Introduction by John Dunnicliff, Editor

This is the seventy-eighth episode of GIN. Two articles this time.

Performance of ShapeAccelArray (SAA)

The first article, by Derrick Dasenbrock, describes the very positive experience of Minnesota Department of Transportation with the SAA instrument. Please read my *Editor's Note* at the end, indicating my concern about including this article in GIN because it may appear to favor one of the items in our tool box too strongly. I'd like to hear from others about their experiences.

Report on a workshop

The second article, by Bob Bachus, reports on a discussion of methods for geotechnical data management and visualization. We've tried to make this more useful that a mere report by including some technical information that we hope will be helpful to readers. If you'd like to have more 'meat', please contact the author.

Is anybody there?

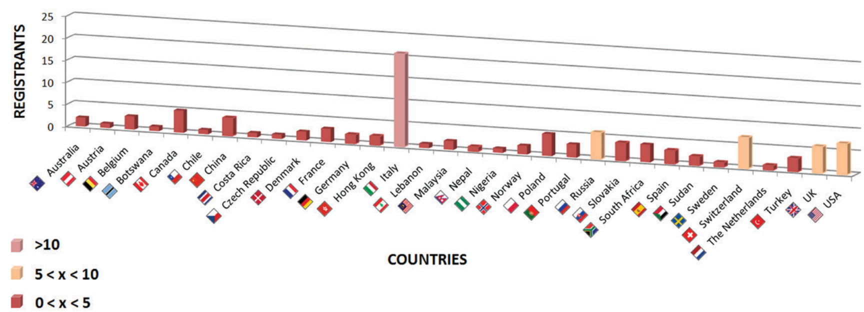
In the previous episode of GIN I asked, **"Do you want GIN to continue? The ball is in your court."** Not a single ball has come my way. I know that some of you read this stuff, so …!

International Course on Geotechnical and Structural Monitoring

Here's a status report on the course to be held in Italy on June 4-6 this year *(www.geotechnicalmonitoring.com)*.

We seem to have a tiger by the tail! At the time of writing, almost two months before the start of the course, there is no more capacity in our 95-seat room in the 10^{th} century castle. We have more than ten on the overbooking list.

Registrants are from 32 countries (see the graphic), predominately from Europe but also from Asia, North and South America, Africa and Australia.



Now that we're encouraged by the worldwide interest in the course, we plan to offer a second course on 4-6 June, 2015, also in Tuscany - the same region as the 2014 course. Perhaps in Poppi, perhaps elsewhere. The 2015 edition will not be an exact repeat, as we already have ideas for different topics, and of course we'll learn from evaluations of the 2014 course

Closure

Please send contributions to this column, or an abstract of an article for GIN, to me as an e-mail attachment in MSWord, to john@dunnicliff.eclipse.co.uk, or by mail: Little Leat, Whisselwell, Bovey Tracey, Devon TQ13 9LA, England. Tel. +44-1626-832919.

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Performance observations of MEMS ShapeAccelArray (SAA) deformation sensors

Derrick Dasenbrock

Introduction

Historically, traversing-probe inclinometers, settlement platforms, or survey hubs with manual surveys have been used for monitoring slope stability, settlement of embankments or movement of foundations or structures. Today, automated technologies to assess deformation include robotic total station systems, hydraulic settlement systems, in-place inclinometers, ShapeAccelArray (SAA) systems (www.measurandgeotechnical.com), and remote sensing methods. Costs and benefits of monitoring techniques need to be evaluated to see if they are well suited to project needs. SAA systems appear to have a particular usefulness in targeted applications with frequent monitoring requirements or large anticipated deformations.

SAA instruments are linear arrangements of linked elements with MEMS accelerometers manufactured to prescribed lengths for installation in geotechnical environments. By relating the segment lengths and the tilt (calculated from the sensor inclinations with respect to gravity) of each segment with reference to a fixed end, the spatial position of the array can be calculated. As the array moves with time, subject to geotechnical effects, deformation along the array is measured, providing information on both the rate and magnitude of the movements. Figure 1 shows a typical up-hole system cabinet and a team installing a SAA sensor in a vertical borehole.

