Rock Engineering Practice & Design

Lecture 13:
Instrumentation Planning & Design
Author's Note:

The lecture slides provided here are taken from the course “Geotechnical Engineering Practice”, which is part of the 4th year Geological Engineering program at the University of British Columbia (Vancouver, Canada). The course covers rock engineering and geotechnical design methodologies, building on those already taken by the students covering Introductory Rock Mechanics and Advanced Rock Mechanics.

Although the slides have been modified in part to add context, they of course are missing the detailed narrative that accompanies any lecture. It is also recognized that these lectures summarize, reproduce and build on the work of others for which gratitude is extended. Where possible, efforts have been made to acknowledge the various sources, with a list of references being provided at the end of each lecture.

Errors, omissions, comments, etc., can be forwarded to the author at: erik@eos.ubc.ca
Instrumentation & Monitoring

The use of geotechnical instrumentation is not merely the selection of instruments but a comprehensive step-by-step engineering process beginning with a definition of the objective and ending with implementation of the data.

Engineering objectives typically encountered in soil and rock engineering projects have led to the design and commercial marketing of numerous instrument types, measuring for example:

- temperature
- deformation
- groundwater/pore pressures
- total stress in soil and stress change in rock
Field Instrumentation

Geotechnical engineering projects often present the ultimate measurement challenge, in part because of their initial lack of definition and the sheer scale of the problem. The measurement problem usually requires information ranging from a coarse scale down to a fine scale and involving a number of instrumentation techniques.

The ultimate goal is to select the most sensitive measurement parameters with respect to the project objectives, e.g. the ones that will change significantly at the onset of failure. However, because of physical limitations and economic constraints, all parameters cannot be measured with equal ease and success.

<table>
<thead>
<tr>
<th>Example of Hazard Warning Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Warning Level</strong></td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
</tbody>
</table>

Franklin (1977)
Planning and Design

Adequate planning is required before proceeding, and these plans should be logical and comprehensive – from defining the objectives to planning how the measurement data will be implemented.

The steps through which planning should proceed include:

1. Define the project conditions.

... these might include project type and layout, geology and structure, engineering properties of materials, groundwater conditions, status of nearby structures or other facilities, environmental conditions, and planned construction method.
Planning and Design

2. Predict mechanisms that control behaviour.

... may involve one or more working hypotheses based on a comprehensive knowledge of the project conditions.

Where brittle fracture mechanisms contribute significantly to rock mass deformation and failure, microseismic monitoring may form an integral part of the monitoring strategy.
Planning and Design

3. Define the geotechnical questions that need to be answered.

... every instrument on a project should be selected and placed to assist in answering a specific question: if there is no question, there should be no instrumentation.

Monitoring serves a number of important functions, including:

(i) Investigative Monitoring: To provide an understanding of the rock mass behaviour and thus enable appropriate actions to be implemented.

(ii) Predictive Monitoring: To provide a warning of a change in behaviour and thus enable the possibility of limiting damage or intervening to prevent failure.

Imrie et al. (1992)
Planning and Design

4. Define the purpose of the instrumentation.

... Peck (1984) stated that, “The legitimate uses of instrumentation are so many, and the questions that instruments and observation can answer so vital, that we should not risk discrediting their value by using them improperly or unnecessarily.”

... monitoring the performance of a waste barrier system designed to prevent the polluting of a major aquifer from a chemical waste dump in Switzerland.
Planning and Design

5. Select the parameters to be monitored.

... Parameters include pore water pressure, joint water pressure, total stress, stress change, deformation, load and strain in structural members, and temperature.

... high precision joint water pressure measurements at the Bedretto tunnel adit, Switzerland.
6. Predict magnitudes of change.

... Predictions are necessary so that the required instrument ranges and required instrument sensitivities or accuracies can be selected.

... 1999 Eibelscrofen rockfall in the Austrian alps.

Post-failure monitoring of the slope included the installation of a fibre-optic extensometer capable of measuring displacements on the scale of $\mu$m. Was this practical?
7. Devise remedial action.

