Geotechnical Instrumentation NEWS

# Geotechnical Instrumentation News

***John Dunnicliff***

### Introduction

This is the forty-eighth episode of GIN. Two articles this time. Also responses to questions that I asked in the previous episode of GIN.

### My 'Umbrella' Questions

In the previous episode of GIN I asked two questions, intending to seek out opinions on how manufacturers and users can cooperate to the maximum extent. I've received six responses. Five are from representatives of North American manufacturers (Applied Geomechanics, Durham Geo Slope Indicator, Geokon, Roctest and RST), and one from a user (Arthur Penman).

### Cable-free Sensors

The article by Chris Rasmussen tells us about recent work with cable-free sensors. He discusses the design parameters that are required for a cable-free system, reviews two installations and looks at some of the lessons learned along the way.

### Interpreting Unexpected Instrument Data

Verne McGuffey comments that many casual users might have information that would be useful to the profession. He has put together a few ideas about evaluating data, and has described some unusual situations where the instrument was assumed to be at fault, but was not.

He comments, "Perhaps this note will invite other users with useful experiences to share them also". **YES PLEASE**.

### Next Instrumentation Course in Florida

The next instrumentation course in Florida will be on March 18-20, 2007 at St. Petersburg Hilton *(www.stpetehilton.com)*. Details of the course are on *www.doce-conferences.ufl.edu/geotech.*

### International Symposium on Field Measurements in Geomechanics (FMGM)

The 7th International Symposium on Field Measurements in Geomechanics (FMGM) will be held in Boston, MA during September 23-27, 2007. FMGM symposia have been held every four years since 1983, in Switzerland, Japan, Norway, Italy, Singapore and Norway again. Information about these past six symposia, together with related information about geotechnical instrumentation, can be found on www.fmgm.no.

The 7th FMGM will concentrate on geotechnical, structural, environmental and geophysical instrumentation methods and applications, and will focus on the following themes and topics:

#### Theme 1. Case Studies

The role of field measurements in problem-solving, research, safety assessment, risk assessment or improving the design of civil engineering structures and works.

- Case histories and monitoring applications
- Instrumentation for innovating design
- Instrumentation and geo-hazards

#### Theme 2. State-of-the-Art and Future Trends

The latest in measurement technology, equipment, communication methods, data management and interpretation, and visions for future development.

- Geotechnical, structural, geodetic, environmental and geophysical instrumentation methods and equipment
- Real-time monitoring
- Remote monitoring, wireless systems
- Early warning systems
- Data acquisition systems
- Analysis and presentation software
- Performance, cost and reliability data
- Capabilities and limitations
- Future trends and needs
- Emerging new technologies
- Fiber optic sensors
- Internet applications
- Global Positioning Satellite systems (GPS)
- Automated total stations
- Problems and pitfalls
- Avoiding electromagnetic interference (EMI)
- Protecting equipment against damage during electrical storms

### Theme 3. The Business Side of Instrumentation

Demonstrating and quantifying the benefits of field measurements to project management teams, owners, engineers, contractors, regulators and insurers.

- Benefits of monitoring to owners
- Benefits of monitoring to designers
- Benefits of monitoring to construction contractors
- Role of monitoring in risk management

Please visit *www.geoinstitute.org* and *www.fmgm.org* for more information, including the requirements for submitting abstracts of papers.

### Third International Symposium and Workshop on Time Domain Reflectometry

The third International Symposium and Workshop on Time Domain Reflectometry for Innovative Soils Applications (TDR 2006) will take place on September 17-20, 2006 at Purdue University in West Lafayette, Indiana.

Details are available at: *https://engineering.purdue.edu/TDR*

Registration is limited to 120 persons. A grant from NSF allows for a nominal registration fee for up to 20 full time students and nontenured faculty persons who hold tenure-track faculty positions, with priority given to women and under-represented minorities.