Performance

Based on an assessment of SAA data from several project sites and applications, the system performance has been found to be sufficient for transportation applications, particularly where relatively large deformations (meters) are being measured. After seven years, Minnesota Department of Transportation (MnDOT) SAA sensors, except for those that have been sheared off by exceptional deformations, continue to function well. SAA systems appear to provide similar accuracy (at the ground or structural surface) to that achieved by robotic total station systems, with the added advantage that movement inside soil masses is characterized. In our experience, we have not observed any systemic data quality effects due to sensor compression, extension, alignment, twist, temperature sensitivity, or other inherent 'device' characteristics. SAA sensors do display occasional spurious readings due to electrical or other effects—absolute data integrity, as with most electronic sensors, is not perfect. Filtering or engineering judgment may be required to properly interpret SAA response. As SAA sensors are manufactured to specified lengths, the array length cannot be changed "on the fly" in the field if changes are made to the monitoring program. Advanced planning of installations is required; the fixed length of the sensor arrays can also limit the efficient reuse of the sensors at new sites.

Automation, particularly when everything is working properly, can lead to undesirable user complacency and poor practice.

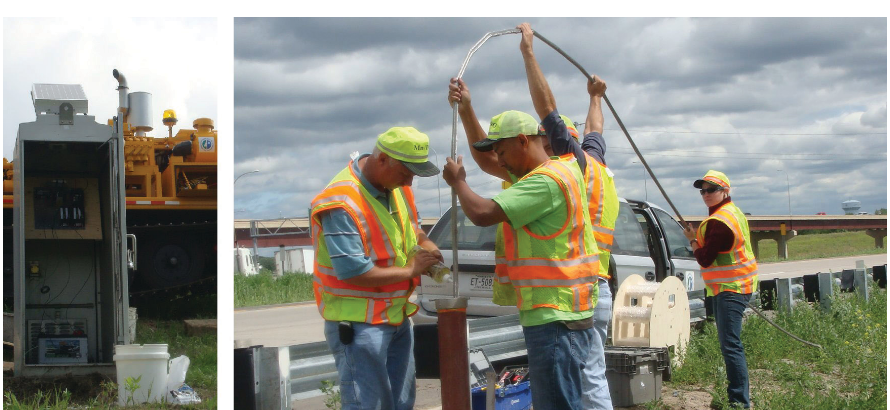

Figure 1. Typical SAA up-hole cabinet (left) and crew installing a SAA sensor in a borehole (right).

Automation

A particular strength of the SAA, which is also present in in-place inclinometers, is the ability of the sensor to remain in-situ and for data to be automatically collected and transmitted to a web-based data storage and presentation system in near-real-time.

However, a warning is appropriate. Automation, particularly when everything is working properly, can lead to undesirable user complacency and poor practice. Schedules should be established to regularly check that automated systems are properly functional. Additionally, automation should not be seen as a substitute for site visits and application of the observational method. Fewer site visits may have the unintended consequence of removing opportunities for important field observations and better understanding of mechanisms and triggers causing deformation. Geo-engineering requires an appreciation of site characteristics that are not always well captured at-a-distance.

Related beneficial aspects to sensor automation include the ability to establish movement thresholds, event triggers, and automated warnings. A bi-monthly interval was previously considered 'frequent' for traditional inclinometer installations. With system automation, it is now possible to read sensors several times daily—allowing for the collection of data sets capable of accurately depicting movement trends, such as seasonal variation, and discrete events such as those induced by contractor operations, rainfall, or earthquake. SAA systems can also provide near-real-time information to multiple users at multiple locations (via the web) with comparative ease, making the systems especially useful for construction monitoring where contractors and owners, in different locations, have an interest in immediate information for decision making.

With increased data frequency there is also the potential for improved data interpretation. If a particular data point from a sensor monitored quarterly appears 'out of line' with earlier readings, the data quality may be immediately suspect. With automated systems, the trend leading up to an apparently anomalous point can be recorded and it may be far easier to assess incongruous data as to whether it is erroneous or representative of actual physical conditions. It has been MnDOT's experience that there is less user-intervention (assessment, validation, and correction) required with SAA installations, as the "human element" has been largely removed from the data acquisition and processing portions of the process—especially when considering the relatively large number of readings associated with frequently acquired SAA data.

SAA systems are useful for monitoring remote sites. There is no significant cost increase to poll the sensors several times daily as compared to monthly or longer intervals, (as was more common with traditional manual systems). In seven years of operations, and today with about 30 operational systems, there has been no data loss related to IT or server problems, although there have been data gaps due to system faults related to power or telecommunications. Electronic components do fail, and while SAA sensors and related architecture of data collectors, uplinks, servers and web-interfaces, have been shown in our experience to be robust, some up-hole electronics are susceptible to influences including lightning, flooding, rodent infestation, temperature, humidity, and vandalism. It is easy to become accustomed to a level of reliability, only to find after several months have passed, that a modem developed a fault or wiring has become part of an industrious bird's nest.

