Introduction by John Dunnicliff, Editor

This is the 88th episode of GIN. Three articles this time.

Acoustic emission

The first article, a nuts-and-boltsy one, by Alister Smith and his colleagues at Loughborough University in England, describes an acoustic emission (AE) slope monitoring system. The article compares the data favorably with ShapeAccelArray (SAA) data. It also includes references to publications about AE monitoring of slopes, how the monitoring system can be purchased, and it invites organizations interested in collaborating to further commercialize the system to discuss opportunities with the authors.

Monitoring a heritage building restoration project

June 2016 GIN included an article by Vincent Le Borgne of GKM Consultants, "Lessons learned in vibration monitoring". Here's another practical article by Vincent about monitoring the 150-year old Parliament Hill's West Block Building in Ottawa while modernizing the building and maintaining its heritage appearance. Particularly interesting to me are the examples of the effects of temperature on monitored data and the importance of obtaining proper baseline data.

General role of instrumentation, and summaries of instruments that can be considered for helping to provide answers to possible geotechnical questions.

The previous four GINs included the following articles:

- Part 1, December 2015. Braced excavations,
- Part 2, March 2016. Embankments on soft ground,
- Part 3, June 2016. Cut slopes and landslides in soil and in rock
- Part 4, September 2016. Driven piles and bored piles (drilled shafts).

Here's the final one in the series, Part 5, Tunnels.

Fourth International Course on Geotechnical and Structural Monitoring, June 13-15, 2017 Rome, Italy. *www.geotechnicalmonitoring.com*

During the last three years more than 330 people have come from 48 countries to attend the "International Course on Geotechnical and Structural Monitoring" in the 1,000 year-old Castle of Poppi in the beautiful countryside of Tuscany. 42 international companies have exhibited their products during the courses.

Evaluations by attendees have shown how very much the courses have been appreciated, both from technical and networking perspectives. We strive to make each edition of the course better than the previous one, including technical, cultural, historical and social considerations.

For 2017 we've decided to take up the challenge of moving the venue to Rome - a city of huge historical and cultural interest that hosts one of the oldest and largest universities in the world: Sapienza University of Rome (the Latin word "sapientiae" means "wisdom" so the university wisely teaches wisdom! Also, sapiens = wise: think "homo sapiens"!). This new venue allows us to satisfy the continuously increasing number of participants and make accessibility for participants easier than in Poppi.

In 2016 we initiated sessions on "New Monitoring Trends" and "Case Histories and Lessons Learned", with presentations given by practitioners and exhibitors. These were well received and in 2017 we plan to strengthen their content. We invite all of you to take advantage of our offer to make presentations during these sessions, by contacting *paolo.mazzanti@nhazca.com*.

In addition, we're organizing some Master Classes that will be held on June 12, the day before the official beginning of the course, led by international experts, specifically oriented to provide practical basic know-how on use of the most common monitoring systems (inclinometers, piezometers, total stations, GNSS, extensometers, terrestrial RADAR). Each class will cover the following main topics: installation, data acquisition, data processing, tricks and tips from everyday experience.

We're very excited about this new "adventure" and we really hope you will share the experience with us. We look forward to meeting you.

Would you or any of your colleagues benefit from basic training about geotechnical engineering?

And/or would you or any of your colleagues benefit from learning how to improve verbal communication skills? If yes, go to:

http://expeditionworkshed.org/workshed/introduction-to-soil-mechanics

These videos, by Dr. John Burland, Professor Emeritus at Imperial College London, help to answer:

- What is geotechnical engineering?
- What is the relationship between civil engineering and geotechnical engineering?
- What does a geotechnical engineer do?
- In what civil engineering projects do geotechnical engineers get involved?

IV INTERNATIONAL COURSE ON GEOTECHNICAL AND STRUCTURAL MONITORING

June 13-15, 2017 (Master Classes on June 12) - Rome (Italy)


2016 Participants


2016 Lecture room


Trevi's Fountain


Sapienza University's entrance


The Statue of Minerva (Sapienza University of Rome)

Course Director: John Dunnicliff, Consulting Engineer
Organizer: Paolo Mazzanti, NHAZCA S.r.l.

THE COURSE: attendance at the course is a great opportunity to establish a valuable network with colleagues from all over the world, to meet manufacturers and see the most recent and innovative instrumentation, thanks to a large exhibition area.

NEW CONTENT:

- Many new speakers, to give the course a fresh look
- Increased sessions for professional presentations about new trends
- Increased case history sessions, presented by selected registrants

COURSE EMPHASIS: the course will include planning monitoring programs, hardware and software, web-based and wireless monitoring, remote methods for monitoring deformation, vibration monitoring and offshore monitoring. Case histories will be presented by prominent international experts.