The registration form is available at *https://engineering.purdue.edu/TDR/* and the registration may be done online. Any questions should be addressed to: *tdr@ecn.purdue.edu*

### Some Anglo-American Trivia

Recently I did something foolish, admitted it and said that I'd "eat crow". Then I realized that I had no idea what that meant, so pulled out my trusty Dictionary of Phrase and Fable and found the following for "Eating Crow":

> *To be forced to do something extremely distasteful. The expression derives from an incident during an armistice of the Anglo-American War of 1812-1814. A New Englander unwittingly crossed the British lines while hunting, and brought down a crow. An unarmed British officer heard the shot and determined to punish the offender. He gained hold of the American's gun by praising his marksmanship and asking to see his weapon. The Britisher then told the American he was guilty of trespass and forced him, at the point of the gun, to take a bite out of the crow. When the officer returned the gun the American in his turn covered the soldier and compelled him to eat the remainder of the crow.*

So now we know!

### Closure

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

Na zdrowie! (the website says "Polish drinking toast" – will someone please tell me what it means? Maybe it's something that I shouldn't print!)

## Responses to 'Umbrella' Questions about Manufacturers and Users Working Together

***John Dunnicliff***

***Geotechnical News, Vol. 24 No. 2, June 2006, p 33***

In the previous episode of GIN I asked:

1. **What is the best way for manufacturers to help users select the most appropriate instruments for their application?** Manufacturers of geotechnical instruments are a resource that should not be overlooked when selecting appropriate instruments for any particular project. However, users can't expect that manufacturers will put themselves in the same position as geotechnical project designers. It seems to me that if users have any uncertainties about which instruments are appropriate, there needs to be interaction with manufacturers so that the decision can be made mutually. Is this practicable?

2. **How can manufacturers help users to learn about the most appropriate installation methods?** For example, in the case of Karkheh Dam, earth pressure cells and piezometers. I've always contended that manufacturers can provide explicit details about such installations as strain gages on steel, because there are no geotechnical variables. However, manufacturers cannot provide explicit details on how to install their instruments in geotechnical surroundings, because they can't possibly know all the details that are required to do so—this is the job of the user. But of course manufacturers can provide general guidelines. In the experience of manufacturers and users, is there a need to improve interaction to en-

sure the most appropriate installation methods? If yes, how?

I've received the following six responses. The response by Louis Marcil of Roctest also had an additional discussion of the article by Ali Mirghasemi about unexpected vibrating wire piezometer data at a dam in Iran *(Geotechnical News, Vol. 24 No. 1, March 2006, pp 32-36).*

## Gary Holzhausen

My answers to your two questions are "Yes" and "Yes". My answer to the "how" part of the second question is, "If unsure, customers should be encouraged to ask questions of the manufacturers".

*Gary Holzhausen, President, Applied Geomechanics Inc., 1336 Brommer St., Santa Cruz, CA 95062, Tel. (831) 462-2801, email:holzhausen@geomechanics.com*

## Louis Marcil

I thank John Dunnicliff and Ali Mirghasemi for raising such an interesting discussion about the Karkheh Dam instrumentation results. The diversity and number of possible explanations put forward by the participants reflect the complexity and importance of the discussed subjects. I wish to revisit an observation made by Elmo DiBiagio, as well as suggest some answers to the two 'umbrella' questions raised by John Dunnicliff.

In his discussion, Elmo DiBiagio made an important observation, namely that in high embankments, it is necessary to use vibrating wire piezometers mounted in robust housings, to ensure that the sensing element inside the piezometer will not be affected by the earth pressure. This was done at Karkheh, where model PWF piezometers were installed. This model is also referred to as thick-walled PWS. The distinction between thin and thick-walled PWS was not made in Mr Mirghasemi's article. Deformation of the piezometers housing is therefore unlikely to have any effect in this case.

Regarding the first 'umbrella' question, my opinion is that good ways for manufacturers to help users to select appropriate instruments include:

- At very the least, advising users when an inappropriate range, model, or type of instrument has been specified
- When possible, suggesting instruments that are most likely to yield good results for the user's specific application
- Ultimately, refusing to quote an order to avoid being associated with a poorly designed instrumentation project.

Regarding the second 'umbrella' question, I feel that manufacturers can play a valuable role in helping users to learn about appropriate installation methods. The instruction manuals provided by manufacturers constitute a helpful tool. They must be prepared with great attention so that they properly describe general guidelines relative to installation methods. The use of explicit images (drawings, photos) should become widespread considering that, in many cases, the installers may not speak English. For important and complex projects, manufacturers may even be asked to send employees on site to assist during installation or to train directly the people who will conduct the installation.