... Inherent in the use of instrumentation for construction purposes is the absolute necessity for deciding in advance, a positive means for solving any problem that may be disclosed by the results of the observation.
Planning and Design

8. Assign tasks for design, construction and operation phases.

... Instrumentation specialists may be employees of the owner or the design consultant or may be consultants with special expertise in geotechnical instrumentation. When assigning tasks for monitoring, the party with the greatest vested interest in the data should be given direct line responsibility for producing it accurately.
Planning and Design


... When selecting instruments, the overriding desirable feature is reliability! Inherent in reliability is maximum simplicity.

- Optical
- Mechanical
- Hydraulic
- Pneumatic
- Electrical

Instruments should be: reliable, rugged and capable of functioning for long periods of time without repair or replacement; capable of responding rapidly and precisely to changes so that a true picture of events can be maintained at all times.
10. Select instrument locations.

... The selection of instrument locations should reflect predicted behaviour and should be compatible with the method of analysis that will later be used when interpreting the data.

... instrumentation layout at the Randa Rockslide Laboratory in the Swiss Alps.

Willenberg et al. (2008b)
11. Account for factors that may influence measured data.

...Details of each instrument installation should be recorded, because local or unusual conditions often influence measured variables.

12. Establish procedures for ensuring reading correctness.

...When reading an instrument, one should be able to answer the question: Is the instrument functioning correctly? The answer can sometimes be provided by visual observations, duplication of instruments, data consistency or through the use of instruments that internally check their own correct functioning.

Instrument Environments

1. Large deformations—often shearing deformations
2. High pressures—both solids and fluids
3. Corrosive—chemical (groundwater, grouts, concrete additives, bacteria) and electrolytic (electrolysis of dissimilar materials, stray electrical currents)
4. Temperature extremes—subfreezing to 100°F + in the sun (temperature can be higher in certain instances, such as nuclear waste storage)
5. Shock—blasting, construction activities, rough handling during transportation to and from site
6. Vandalism, destruction by construction equipment, fly rock
7. Dust, dirt, mud, rain, chemical precipitates
8. High humidity, flowing or standing water
9. Erratic power supplies (electrical instruments)
10. Loss of accessibility to instruments when covered by rock, soil, shotcrete, and other supports

Dunnicliff (1993)
13. List the specific purpose of each instrument.

... It is useful to question whether all planned instruments are justified. If no viable purpose can be found for a planned instrument, it should be deleted.


... A budget should be prepared for all instrumentation-related tasks to ensure sufficient funds are indeed available. A frequent error in budget preparation is to underestimate the duration of the project and the real data collection and processing costs.

15. Prepare instrument procurement specifications.

... There are several competing instrumentation manufacturers, each offering products designed for similar geotechnical purposes. Be aware of an instrument’s capabilities (and limitations), as well as those of competing products. Instruments should be purchased from established manufacturers.

... Installation procedures should be planned well in advance of scheduled installation dates. The step-by-step procedures should include a detailed list of required materials and tools, and installation record sheets for documenting factors that may influence measured data.

... schematic diagram of the borehole instrumentation and installation design developed for the Randa Rockslide Laboratory in Switzerland.
Planning and Design

17. Plan data collection, processing, presentation, interpretation, reporting and implementation.

... The effort required for these tasks should not be underestimated. Many consulting firms have files filled with large quantities of partially processed and undigested data because sufficient time/funds were not available for these tasks.
Geodetic monitoring provides a means to measure the magnitude and rate of horizontal and vertical ground movements. Methods are well established, and are often entirely adequate for performance monitoring.

Advantages: automated (total station), inexpensive, versatile.
Accuracy: typically ±2mm + 2 ppm x D mm over 3000 m

Bonzanigo et al. (2007)
Measurement accuracy (and reliability) is controlled by the characteristics of reference datums and measuring points. Checks are required to make sure these datums are located on stable ground.
... satellite measurements and base-stations at known locations are used to provide simultaneous corrections and refinements to the computed locations of one or several differential global positioning system (DGPS) stations positioned on the slide body.

Advantages: automated, economical (especially over large areas).
Sensitivity: better than 1 cm in ideal conditions
Instrumentation - Crackmeters

... used to measure and monitor the opening of surface fractures and tension cracks.