WHO: engineers, geologists and technicians who are involved with performance monitoring of geotechnical features of civil engineering, mining and oil and gas projects. Project managers and other decision makers who are concerned with management of RISK during construction.

LOCATION: the 3-day course will be held in Rome (Italy), a city of huge historical and cultural interest

MASTER CLASSES: on the day before the main course, six Master Classes will be led by international experts, specifically oriented to provide practical basic know-how on use of the most common monitoring systems. Each class will cover the following main topics: installation, data acquisition, data processing, tricks and tips from everyday experience.

www.geotechnicalmonitoring.com

- What is soil mechanics?

In addition, John Burland has an outstanding presentation style – a model for us all. During the monitoring course in Italy (see above), John will again be telling us about his work to stabilize the Leaning Tower of Pisa and to protect Big Ben in London while excavating for a new "Underground" (subway) station alongside.

Closure

Please send an abstract of an article for GIN to *john@dunnicliff.eclipse.co.uk*—see the guidelines on *www.geotechnicalnews.com/instrumentation_news.php*

Kasutta ("Let our glasses meet") - Greenland

An acoustic emission slope displacement rate sensor: Comparisons with established instrumentation

Alister Smith, Neil Dixon, Daniela Codeglia, Gary Fowmes

What it can do

The following are lessons learned from extensive laboratory experiments and field trials of the Acoustic Emission (AE) slope monitoring system:

- It provides information on slope displacement rates continuously and in real-time.
- It is sensitive to small displacements and very slow displacement rates.
- It is able to inform operators in real-time that a slope is accelerating (or decelerating) with quantification of changes in rates of movement.
- It continues to operate at larger displacements (at >500 mm of shear surface displacement) than other subsurface instruments.
- Inclinometer casings and standpipe piezometer pipes can be retrofitted with the AE system and converted into continuous real-time displacement rate sensors.
- Quantification of displacement rates from detected AE is independent of host slope soil.
- One sensor at a site can inform timing of site inspections and trigger manual readings of inclinometer casings.
- All sensor elements are located at ground level for ease of maintenance and reuse.
- Sensor costs are lower than current continuously read in-place inclinometer systems.
- Low-cost materials are installed in the borehole and are easily reproducible (comparable installation cost to inclinometer casings).

How it works

Acoustic Emission

AE are high-frequency stress waves that propagate through materials surrounding the generation source. In soil, AE is generated by inter-particle friction and in rock by fracture propagation and displacement along discontinuities. Hence, the detection of AE is an indication of deformation.

System overview

The active waveguide (Figure 1) is installed in a borehole that penetrates existing or anticipated shear surfaces beneath a slope. It comprises a metal waveguide tube with a granular backfill soil surround. When the host slope

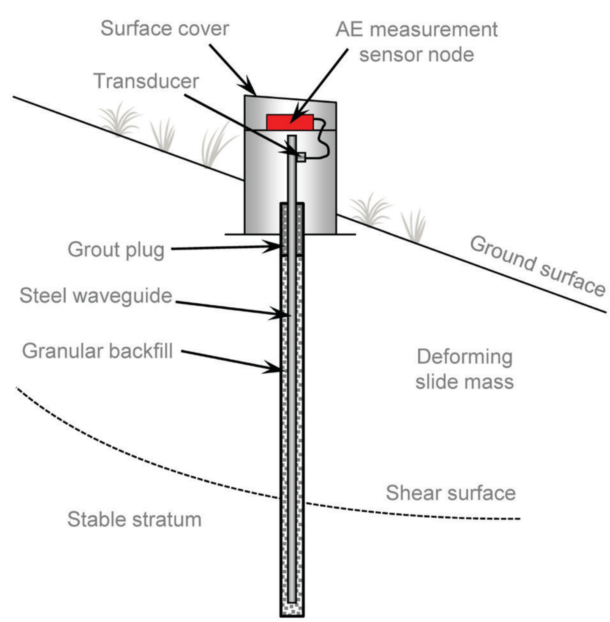

Figure 1. Schematic of an active waveguide installed through a slope with an AE monitoring sensor connected at the ground surface.

deforms, the active waveguide deforms, generating AE that can propagate along the waveguide. A transducer coupled to the waveguide at the ground surface converts the AE to an electrical signal, which is processed by the AE sensor. The AE sensor amplifies the signal and attenuates frequencies outside of the 20 to 30 kHz range, removing low frequency (<20 kHz) environmental background noise (e.g. traffic and construction activity). The sensor records the number of times the waveform crosses a pre-programmed voltage threshold level within pre-set time intervals; ring-down counts (RDC) per unit time (AE rates). The developed AE monitoring system is called Slope ALARMS (Assessment of Landslides using Acoustic Real-time Monitoring Systems).