Manufacturers can then play a positive role for both selecting the instruments and helping users to learn about installation methods. This comes, among others, from their capacity closely to relate the design of the instruments to their performance on site. Manufacturers who realize the importance of such a role will devote maximum resources in order to improve their knowledge of applications, to select technically skilled distributors, to maintain close relationships with specialists in instrumentation, etc.

Users who are aware that manufacturers can help will then seek their assistance. However the users must keep in mind that they are ultimately responsible for the decision-making on which instruments will be used and how they will be installed. The manufacturers are not substitutes for the geotechnical project designers; they can only give general guidelines. Every engineering work is unique and requires specific care as to the selection and installation of instruments.

In conclusion, I feel that constant efforts should be made to develop good interactions between manufacturers and users. This will help users select instruments and learn about installation methods, and in return it will give valuable feedback to the manufacturers about the performance of their instruments. This interaction is in the long-term interests of both parties.

*Louis Marcil, Product Line Manager and Technical Services, Roctest Ltd,, 665 Pine Street, Saint-Lambert, Qc, Canada, J4P 2P4, Tel. (450) 465-1113, email: lmarcil@roctest.com*

### Rick Monroe

It is in any manufacturer's best interest to work closely with the geotechnical designers. Their success is our success. Given the chance to participate in the selection of instruments, the manufacturer can manage expectations of instrument performance and suggest alternatives when the instrument is marginal for the application.

Most manufacturers provide installation guidelines in their manuals, but users need access to those manuals before they purchase the instruments. Websites provide an excellent way to distribute both manuals and other information to users. When users have read the manual and looked at supplementary technical notes on the manufacturer's website, they can ask more informed questions and bring up issues that the manual does not address. This helps both the manufacturer and the user.

*Rick Monroe, Applications Specialist, Durham Geo Slope Indicator, 12123 Harbour Reach Dr., Mukilteo, WA 98275, Tel. (425) 493-6200, email: rmonroe@slope.com*

### Arthur D. M. Penman

In relation to the two umbrella questions about instrumentation, I would say that the only persons who can decide on any required instrumentation are those who are designing the dam and know the weaknesses they need to cover. When they know what they want, they then look at manufacturers' catalogues to find an instrument that will do what they want. The manufacturer can answer questions about exactly what their instrument can do but they cannot be expected to give instructions on installation because those details depend on the conditions on site.

For dams being built of layers of fill, placed and compacted on site, it is generally better to use instruments with horizontal connections. Vertical units cause a nuisance to the placing machinery and may be damaged during night-shift and also leave a poorly compacted zone around them. Vertical inclinometers are fine to observe movements of natural slopes, but not for a dam during construction.

In general it is not practicable for an instrument manufacturer to supply AND install their instruments because, even if they have enough experience of installation to be able to do that, they can never be at the site at just that moment when construction had reached the stage for installation. In practice it is much better for engineers working on the site, and with a high enough seniority to be able to make demands on the contractor, to make the installation, or any rate, supervise installation. The manufacturer must have supplied the required instruments so that they are on site when needed, and will work.

Often the instruments are supplied, particularly to dams overseas, with no spare parts, so that they cannot be repaired on site. A case that I know about is with an instrument to measure settlement under a dam. A simple water-balance unit was pulled through a tube built under the dam during construction, and readings being taken at specific positions. The unit contained a thin-walled rubber bag and no spare bags were included. The bag was found to be perished and we had to scour the region to find a shop selling balloons. We needed the cylindrical type balloon and after miles of travel we came across a shop with balloons hanging outside. They very kindly went through their stock, picking out this type and gave us several as spares.

When overseas it is always too late to request spares from the manufacturer because of the time for transport plus port delays. The manufacturers never manage to provide paperwork that will satisfy customs. So manufacturers sending their instruments overseas must predict what is going to suffer during transport and from being left in hot sun plus dust for months after arrival, and provide secured and protected spares. Of course customs will unpack everything for detailed examination, and then leave it lying loose so it is extremely difficult for manufacturers to get it all right. They rely on site engineers being aware of the problems and going to the port to receive the goods: this hardly ever seems to happen. Perhaps the manufacturers should have staff at the port (airport) to receive the instruments and get them to sites where they are to be installed. But this would presumably be much too expensive.