System automation of data acquisition, monitoring, and reporting tasks also requires some degree of specialty computer support. SAA system set-up has a distinct learning curve. Reliance on computers, coding, and infrastructure design and support is greater than with manual systems. In general, the most challenging aspects of automated systems have been related to initial system deployment, cellular modem telecommunication set-up and service, and maintaining system power at remote locations.

Large deformation applications

MnDOT first installed three SAA systems in the summer of 2007 in Crookston, MN at a site where large known movements were occurring. Several traversing-probe inclinometer installations at the site had crushed, sheared, and in one case trapped a probe in the ground. An early conclusion from that project was that the SAA systems appeared to be ductile in nature and the sensors could report exceptionally large deformations while maintaining operational integrity. Deformations of several feet were observed in two of the three sensors along relatively narrow shear bands (slip planes); the other SAA was installed outside the active slide area.

Based on the success of that project, two additional sensors were installed to monitor a nearby project where a roadway embankment failed only a few months after the monitoring program began in the summer of 2008. Lateral movements of over 100 inches (2.5 m) were accurately recorded by the two SAA sensors—well outside the operational boundaries of typical traversing probe systems. The frequent monitoring of the SAA sensors at this second site enabled MnDOT to close the roadway and begin building emergency bypasses prior to the collapse of the westbound portion of the highway. Figure 2 shows the embankment failure area where the SAA systems identified multiple slip surfaces and recorded significant lateral deflections.

MnDOT has also successfully installed SAA systems below roadway embankment surcharge operations to monitor large settlements over soft compressible soils. Based on project data, it appears likely that the curvature of traditional plastic conduit would have been challenging for a horizontal traversing-probe to negotiate (especially with single-end entry). On this project, contractor operations were controlled based on embankment settlement response. Monitoring the SAA systems and other sensors to review construction activities on a daily basis had significant project benefits, particularly as it could be done via the internet.

Broader application of automated systems

While not immediately appreciated, it became clear that SAA systems had additional advantages over manual systems. The sensors can be polled even in poor weather conditions such as when the installation area may be covered with snow and ice. SAA systems also continue to function when the sensing elements are below floodwaters. The ability to monitor a

Figure 2. SAA systems reported and recorded a significant landslide event in near-real-time to geotechnical offices five hours away. The SAA systems remained fully operational as over 100 inches (2.5 m) of lateral deformation was measured.

slowly creeping landslide during flood conditions played an important role in quantifying the stabilizing influence of high water levels on the project. SAA sensors can be installed within embankments, walls, or slopes immediately below travelled roadways. Monitoring then occurs without traffic interruption—an important consideration from cost, roadway user inconvenience, and safety standpoints.

SAA systems have also been useful in monitoring construction deformation of spread footing foundations in response to loading. Construction projects are often active, dynamic, and unsafe. As SAA systems can be installed and buried with only a small up-hole cabinet for support, high quality, frequent data, can be obtained to monitor the influence of construction sequencing safely and with minimal contractor impact. In general, automated sensors and systems (of all types) have been shown to be highly beneficial on projects where the influences of construction staging are of interest and frequent monitoring intervals are desired.

System costs

In common uses, the cost to install a borehole for a vertical monitoring system in native ground is roughly the same for a traditional inclinometer as it is for a SAA. A traversing probe may be used at multiple installations—it is possible for a $6K probe to be used to effectively monitor either one borehole or ten nearby boreholes. Conversely, a SAA system for one similar hole may cost $15K and perhaps $10K for each additional nearby hole for the sensing element (sharing some up-hole resources). It may therefore appear that SAA systems may only be appropriate for very specialized projects. However, the difference in total monitoring cost for a project depends on more than the initial cost. If a site with ten instrumented boreholes was four hours from the closest project office, it could take a technician an entire day to collect data, with associated time and travel expenses. For a five-year project with monthly reporting, sixty site trips would be needed; weekly reporting would require 260 trips, and daily reporting would require 1825 trips. On inspection of the cost of daily trips, this option might not even be considered as a plausible alternative—it would be clearly "cost prohibitive." Here, automation can bring previously discounted options back to the table. SAA systems become more cost competitive if system components, or entire systems, can be redeployed elsewhere at the end of a monitoring program; costs can be amortized across projects. Several MnDOT systems have been removed from service on initial projects and repurposed at new sites.