Interpretation of AE

An increasing rate of displacement generates an increasing number of particle-particle/particle-waveguide interactions in the active waveguide. Each interaction generates a transient AE event, which combine and propagate along the waveguide where they are monitored at the ground surface. Hence, AE rates produced and measured by the system are proportional to the velocity of slope movement. The coefficient of proportionality is a measure of the systems sensitivity (i.e. the magnitude of AE rates produced in response to an applied velocity) and is dependent on a number of variables related to the AE measurement system, such as: the sensor sensitivity controlled by signal amplification and voltage threshold; the depth to the shear surface, which influences the magnitude of AE signal attenuation as it is transmitted from the shear zone to the ground surface by the waveguide; and active waveguide properties such as the tube geometry and backfill properties. The magnitude of AE rate responses produced by each measurement system will depend on these factors, in addition to the rate of slope displacement.

Warning messages

AE rates recorded in each monitoring interval are compared to threshold levels, which are derived for the order of magnitude slope displacement rate classifications (e.g. Cruden and Varnes 1996); ‘slow’ (e.g. 1 mm/hour), ‘moderate’ (e.g. 100 mm/hour) and ‘rapid’ (e.g. 10,000 mm/hour). If a sensor detects RDC within a set time period that exceeds a trigger warning level, the sensor transfers this to the communication system through a wireless network link. The communication system subsequently sends an SMS message to responsible persons so that relevant action can be taken (e.g. send a suitably qualified person to inspect the slope, stop traffic or other relevant action). The absence of generated SMS messages means that slope displacement rates are lower than the minimum threshold set. Automatically generated daily health SMS messages provide information on the status of the system, demonstrating it is operational. The system therefore provides continuous real-time information on slope displacement rates with high temporal resolution (i.e. monitoring periods are typically 15 or 30 minutes). Figure 2 shows an operation schematic of the AE early warning system.

Installation

Active waveguides are typically installed in 130 mm diameter boreholes, although smaller diameter boreholes can be used (e.g. down to 50mm as detailed below). A minimum depth of approximately 2 m below existing or anticipated shear surface(s) is advisable. The waveguide typically comprises lengths of 50 mm diameter 3 mm thick steel tubing connected with screw threaded couplings. The annulus around the steel tubing is backfilled with compacted angular 5-10 mm gravel. The top 0.3 m of the borehole is backfilled with a bentonite grout plug to seal against the ingress of surface water. The steel tube extends 0.3 m above ground level and is encased in a secure protective chamber. The AE sensor is located inside the protective cover. A piezoelectric transducer is attached to the waveguide and linked to the sensor via a cable. Waveguides can also be installed in inclinometer casings as detailed below.

Proof that it works

Comparisons with ShapeAccelArray (SAA) measurements

SAAs installed at Hollin Hill, a shallow reactivated landslide in North Yorkshire, UK, have allowed the comparison of continuous AE with continu-

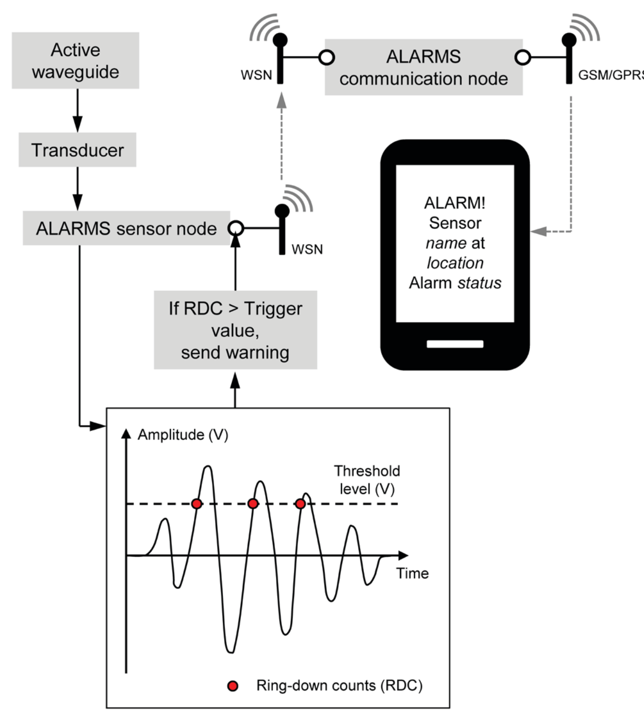

Figure 2. Schematic of operation of the AE monitoring and communication system.