So from the point of view of the manufacturers, the best they can do is to provide detailed catalogues than answer questions about expected reliability or other details on the instruments, but they cannot be expected to give instructions for installation.

*Arthur D. M. Penman, Chartered Engineer, Sladeleye, Chamberlaines, Harpenden, Herts AL5 3PW, England, Tel. +44-1582-715479, email: admp@sladeleye.freeserve.co.uk*

### J. Barrie Sellers

Manufacturers can be helpful in meeting the specific requirements of particular projects. The best and easiest way for users and geotechnical project designers to avail themselves of manufacturers' expertise is to contact them directly by fax, e-mail or telephone, and to request whatever is required. All major manufacturers have websites which offer a wealth of information on both instrument types and installation details. Most manufacturers have technical service groups that can offer advice and training both in the office and in the field.

Manufacturing bias can be minimized by accessing multiple sources and, in this way, a consensus of opinions can be arrived at and the best ideas incorporated. From the manufacturers' standpoint there is no need to improve methods of interaction with users beyond using to their fullest those methods outlined above.

*J. Barrie Sellers, President, Geokon Inc., 48 Spencer Street, Lebanon, NH 03766, Tel. (603) 448-1562, email: barrie@geokon.com*

### *Robert Taylor*

**What is the best way for manufacturers to help users select the most appropriate instruments for their application?**

By all means call us. Lots of people do. Just remember, we are primarily suppliers, with the limitations which that implies.

**How can manufacturers help users to learn about the most appropriate installation methods?**

This one is less clear. Suppliers typically sit in their factories, know little of your soil, access, design objectives, materials, contractors etc, and aren't usually in a position to research all those critical details for you. We can suggest installation alternatives, name journal literature and books, give cautionary anecdotes, point out theoretical and practical aspects of the instruments themselves etc—but making the final installation recommendations is the business of the person(s) who must live with the result.

*Robert Taylor, President, RST Instruments Ltd, 200-2050 Hartley Avenue, Coquitlam, BC, Canada, V36 6W5,*
*Tel. (604) 540-1100,*
*email: rtaylor@rstinstruments.com*

# Experiences Gained from the Installation of Cable-free Sensors for Geotechnical and Structural Monitoring

***Chris Rasmussen***

## Introduction

For many years, as instrumentation has improved, the Achilles heel of many installations has been the cables from the instruments to the readout point, which sometimes includes a datalogger. Cables by their very nature are expensive, time consuming to install and difficult to protect from site conditions. Add into this the increasing demand for monitoring in sensitive areas, often inner city and historic sites where owners and stakeholders demand minimum disruption and visual intrusion and it becomes increasingly more and more difficult to install the instrument needed for the job.

With the advent of the various low-power, license-free radio frequencies, approved to national and international standards in recent years, it has been possible for the first time to configure a cable-free interface to the sensors that are used in our profession. This gives several advantages, provided that the pitfalls of battery life, data security, transmitted range and transmission reliability can be addressed adequately.

A number of installations utilizing cable-free sensors have taken place on a wide variety of sites in the UK and overseas during the past three years. This article will discuss the design parameters for a cable-free system, review two installations and look at some of the lessons learned along the way.

## Radio Transmitters

A cable carries an analogue signal from the sensor to the readout or datalogger. It was not considered the most secure way forward simply to replace this cable with a radio. This would provide a cable-free system by replicating the analogue signal with, for example, a frequency modulation (FM) radio, but would still be prone to interference and other detrimental effects. A more robust way forward was to design a transmitter unit which could be fitted to new sensors at the time of manufacture, or retrofitted to existing sensors. Pictured in Figure 1, this device contains a battery, excitation circuitry for the sensor, signal conditioning, analogue to digital conversion, and a radio transmitter to send the digitized reading to a receiver.

At the selected reading frequency (for example hourly), the transmitter awakes from 'sleep' mode, energizes the sensor, waits for the reading from the sensor to stabilize, takes a set of readings, averages them, digitizes the result, and sends this along with the radio/sensor ID number (unique for each sensor) and the transmitter battery voltage to a receiver. The transmitter

*Figure 1. Radio transmitter for fitting to existing sensors.*


*Figure 2. Integrated senor and transmitter to form a complete cable-free tiltmeter.*

then returns to 'sleep' mode until the next reading. By using power management in this way it is possible to have a battery life in excess of ten years from a small (4" x 1½" square) package. Alternatively, a more integrated complete sensor and radio package in a single housing can be used, as shown in Figure 2.

