Developments in slope warning systems

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Presentation overview

- Early warning of slope instability
- Acoustic emission (AE) monitoring
  - Slope ALARMS and the active waveguide
- Field monitoring case studies and comparisons with other instruments
  - UK, Italy, Austria and Canada
- Monitoring first-time failures: large-scale physical modelling
- Summary: The benefits
Slope warning system specification

- Sufficient warning to enable action to be taken (implement emergency plan)
- No false alarms (undermines confidence)
- Provide information on rates and magnitude of movement (assess likelihood and significance)
- Identify mode of failure (assess significance)
Early warning of slope instability

- Reactivation vs. first-time failure
- Mechanisms driving failure:
  - Increased pore-water pressures and reduced effective stress
  - Loss of shear strength, shear surface development, progressive failure
- What can we monitor to give early warning?
  - Rainfall? Pore-water pressure? Moisture content?
  - Deformation (is it moving?)
  - Rates of movement (how fast is it moving?)
  - Changes with time (is it accelerating?)
Acoustic Emission (AE)

- AE are relatively high-frequency stress waves which propagate through materials surrounding the generation source (10s of kHz)
- The AE monitoring technique is well established in other industries
- In soil, AE is generated by inter-particle friction and hence the detection of AE is an indication of deformation
- Research over a 50 year period has shown that AE can be used to detect deforming soil bodies (slopes)
The active waveguide and Slope ALARMS

System operation

Slope ALARMS

- Collaboration between Loughborough University and the British Geological Survey
- Unitary battery-powered device
- Piezoelectric transducer detects AE
- Sensor node measures AE ring-down counts (RDC) and logs the number for a set time period (e.g. 15, 30, 60 minutes)
- Automatic SMS messages sent when thresholds are exceeded
- Trials are underway at sites throughout the UK and in Austria, Italy and Canada
Hollin Hill landslide, UK: Comparison between continuous AE and SAA measurements

Challenges

- High attenuation of soil-generated AE as it propagates through the soil mass in 3-dimensions
  - **Solution:** Development of the active waveguide

- Need to filter out background noise (e.g. generated by environmental noise, construction activity and traffic)
  - **Solution:** Use of high (>20 kHz) monitoring frequencies

- Requirement for a unitary portable technology that can monitor AE continuously for long-durations in the field environment
  - **Solution:** Development of the Slope ALARMS sensor node

- Need for strategies to interpret and quantify deformation behaviour from the measured AE
  - **Solution:** Physical modelling and field trials

Field trials of the AE monitoring approach

- Trials through installation of active waveguides in unstable (and marginally stable) natural and engineered soil slopes, AND grouted waveguides in rock slopes

- Performance is compared with conventional periodic inclinometer measurements and continuous subsurface ShapeAccelArray deformation measurements
National field trials

Nafferton embankment, Newcastle

Flat Cliffs, Filey, North Yorkshire

Hollin Hill, North Yorkshire

Scarborough Spa, North Yorkshire

Ruthlin & Dyffryn, Monmouthshire

Totton, Southampton

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Peace River, Alberta, Canada
Ripley, British Columbia, Canada
Grossreifling, Austria
Passo della Morte, Italy
International field trials
Hollin Hill field trial: site description

Hollin Hill field trial: instrumentation

Typical AE response to reactivated slope movements (Hollin Hill)

Quantification of velocity and displacement from AE (Hollin Hill)

Comparisons with continuous subsurface ShapeAccelArray deformation measurements (Hollin Hill)

Comparable AE and deformation behaviour

Velocity (mm/hour) and Velocity (smoothed) (mm/hour)

AE rate (RDC/hour) and AE rate (smoothed) (RDC/hour)

Triggering rainfall events

Retrofitted inclinometer casing (Hollin Hill)

Retrofitted inclinometer casing performance (Hollin Hill)

Players Crescent rail cutting slope trial

Players Crescent rail cutting slope trial: comparison with SAA

1 mm in 2 weeks
0.075 mm/day!

Players Crescent rail cutting slope trial: warning of movement

Trial for the Austrian Railways

- SART – Sentinel for Alpine Rail Traffic

- In partnership with German Company INGLAS

- Combined system of monitored debris catch fence for immediate warning of threat to line, and Slope ALARMS for early warning for inspection/remedial action

- System linked to OeBB Operation Control Centre

- April 2013 to June 2014 plus extended trial
Trial for the Austrian Railways
Trial for the Austrian Railways: waveguide installation
Trial for the Austrian Railways

Weak conglomerate

Instrumented fence
Trial for the Austrian Railways: event example
Slope ALARMS: Benefits

- AE monitoring can provide an early warning of slope failure
- Information on slope displacement rates is continuous and in real-time
- AE rates generated by an active waveguide are indicative of slope displacement rates
- AE rates increase instantaneously in response to a decrease in slope stability, they are sensitive to small displacements and slow rates, and will continue operating at large displacements (larger than conventional inclinometers)
- Inclinometer casings can be converted into acoustic continuous and real-time displacement rate sensors
- Slope ALARMS sensors have been trialled in a range of applications and compared to traditional instruments
- A low cost ‘Lite’ system could protect vulnerable communities
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- **Stakeholders:** Network Rail, OeBB (Austrian Railway), Alberta Transportation, Scarborough Borough Council, Monmouthshire County Council, Canadian Pacific Railway, Canadian National Railway
Thank you

www.SlopeALARMS.com

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