Advantages: simple, ideally suited for early warning systems.
Sensitivity: <0.01mm with 50-100 mm range
Instrumentation - Convergence Indicators

Convergence is one of the most frequently made underground measurements. Made between two or more fixed points around the excavation perimeter, repeat monitoring provides rates of convergence, changes in rate and total convergence values.

Advantages: simple, inexpensive and robust in an underground environment.
Sensitivity: <0.1mm over a 10m span

Brady & Brown (2006)
Borehole Instrumentation - Inclinometers

Inclinometers monitor differential subsurface deformations by means of a probe that measures changes in inclination along the length of a borehole.

Advantages: can detect and monitor complex slope deformations and displacements along multiple shear planes.
Sensitivity: ±10 arc seconds (±0.05mm/m)
Inclinometer Casing

OUTSIDE OF COUPLING

ALUMINUM

GROOVES TO ALIGN INCLINOMETER SENSOR

ABS PLASTIC

152 mm (6 in) ALUMINUM COUPLING BUTT JOINT AT CASING END

305 mm (12 in) ALUMINUM COUPLING POINT OF CONTACT FOR SETTLEMENT PROBE WHEN MAKING SETTLEMENT MEASUREMENTS

152 mm (6 in) CASING END

ALUMINUM CASING

POP RIVETS AT END OF COUPLING

ALUMINUM CASING

POP RIVETS AT 1/4 POINTS

1.5 m (5 ft) or 3 m (10 ft) STANDARD CASING LENGTH
Inclinometer Installation
Inclinometer Measurements

Bonzanigo et al. (2007)
... extensometers measure the relative change in position between several fixed points.

Advantages: simple to install, inexpensive, can measure larger slope displacements than inclinometers.

Accuracy: ±0.01 mm/m
Time Domain Reflectometry (TDR) - uses characteristics of returned electrical pulses to determine the amount of strain, or the existence of a rupture, in a coaxial cable.
Vibrating wire piezometers consist of a diaphragm, which when deflected by pore pressures, can be measured by an electrical transducer. These have the advantage of a negligible time lag and being extremely sensitive.
Fiber-Optics - light that is launched into and confined to the fiber core propagates along the length of the fiber unperturbed unless acted upon by an external influence. Any disturbance of the fiber alters the guided light which can then be related to the magnitude of the disturbing influence.
Case History: Investigative Slope Monitoring

1991 Randa Rockslide

current instability

Scarp (May 9, 1991)
Scarp (April 18, 1991)

Orthogneiss
Perigneiss

topography before rockslide

200 m

current topography

Courtesy - H. Willenberg
Case History: Investigative Slope Monitoring

- Brass rings for electromagnetic induction extensometer
- Inclinometer casing
- Geophone
- Piezometer
- Measuring position
- Increment probe
- Pipes and casing
Case History: Investigative Slope Monitoring

Wind generator (400 W) — Solar panel (600 W)

On-Site PC
- control software
- temporary storage

Geotechnical Datalogger

off-site

Valley PC
- data backup

ETH Zurich PC
- on-site clock synchronization
- data backup
- data processing

SB 120
SB 50N
SB 50S
Shallow Boreholes

Sensor types:
- Geophone
- Piezometer
- In-place inclinometer
- Crackmeters
Case History: Investigative Slope Monitoring

Geological investigations

Geophysical investigations

3-D geological model

Rock Slope Instability

Willeberg et al. (2008a)
Case History: Investigative Slope Monitoring

- **Geological investigations**
- **Geophysical investigations**
- **3-D geological model**
- **Rock Slope Instability**
- **Kinematics of the rockslide**
- **Geotechnical monitoring**
- **Microseismic monitoring**
- **Numerical modelling**

Willenberg et al. (2008b)
Case History: Investigative Slope Monitoring

Frequency content of attenuated microseismic signals suggest the presence of large open fractures, deep (>100 m) below surface.
Integrated data model: Probability density functions (PDF) of microseismic event locations, and relative displacement rates of ongoing block movements.

Kinematic model defined by the collective measurements.

Willenberg et al. (2008b)
Monitoring data provides a key means to constrain numerical models. At the same time, numerical modelling provides an ideal means to support and/or refute interpretations drawn from investigative monitoring, as well as to explore possible future behaviour.
Lecture References


Lecture References