## Radio Receivers

Data from transmitters can be received in a number of ways, the most basic of which consists of a simple receiving station connected to a PC. For stand-alone applications there is a receiver/logger which stores transmitted readings until downloaded either manually or remotely. More sophisticated still are loggers with a built in wireless Internet connection. These loggers use the third generation cellular data network to place received data direct to the Internet. This type has proven to be the most popular and robust, with a very fast update time where the reading is taken, transmitted to the logger and then placed on to the Internet in less than five seconds.

As often is the case, users were at first reluctant to take up the new technology, due to a misunderstanding of and a degree of mistrust in the robustness and reliability of any radio system - many citing the unreliability of their mobile phone signal as a reason!

Fortunately for the developers, a number of projects were faced with the prospect of costly manual monitoring where the layout and position of the structures to be monitored precluded any cabling. Therefore automated or even manually-read instrumentation were rejected and the case for a radio system became overwhelming. In the following examples a system was proposed and adopted, using the cable-free system, which in both cases resulted in significant cost savings.

## Lewes, East Sussex UK

Following initial development and testing, the first sizeable installation was conducted in Lewes, East Sussex in the UK in late 2003 through to early 2004. Lewes is a predominately Victorian/Edwardian town with narrow hilly streets. A new storm water outfall tunnel and associated underground pumping stations was being constructed, requiring the monitoring of many separate structures along a zone approximately 1.6 Km (1 mile) in length. Figure 3 shows an overview of the project with the tunnel centerline, predicted settlement zone and the primary structures to be monitored.

Manually-read sensors were precluded, despite the relatively accessible nature of the site. The number of sensors and the amount of data required would have required a small army of monitoring technicians to take readings. Sensors cabled to dataloggers were not possible because of the large number of buildings, their historic nature and the number of roads and passageways which would have to be crossed; a large number of data loggers would have been needed, at a substantial cost.

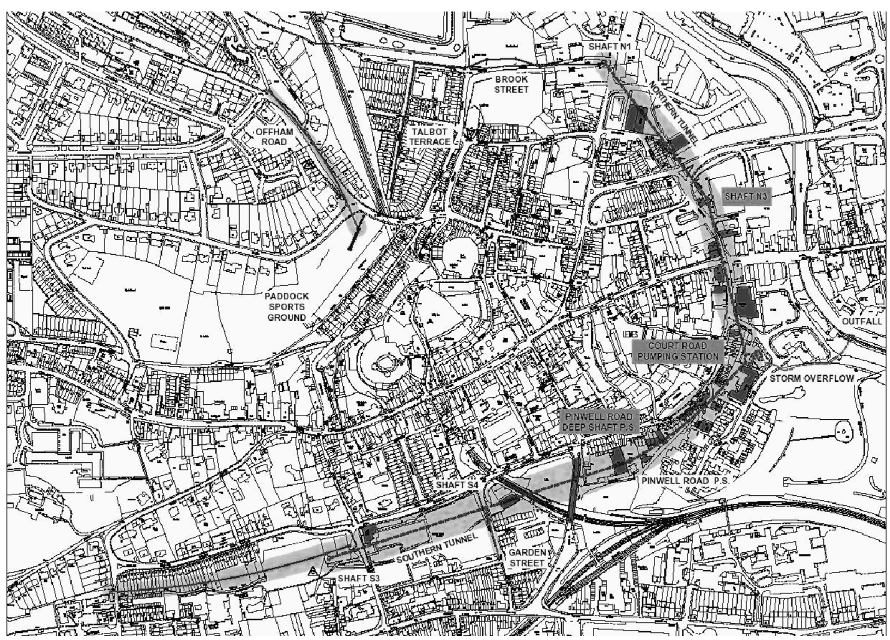


*Figure 3. The Lewes project. Predicted settlement zone in light gray, with tunnel centerline central with the zone. Primary buildings being monitored in dark gray.*

The nature of the site posed some challenges from a cable-free perspective. The desire was to cover the entire monitored section with radio receiver/loggers, which would then be downloaded via built-in cellular modems. As radio waves work best in a straight line without obstructions, a curved site (see Figure 3 above) with many different buildings made this goal difficult to achieve. Whilst the transmitters have a theoretical line-of-sight range of up to 250m (820ft), in such a congested environment it was necessary to split the monitoring into three sections, each covered by a separate receiver. Despite this, careful positioning of extended-gain receiving antennas was needed in order to capture all of the sensors for each of the three sections. A number of lessons were learned from this first full-scale installation of radios.