Ten observations on SAA system performance

SAA systems have both positive and negative attributes. "Lessons learned" from a number of installations and projects include:

1. Predetermined sensor lengths require advance planning and can limit the potential efficient reuse of the sensors at new sites.
2. Reliance on computers, coding, and system support is greater than with traditional systems; electronic systems have a distinct "learning curve."
3. Cellular modems and power supplies are often "weak links" in system.
4. Sensor readings can be subject to some spurious (electrical or other) effects—the data quality, as with most electronic sensors, is not perfect. Filtering or engineering judgment is required in some cases.
5. Installation procedures are similar to traditional inclinometers.
6. SAA sensors are very robust in large-displacement environments.
7. With seven years of operational experience, data can be acquired in severe environmental conditions (during floods, below ice and snow, under roadways).
8. Automation allows high frequency readings for better data analysis of rate information and capture of seasonal variation and unexpected events.
9. SAA systems provide generally well-behaved data-sets in horizontal applications, especially as compared to many common settlement sensors;
10. Relatively high initial costs are offset by improved data quality, near-real-time event reporting, and life cycle savings in manual labor and travel costs, particularly if components can be re-used on future projects. Systems can also improve safety with fewer field visits and reduced field construction conflicts.

As with other automated systems, users should take care that SAA monitoring systems compliment site visits, observations, and thoughtful evaluations of the geologic character of project sites to better evaluate causes and impacts of the ground movements being monitored.

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Editor's Note

I've had some concerns about including this article in GIN because it may appear to favor one of the items in our tool box too strongly. If you have experience with the SAA instrument and have anything to add about performance, pro or con, will you please send me a discussion of this article, and I'll consider it for a future GIN?
JD

Advances in geotechnical data management and visualization

Robert Bachus

What were you doing on Sunday morning, 12 January 2014? If you are a die-hard, geotechnical data "geek" you should have been at the Transportation Research Board (TRB) annual meeting in Washington, D.C at 9:00 am with 75 of your colleagues to participate in a workshop titled "Advances in Geotechnical Data Management and Visualization." I served as the moderator for the workshop. TRB established the theme for the 2014 annual meeting as "Celebrating Our Legacy, Anticipating Our Future" and the workshop certainly reflected that motto. The three-hour long session included seven invited podium presentations and a panel discussion that featured six invited panelists, as well as participation from the early-risers in the audience. While the workshop participants certainly wanted to celebrate the legacy of geotechnical data management, the real focus of the presentations was to alert all participants to the opportunities that we will be afforded in the future should we adopt these advances. A wide range of discussion and presentation topics were broadly categorized to capture advances in:

- Software and data formats
- Data capture and interpretation
- Data management and visualization.

Highlights and lessons from the workshop are summarized below.

Software and data format updates

The workshop started with a reflection and recognition of the series of articles from the December 2010, March and June 2011 issues of Geotechnical Instrumentation News that highlighted advances in web-based data management software, given that this was the most recent compilation of articles on this topic. *[The initial article by David Cook, titled "Fundamentals of Instrumentation Database Management – Things to Consider" was followed by eight one-page articles by ten suppliers of the software. These are, of course, accessible on www.geotechnicalnews.com/instrumentation_news.php. JD].*

At the TRB workshop, recent additional updates and innovations to these software packages were presented by some of the presenters/developers, including Ed Kirby (itmsoil usa), Andres Thorarinsson (Vista Engineering), and Allen Marr (Geocomp), who provided updates to Argus, Vista Data View, and iSiteCentral, respectively. As a tribute to the benefits of technology, Roger Chandler (Keynetix) was unable to attend the workshop but through the use of a video presentation from his office in the U.K. was able to provide software updates and reported on the recent efforts in the U.K. to require/incorporate geotechnical data into Building Information Modeling (BIM) software. A primary message from these presenters was that members of the software development community have their collective ears close to the ground and are continuously refining products and utilizing technology that allows the geo-professional to be more effective at doing their job. A good example of this was the relatively recent capability to store and manage information "in the Cloud", as do many of the software packages presented. It was interesting that many of the presenters acknowledged the benefits and recent efforts in the U.K. and the U.S. to standardize the storage and transfer of geotechnical data using the Association of Geotechnical and Geoenvironmental Specialists (AGS) format that is used across the U.K. and the Data Interchange for Geotechnical and Geoenvironmental Specialists (DIGGS) format being advocated in the U.S. Rob Schweinfurth (Geo-Institute of ASCE) and Marc Hoit (North Carolina State University) subsequently provided the participants with an update of recent efforts to resurrect the DIGGS development efforts and indicated that the Geo-Institute of the American Society of Civil Engineers (ASCE) has recently taken responsibility for final development and public release of the DIGGS format by October 2015.

