differential Global Positioning System: Base station+measuring stations

Britannia Mine, B.C. Disturbed Area
**East Block, failure model**

![East Block](image)

- **PR #100**
- **PR #104**
- **PR #102**

Elevation (m): 1000, 1050, 1100, 1150, 1200, 1250, 1300, 1350, 1400

- Toppling (schematic)
- Tension cracks

Toppling volume: 300,000 m³
**Wire extensometer**

With data logger

**Borehole extensometer** (Slope Indicator, Ltd.)
Surface rod extensometer ("crackmeter")

Vibrating wire displacement gauge (or a vernier for manual readings or a linear transducer) accuracy <1mm

Tape extensometer

Rod Extensometers
ISMES, Valtellina, Italy
ETH, Switzerland
Borehole inclinometer (“Slope Indicator”)

Some inclinometer applications (Slope Indicator, Ltd.)
Time domain reflectometry (TDR)

Principle of TDR
1. Electrical pulse sent down ideal cable
2. Pulse reflected at open and breaks
3. Severity of and distance to reflection is determined

TDR Signatures

California Highway 1 - Gorda
Monterey County, California

Synthetic aperture radar interferometry (SAR)

Table:

<table>
<thead>
<tr>
<th>Lane</th>
<th>Description</th>
<th>Speed</th>
<th>Speed Kind</th>
<th>SAT Status</th>
<th>D2 Dine SAR</th>
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<tr>
<td>1</td>
<td>Laneside</td>
<td>5.15 m/s</td>
<td>5.15 m/s</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td>2</td>
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<td>5.15 m/s</td>
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<td>No</td>
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<td>No</td>
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<td>7</td>
<td>Laneside</td>
<td>5.15 m/s</td>
<td>5.15 m/s</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
Piezometers

1) Observation well (open) – not a piezometer
2) Pneumatic piezometer
3) Standipe (Casagrande) piezometer
4) Electric piezometer (Vibrating Wire)

Piezometer comparison

<table>
<thead>
<tr>
<th></th>
<th>Standpipe</th>
<th>VW</th>
<th>Pneumatic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>Depth of standpipe</td>
<td>50, 100, 250, 500 psi</td>
<td>100 psi</td>
</tr>
<tr>
<td>Response Time*</td>
<td>Slow</td>
<td>Fast</td>
<td>Fast</td>
</tr>
<tr>
<td>Reading Time*</td>
<td>Minutes</td>
<td>Seconds</td>
<td>5 minutes with 200 feet of tubing. Longer times with longer tubing.</td>
</tr>
<tr>
<td>Readout*</td>
<td>Water level indicator</td>
<td>Portable readout. Lighter, smaller.</td>
<td>Portable readout. Larger and heavier because of internal tank.</td>
</tr>
<tr>
<td>Remote Access*</td>
<td>No. Reading is obtained at top of standpipe</td>
<td>Yes. Signal cable can be run to remote readout station.</td>
<td>Yes. Tubing can be run to remote readout station</td>
</tr>
<tr>
<td>Damage*</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Main Limitations</td>
<td>No remote access.</td>
<td>Long horizontal runs of cables should be protected from electrical transients.</td>
<td>Slow reading time</td>
</tr>
<tr>
<td>Main Cost of Installation</td>
<td>Borehole. Components are the least expensive of any type of piezometer.</td>
<td>Borehole. Components are more expensive than pneumatic or standpipe.</td>
<td>Borehole. Components are less expensive than VW piezometers.</td>
</tr>
</tbody>
</table>
Slope Indicator multi-point vibrating wire piezometer

Monitoring Interpretation

Grasberg, 2003
Chuquicamata Mine, Chile, 1968

Movement vector F-2

Micro-seismic events/day

Chuquicamata Mine

Movement vector F-2

Micro-seismic events/day
Inverse Velocity Method (Fukuzono, 1985)

Inverse Velocity Method, more examples

Tripp Mine: slow failure
Inverse Velocity Method, another example

Regression coefficient (R²) = 99%
for all inverse-velocity fits

Predicted velocity curves (based on inverse-velocity fits) compared with actual velocity data

18 million m³ pit slope failure prediction (Rose and Hungr, 2006)
Use of inverse velocity to monitor stabilization progress (Rose and Hungr, 2006)

Two faults and a pre-sheared silt layer, 3 million m$^3$

Regression Coefficient ($R^2$) = 96 to 99% for all inverse-velocity fits.

Total Displacement?
100 m pre-historic movement

ValPola rock avalanche, 1986
Small rock slides

Libby Dam, Montana, 1971
Prediction not feasible

Purpose of monitoring

1) Movement detection, failure prediction
2) Vector solutions, interpretation of failure mechanism

Predicted rupture surface

(Cruden, 1986)