On the technical side refraction, where the radio signals are 'bent' by topography and structures and reflection, where the signals change direction due to the physical environment, caused both unexpected shortening and lengthening of transmitted range. It was discovered that by moving the sensor or just the transmitter by as little as a few inches, performance could be radically altered as a result of these effects. In addition, different receiving antenna types needed careful design and placement to maximize the distance which could be reliably achieved between the transmitters and the receivers, and to minimize the number of antenna and receivers required. Actual ranges between transmitter and receiver varied between 100m (330ft) and 750m (2500ft), although this range was only achieved with a specialist high gain, directional antenna.

In terms of the suitability of the system to perform the required monitoring task, this was a considerable success. In the early days of the installation, the contractor proceeded with a great deal of manual survey as a back-up, most probably due to a lack of confidence in radio technology as outlined above. As the job progressed, it became apparent that high quality reliable data were available from the cable-free sensors and therefore the survey work was substantially scaled down—much to the contractor's relief due to the large cost saving.

Aesthetically, the system was a notable success with members of the public and owners whose buildings were being monitored; there was some relief that holes would not be drilled and unsightly cables run. Instead, a small package which could be painted to match the building was installed. Additionally, the lack of disruption caused by daily surveys, particularly where these required access into buildings (as the majority of them did), was welcomed. Such was the popularity of the sensors with members of the public that unusually the contractor found himself with many requests to install instrumentation rather than remove it—'why are you monitoring next door and not me?'!

## Perth, Western Australia

Another successful project was in Perth, Western Australia. The New MetroRail Project is a A$1.5 billion (US$1.1 billion) rail line being built to extend services to outer metropolitan areas. It will run from Perth to Mandurah, augmenting the existing railway with more than 80km (50 miles) of new track. It is the largest public infrastructure project ever undertaken in the Perth Metropolitan area.

In one of the more challenging aspects of the project, twin tunnels have been bored under the Central Business District, opening up opportunities to revitalise shopping and business areas in a section of the city, and providing a doorstop service to Perth's new Convention and Exhibition Centre.

Leighton Kumagai Joint Venture (LKJV) is the contractor responsible for the inner city component of works. This includes the construction of:

- 770 metres (2500ft) of twin bored underground rail tunnel
- 600 metres (2000ft) of cut and cover tunnel (3 sections)
- New William Street underground platforms
- A below-ground station at The Esplanade

A comprehensive monitoring program was implemented to warn of any potential damage to buildings and structures along the alignment. In particular, intensive instrumentation and monitoring was applied to the buildings under which the tunnel boring machine passed before entering the William Street station box, which can be seen in Figure 4. Compensation grouting was used to control any potential settlement of the buildings in the zone of influence of the tunnel.

*Figure 4. Buildings being monitored around the William Street Station Box in Perth, Western Australia.*

*Figure 5. Radio EL beams installed above a false ceiling.*


*Figure 6. Excavation in Perth and buildings being monitored.*

Instrumentation for the buildings in this area performed two vital functions: (a) Assess any differential settlement of the structures; (b) Control the compensation grouting system.

The original monitoring design called for manual surveying and a "water level sensor system" to be used in combination with robotic total stations. On further review, and considering the complexity of various structures, it was realized that the installation of such a system was impracticable, both on the basis of technical logistics for installation in working businesses and cost. An alternative proposal was put forward to use a combination of robotic total stations and electrolevel (EL) beams in "strings", running from outside the area of the expected settlement through the length of each structure. This would provide a "network" of monitoring points.

The next two challenges for the LKJV Geotechnical Engineering Group were: (a) How to manage the proposed 2.5 kilometers (8200ft) of cable in such tight constraints without upsetting the property owners and occupiers?; (b) How to retrieve the data from five dataloggers to their network in near real time?

An innovative design was determined that used cable-free EL Beams. This system had the advantage of requiring no cables in the buildings, and allowed the data to be transmitted to a single receiver in the site office.