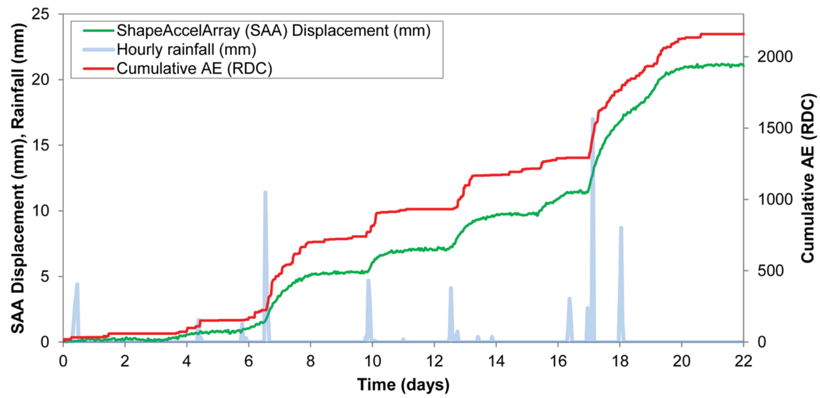

Figure 3. Time series for reactivated slope movements at Hollin Hill landslide: Rainfall, cumulative AE and cumulative SAA displacement.

ous subsurface displacement measurements. A series of reactivated slope movements occurred in response to periods of rainfall that produced transient elevations in pore water pressure along the shallow shear surface (1.5 m deep) in January 2014 (Figure 3). These comparisons confirm that AE rates generated by the system are directly proportional to the rate of displacement.

Retrofitting inclinometer casings

Retrofitting inclinometer casings with the AE system has two key benefits: the provision of continuous real-time information on slope movements; and continued operation beyond displacements that would normally be sufficient to render inclinometer casings unusable (i.e. not allow the torpedo probe to pass the shear surface). To trial this approach, an inclinometer casing was retrofitted with an AE system at the Hollin Hill landslide; results from this trial for a period of movement are shown in Figure 4, which demonstrate that inclinometer casings retrofitted with active waveguides can provide continuous information on slope displacements. As the inclinometer casing diameter is only 70 mm, waveguide tubing with smaller diameter (25 mm diameter and 2 mm wall thickness) and sand backfill (sub-angular 0.6-2 mm) were employed. Active waveguides retrofitted inside 50 mm diameter standpipe casings have also been shown to work effectively.

Further information

Multiple references to publications about AE monitoring of slopes can be found at www.slopealarms.com, including further details of the system, laboratory studies and detailed case study information. Slope ALARMS sensors can be purchased from Loughborough University along with associated technical support and organisations interested in collaborating to further commercialise Slope ALARMS are invited to discuss opportunities with the authors (full contact details are given at www.slopealarms.com). A very low cost version of the sensor has been developed for use in low and middle income countries to help protect vulnerable communities, field trials are in progress and details will be available in the next 12 months, and will be submitted for publication in GIN. Other sources of AE monitoring systems and services are:

- www.tuv.com
- www.mistrasgroup.com
- www.physicalacoustics.com

However, it should be noted that these do not currently have equipment optimised for continuous slope monitoring in remote locations or experience of such applications.

Summary

For soil slopes, the field evidence from multiple long-term trials, supported by controlled laboratory studies, prove conclusively that AE rates measured using an active waveguide system are proportional to slope displacement rates. AE rates can show when the slope is stable, accelerating or decelerating. Therefore, when employed with user defined thresholds, AE monitoring can provide a warning of instability. In addition, the AE monitoring technique has been shown sensitive to small magnitudes of movement and very slow slope displacement rates, which means that it can provide early information on the occurrence of slope movements and changes in the rates of these movements. This information is automatically communicated in real-time to nominated parties so that appropriate actions can be taken. Monitoring of AE has been in progress at example sites for over five years with very few false alarm events, giving confidence in the robustness of the approach.

AE monitoring of rock slopes employing grouted waveguides is showing potential to provide information on

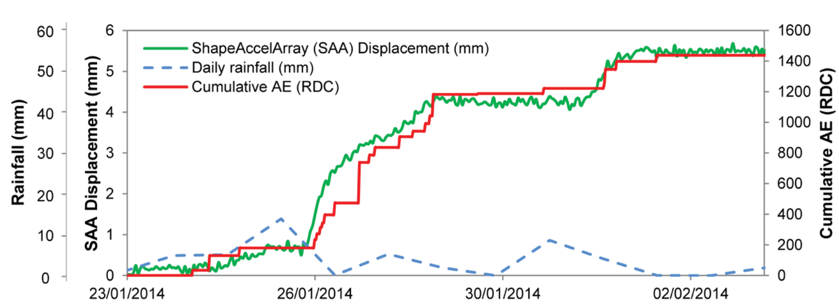

Figure 4. SAA measured displacement, retrofitted inclinometer AE and rainfall time series for a period of reactivated slope movements at Hollin Hill.

rock mass displacement mechanisms. Research is on-going to establish AE signatures that can be used to warn of instability as increasing AE rates could be related to accelerating damage events at the micro-scale as precursors of a macroscopic brittle failure.