Data capture and interpretation

A number of the presentations were focused on the interest in and propensity to require collection of large amounts of data and the accompanying need and importance of accurately interpreting these data. Shaun Dustin (Campbell Scientific) summarized the efforts and commitment of vendors/developers to provide reliable data collection hardware, but cautioned that as an equipment provider, their job is not to maintain the project databases. Gary Young (Underground Imaging Technologies) discussed how equipment manufacturer partners are utilizing instrumentation on equipment to monitor engineering performance, but emphasized the need to be able to quickly and reliably interpret results. He specifically acknowledged collaboration/interaction with Caterpillar and its project teams working with Caterpillar's Katherine Braddy. Two examples were provided to demonstrate the benefit (and thus the necessity) to accurately interpret the collected data. Ken Fishman (McMahon and Mann) presented a case history regarding corrosion in steel strips and performance monitoring of mechanically stabilized earth (MSE) structures. Hai-Tien Yu (itmsoil usa) presented a case history regarding the corrections that need to be applied to collected vibrating wire strain gage data to account for temperature impacts on readings. These examples illustrate the closing gap between data collection and interpretation. While the previous discussions focused on data collected from geotechnical instrumentation, Jamey Rosen (Geosyntec Consultants) provided information regarding the "philosophy" of good data management and showed how construction performance "information" can be collected and managed as "data." Lessons learned from this block of presentations were:

- We now have instruments and capabilities to capture significant amounts of data/information…so owners and engineers now often require that these be captured.
- If we collect the information, we have to be prepared to review and interpret the information in a timely manner.
- There exist much more information that should now be considered geotechnical "data" and we need to be prepared to capitalize on the opportunities the capabilities presented by timely and efficient data capture.

Data management and visualization

There was significant interest and numerous examples were cited by several of the presenters regarding the advances and benefits regarding the visualization of collected data. Semiha Ergan (Carnegie Mellon University) provided illustrative examples of how the BIM software historically used by the construction industry has evolved and is now being used by designers and architects to visualize a wide range of data to allow modeling of building life-cycle costs. Raphael Siebenmann (Geosyntec Consultants) offered several examples of how the use Cloud-based data collection and geographic information system (GIS) technology have been used to capture information and visually present geotechnical and construction information to the user. Scott Deaton (Dataforensics) highlighted many examples of the benefits of data visualization and demonstrated the benefits of developing and using standardized data formats to truly capture these benefits. The primary lessons from these discussions were:

- Data visualization is an emerging area that provides immeasurable benefits to all project stakeholders.
- Geotechnical professionals will benefit from the collaboration of colleagues in practice areas (e.g., computer science and informatics) that are considered non-traditional to the geotechnical engineer.

Looking to the future

The advocates of geotechnical data management, and many of the readers of Geotechnical Instrumentation News, know all too well that advances in technology have allowed geotechnical engineers to do so much more with geotechnical information that was simply not available 20 years ago. Many of the participants noted that as technology has advanced the profession's ability to capture data, recent project experience has shown that owners are fast to require that more data be collected. In some cases, the ability to capture the information seems to become the justification for collecting the information. It is doubtful that this trend will change in the foreseeable future. Unfortunately, many of the participants at the workshop voiced opinions that the collection and management of this information has been a source of ongoing frustration regarding the various procedures for data management that are being used across the industry. The discussion at the workshop indicated that there was little doubt regarding the benefits of "standardized" data collection, reporting, and management. However, the participants acknowledged that despite the mood of the workshop, the vast majority of practicing engineers involved in this field likely will not voluntarily adopt the standardized data concept because it will require them to change their current practice and processes. Therefore, there was a feeling that "change" had to be driven by the owner or by project specifications. An action item from the workshop was to continue the advances but also to encourage the development and implementation of standardized data formats (e.g., AGS and DIGGS efforts) by demonstrating the benefits of adoption. So, the readers of Geotechnical Instrumentation News should expect to be hearing more about this important workshop outcome in future issues.

I appreciate that this brief report on the workshop is only an outline of what took place. If readers would like to have more information regarding the workshop, they are encouraged to contact me.

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