Acknowledgements

The support provided by the Engineering and Physical Sciences Research Council (EP/H007261/1, EP/D035325/1) is gratefully acknowledged. The authors also acknowledge the collaboration with Philip Meldrum, British Geological Survey, in development of the AE measurement system.

Reference

Cruden DM and Varnes DJ (1996) 'Landslide types and processes', in KA Turner & RL Schuster (eds), Landslides—Investigation and mitigation: Transportation Research Board Special report no. 247, National Research Council, National Academy Press, Washington, pp. 36–75.

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Monitoring a heritage building restoration project with geotechnical instrumentation

Vincent Le Borgne

Introduction

2017 will mark the 150th anniversary of the Canadian Confederation. Amidst the preparations for the celebrations, infrastructure projects have been undertaken, including major work to modernize, both structurally and esthetically, the 150-year old West Block Building in Ottawa while maintaining its heritage appearance (depicted in Figure 1). The project required extensive monitoring with geotechnical instrumentation. The structural work requiring instrumentation had three phases:

1. Backfilling of abandoned tunnels
2. Excavation of the inside of the north wing to add new basement floors
3. Excavation of the inner courtyard to add new basement floors

Figure 1. Picture of Parliament Hill's West Block in Ottawa.

An overview will be provided of what to be aware of regarding instrumentation, and some issues that arise from working in a demolition-related project. Additionally, there will be specific examples regarding the effects of temperature and the importance obtaining and generating proper baselines.

Settlement system

Purpose and description of instruments

During Phase 1, tunnels running under the building were reinforced and backfilled. Because this phase could induce significant differential settlement, a highly sensitive settlement measurement system was installed (Geokon model 4675). In this system, the sensors are connected to each other with liquid-filled flexible tubing. Each sensor measures the liquid level within its housing. The liquid level difference with respect to a reference sensor is equal to the differential settlement value

Sources of inaccuracy

Temperature variations create challenges. Since these systems measure differential liquid levels, temperature changes at one part of the system will alter the specific gravity of the liquid locally, inducing inaccurate readings.

In addition to temperature, the presence of air bubbles can severely impact the quality of measurements. Indeed, air being a compressible fluid, it can "dampen" shifts in position of the water containers and yielding unreliable.

One-point liquid-based settlement systems can be back-pressured to push out the bubbles but it is not feasible in this system given that there are several measurement locations on the same line and that bubbles can be trapped in localised "kinks."

Installation

There are several limitations that were to be overcome during installation. The line and sensors had to be installed in cramped spaces, around beams, inside doorframes and so on. The complex arrangement in the building made it impossible to avoid curves that could trap air bubbles in the liquid, so the line had to be filled before being attached to the wall. However, filling the line before running it makes installation even more demanding because of the added weight.

To minimize inaccuracy due to temperature changes in the liquid and to have access to the full measurement range, these settlement measurement systems also require that the sensors be at the same elevation, within 10 mm of each other. While this is reasonably easy to achieve on a single long wall or a tunnel, it is much more difficult where there is little to no line of sight for use of laser levels, obstruction rendered the use of water levels arduous, and where floors and ceilings are either absent or uneven. We modeled the effect of lowering or raising each liquid container with respect to its sensor before we were able to position each of them at the right height. Moving any one of the reservoirs up or down would have an effect on the readings of the other measurement points.

Results

We were asked to place some of the sensors outdoors, where the sun would heat up the sensor housing, yielding unreliable data during daytime (i.e. sunlight would heat one part of the line). This can be seen in Figure 2, where measurements (blue curve) shift rapidly from daytime to nighttime as it follows air temperature (orange curve). It can also be seen that perceived settlement changes over months in such a way that is difficult to specifically attribute to real differential shifting or to temperature effects. There is a correlation between the two curves, but the exact relation between the two is unknown. In addition to these concerns, workers would occasionally operate space heaters in the vicinity of the instruments without telling anyone, inducing false readings of shifts.

One of the liquid lines was accidently damaged and this has been a recurring theme throughout this project, an expected outcome of instrumenting a demolition project. Though a cut can be fixed, it makes comparison of data before and after the break difficult to perform.

Recommendations for future use

If there is critical safety and data resting on the settlement system, it is crucial to protect the lines and they should be put entirely out of reach or be protected by a conduit.

Ideally, settlement systems such as these need to be installed in temperature-controlled environment to provide best accuracy.

If the system cannot be back-pressured, it is a better practice to fill it with liquid before installation and make sure no air bubbles remain in the system.

Using laser levels is the best approach to install sensors at the right height when the conditions permit it.

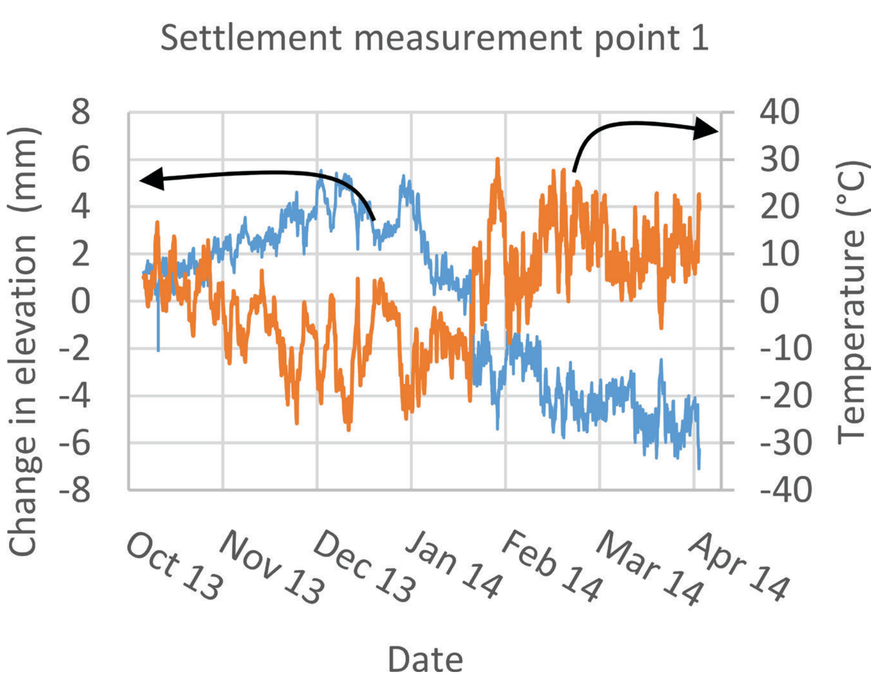

Figure 2. Differential settlement measurement of an outdoor wall (blue) and measured temperatures (orange)

Multi-point borehole extensometers (MPBX)

Purpose and description of instruments

Over the course of phases (2) and (3), instruments such as vibrating wire MPBX (Geokon model 1280) and in-place inclinometers were routinely used to follow the effects of excavation both inside and outside the building. They provided independent data and complemented measurements from settlement systems.

Sources of inaccuracy

MPBX are fairly robust instruments that do not have many sources of inaccuracy once they are properly installed. The main source of inaccuracy for this type of instrument would be caused by a mismatch between the soil and the grout's hardness.

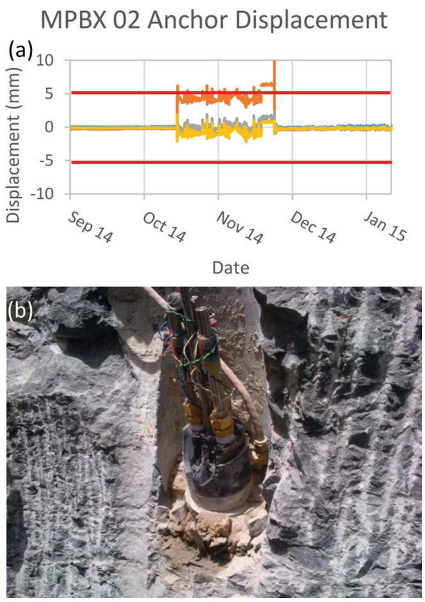

Figure 3. (a) Anchor displacement of a damaged MPBX (b) Photograph of the head of a damaged MPBX).

Vibrating wire MPBX, despite being tedious to install properly when compared to other solutions, were chosen because we would have a single type for all instruments. This gave us the opportunity to greatly reduce cabling and to facilitate integration into the dataloggers.

Given the long cabling distances in this project, using vibrating wire instruments sidesteps the issues of voltage drops that occur with potentiometer-based MPBX.

Installation

In this project, the MPBX were installed directly into the bedrock and there was very little risk of using an improper (too soft) grout mix.

Results

This project showed that confidence in the instruments and their reliability can prove critical. Indeed, every MPBX installed in this project gave nearly-constant and consistent measurements over months. In October 2014, the measured values of one MPBX jumped to more than 5 mm, above the alarm threshold (figure 3 (a)). A rapid investigation found that a worker had excavated just beyond the planned limit and hit the head of the instrument.

Relying on redundancy and historical data, the engineers were confident enough in the instrument and in the redundancy we had implemented to not immediately stop work despite going against their internal processes.

Damage to the head occurred on a few occasions, an example of which is depicted in the photograph of figure 3 (b). It can be seen that, in this case, half the head of the instrument was torn off. The simple fact that the instrument was nearly destroyed shows their vulnerability in a demolition and restoration project.

Recommendations for future use

Performing long term-monitoring to build confidence in the instrument and the measurements is strongly recommended whenever possible. This confidence helps the engineers to make the right decision when unexpected jumps or breaks in the data occur.

Tiltbeams

Purpose and description of instruments

Vulnerable walls were monitored with vibrating wire tiltbeams (Geokon model 6350). Though tiltmeters are commonly used in structural health monitoring, tiltbeams were selected because they were to be installed on masonry walls which can flex due to their mortar joints. Using long (2 m) tiltbeams averages out localized tilts and provides a better image of the behaviour of the walls.

Vibrating wire tiltbeams were selected over electrolytic or MEMS sensors, two other common types of tiltmeters. First, they are less sensitive to temperature effects than electrolytic tiltmeters. Second, integration is facilitated by using a single signal types and by requiring very little power over long distances.

Sources of inaccuracy

Temperature-induced errors are the main sources of inaccuracy in this type of instrument. First, temperature affect

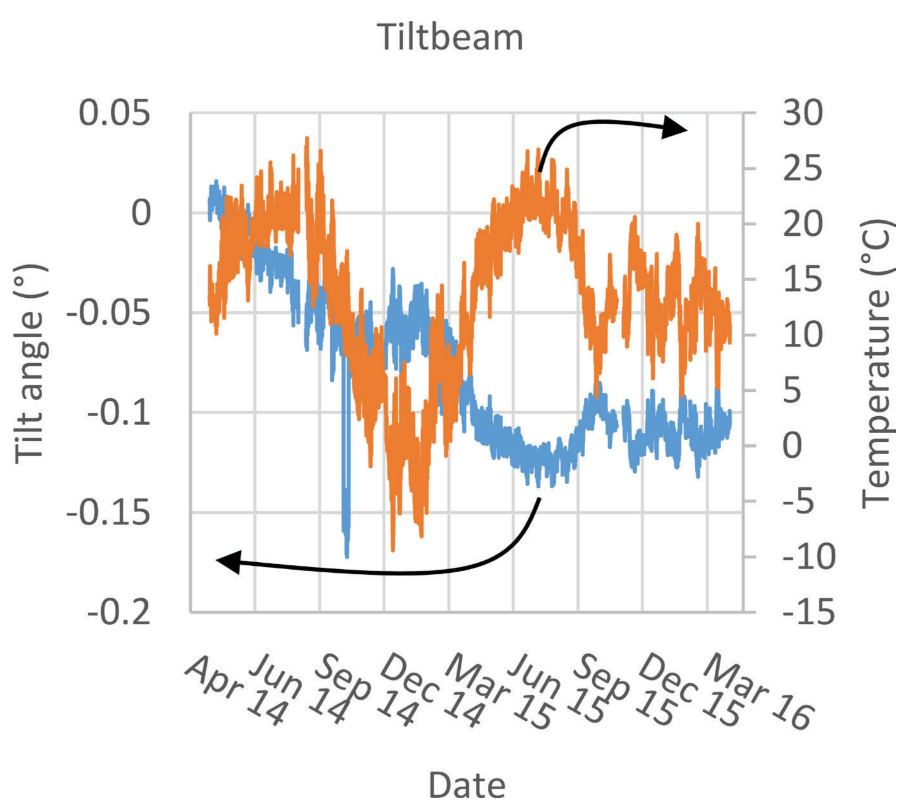

Figure 4. Tilt angle over time (blue) and temperature (orange).

the reading itself, but this can be corrected to an extent with proper calibration curves. Second, temperature can have an effect the monitored structure and induce real local tilt, often hours after air temperature (i.e. the temperature measured by the on-board thermometer) has changed.

Installation

For phase (2) and (3), effects of the excavations on the walls were monitored with tiltbeams. Like MPBX, vibrating wire tiltbeams are robust instruments that can be relied upon over long periods of time provided that they are correctly used. Avoiding exposure to sunlight is often recommended as local heating of the structure can induce a small amount of tilt from local sensor and structure deformation. Putting tiltbeams in the shade is not always possible since the outer walls of a building are often more accessible.

Results

Measuring variations over weeks or months before work starts can prevent a lot of head scratching because the effect sunlight on the system can be quantified before work begins. The graph in figure 4 shows the effect of temperature and sunlight on tilt measurements for a single tiltbeam in the inner courtyard. From April to December 2014, the measured tilt variation (blue curve), with respect to an initial measurement (blue curve) steadily decreased as temperatures went down (orange curve). Starting in the spring of 2015 values remained low while the temperature increased again. It was impossible to accurately measure the value of tilt until temperatures had climbed back to as high as the initial value. Hour-to-hour comparisons, when temperatures are similar, should give smooth increases and decreases that are repeated day after day. Any sharp or fast change might indicate a blow to the instrument or an actual shift in the wall. Slow and long term tilting can be difficult to detect without a proper base line.

Recommendations for future use

Installing the tiltmeters indoors or in the shade, though often not possible, can improve the quality of long-term measurements.

In addition to this, when monitoring an already existing structure, a long enough baseline will allow engineers to work out the relationship between temperature and tilt and thus enable the analysis of all subsequent data acquired during the project. In short, baselines are a simple but often overlooked method of improving the reliability of instruments such as tiltbeams and MPBX.

There are several points to take into consideration when choosing between competing technology when choosing an instrument, such as signal type, accuracy, reliability and temperature-dependence.

Conclusion

In conclusion, restoration of Parliament Hill's West Block is an unusual project for geotechnical instrumentation. In a demolition and restoration project, instruments are constantly put at risk. Communications cables, liquid lines and instruments heads can all be damaged. It is therefore critical to protect the cable and lines, use reliable and trustworthy instruments, plan for redundancy and perform long-term baselines. Applying these measures to any project, and to restoration projects in particular, will greatly improve any monitoring in restoration-related projects.

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General role of instrumentation, and summaries of instruments that can be considered for helping to provide answers to possible geotechnical questions. Part 5.

John Dunnicliff

Introduction

This is the fifth and last in a series of articles that attempt to identify:

- The general role of instrumentation for various project types.
- The possible geotechnical questions that may arise during design or construction, and that lead to the use of instrumentation
- Some instruments that can be considered for helping to provide answers to those questions.

Part 1, covering internally and externally braced excavations, was in December 2015 GIN. Part 2, in March 2016 GIN, covered embankments on soft ground. Part 3, in June 2016 GIN, covered cut slopes and landslides in soil and in rock. Part 4, in September 2016 GIN, covered driven piles and bored piles (also called drilled shafts). This Part 5 is about tunnels.

Four introductory points were made in December 2015 GIN (www.geotechnicalnews.com), for Part 1 of this series of articles, and these also apply here.

Tunnels

General role of instrumentation

The consequence of poor performance of a tunnel can be severe and may on occasion be catastrophic. A monitoring programme may not be required if the design is very conservative, if there is previous experience with design and construction of similar facilities under similar conditions, or if the consequences of poor performance will not be severe. However, under other circumstances a monitoring programme will normally be required to demonstrate that the tunnel is stable and that nearby structures are not affected adversely.

Summary of instruments that can be considered for helping to provide answers to possible geotechnical questions

Table 10 lists the possible geotechnical questions that may lead to the use of instrumentation for tunnels, together with possible instruments that can be considered for helping to provide answers to those questions.

Table 10. Some instruments that can be considered for monitoring tunnels

Possible geotechnical questions	Measurement	Some instruments that can be considered
What are the initial site conditions?	Groundwater pressure	Open standpipe piezometers Vibrating wire piezometers installed by the fully-grouted method (Pneumatic piezometers)
	Vertical displacement	Conventional surveying methods Remote methods
	Widths of cracks in structures	Crack gauges
Is the tunnel stable, and are overlying structures being affected adversely by ground movement?	Settlement of ground surface and structures	Surveying methods Remote methods
	Horizontal displacement of ground surface and structures	Surveying methods Remote methods
	Change in width of cracks in structures and utilities	Crack gauges
	Subsurface horizontal displacement of ground	Inclinometers In-place inclinometers (Fibre-optic instruments)
	Subsurface settlement of ground and utilities	Probe extensometers Fixed borehole extensometers
	Displacement within tunnel	Surveying methods Remote methods (Fibre-optic instruments)

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June 13-15, 2017 (Master Classes on June 12) - Rome (Italy)

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2016 Participants

2016 Lecture room

Trevi's Fountain

Sapienza University's entrance

The Statue of Minerva (Sapienza University of Rome)

THE COURSE: attendance at the course is a great opportunity to establish a valuable network with colleagues from all over the world, to meet manufacturers and see the most recent and innovative instrumentation, thanks to a large exhibition area.

NEW CONTENT:

- Many new speakers, to give the course a fresh look
- Increased sessions for professional presentations about new trends
- Increased case history sessions, presented by selected registrants

COURSE EMPHASIS: the course will include planning monitoring programs, hardware and software, web-based and wireless monitoring, remote methods for monitoring deformation, vibration monitoring and offshore monitoring. Case histories will be presented by prominent international experts.

WHO: engineers, geologists and technicians who are involved with performance monitoring of geotechnical features of civil engineering, mining and oil and gas projects. Project managers and other decision makers who are concerned with management of RISK during construction.

LOCATION: the 3-day course will be held in Rome (Italy), a city of huge historical and cultural interest

MASTER CLASSES: on the day before the main course, six Master Classes will be led by international experts, specifically oriented to provide practical basic know-how on use of the most common monitoring systems. Each class will cover the following main topics: installation, data acquisition, data processing, tricks and tips from everyday experience.

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