Each of the EL beams was fitted with a specially designed radio transmitter, operating on a low transmission frequency (434 MHz), as required by Australian regulations. Data transmission proved more of a challenge than even the Lewes project, with many of the sensor strings being located in basements or behind partition walls or ceilings. Unlike Lewes, directional and high-gain antennas were not the solution; instead it was necessary to install 'repeater' units. These, as their name suggests, are tuned to the frequency at which the radio transmits, and they then simply 'repeat' any signal they receive at a higher power than the incoming signal. By using a series of repeaters, located outside the buildings being monitored (in the site compounds), it was possible to use a single receiver connected direct to the monitoring PC to receive data from all the sensors, even those many hundreds of meters away in basements. An example of the nature of the site can be seen in Figure 5, where the basements of the properties shown required monitoring, and Figure 6 where a line of EL Beams is installed in one of those basements. To receive all of these signals from a single antenna without some form of repeater system would have been extremely difficult to impossible.

The lessons learnt at Lewes were applied to the installation in Perth, but here other unique factors came into play. The first of these was a requirement for 2 minute transmission intervals rather than the normal 1 hour. This posed problems with both battery life and ensuring that the thousands of transmissions each hour were all correctly received and logged.

With careful manipulation of the power management, battery life was estimated, with no change of components to be two years. To ensure all data are recoded, the receiver was configured to record at a higher speed than normal, and as each transmission has a unique digital ID, even if two or more transmissions arrive at the receiver at the same time, they were both recorded. Battery level is transmitted with each reading and to date, after 18 months is still at 75% of capacity for the transmitters.

Secondly, in the summer months Perth has very high daytime temperatures While this was not a concern for the transmitters, most of them being inside buildings, several repeater units installed in full sunlight did shut down after their internal temperature reached 80ºC (176ºF). It was necessary to provide shade for these units to prevent a reoccurrence.

As with Lewes, the system found a high degree of acceptance from third parties, particularly shop owners, where the speed of installation and the ability to hide the sensors above false ceilings and within partitions was welcomed. There were some problems in stock-rooms where shop staff would place boxes against sensors or hang things from them, leading to some false alarms, but these were easily resolved with a quiet word in the right ear.

### Conclusions

Since the introduction of cable-free sensors the technology has found wide acceptance in the UK and many other countries. With further development work the system will become more sophisticated and reliable and the cost will inevitably fall. The case for continuing to use cables, currently often favoured on a cost basis, will become even weaker once this stage is reached.

With care in installation, cable-free systems do appear to work to a level which both exceeds our design expectations and overcomes our customers' initial fears in real-world site conditions. There are no serious detrimental effects due to poor transmission range, or interference to transmitted signals, even when installed in basements, tunnels or electrically noisy environments. When used in sensitive areas, such as railways (where stringent emf standards apply), it is important to have the system certified to the relevant standards. Without such certification many owners will not allow the systems to be used.

New sensor types are becoming available, such as solid state accelerometers and pressure sensors. These require very low power and have a far lower cost than traditional force balance accelerometers or vibrating wire sensors. By combining these new sensors with radio transmitters, the opportunity exists to advance the use of instrumentation beyond that currently experienced on many projects. When combined with the proliferation of web-based data collection and presentation, the use of instrumentation will continue to grow, particularly in congested urban environments.

*Chris Rasmussen, Soil Instruments Ltd, Bell Lane, Uckfield, East Sussex, TN22 1QL, UK, Tel. +44 1825 765044, email: chrisr@soil.co.uk*

# Interpreting Unexpected Instrument Data

***Verne C. McGuffey***

### Introduction

The sharing of detailed information on instrumentation difficulties in the article by Mirghasemi (*Geotechnical News*, *March 2006, pp 32-36*) and the comments of the seven specialists in the field (*Geotechnical News*, *June 2006, pp 34-43*) led me to believe that many of us casual users might have similar information that would be useful to the profession. Perhaps this note will invite other users with useful experiences to share them also.

All users sometimes encounter unexpected data from instruments. The field staff on many of my projects were instantly into the instrument manual trying to fix the *#* machine. Their efforts often resulted in damaged or destroyed instruments and/or recording equipment, or improper construction decisions. My experiences lead me to believe that the instruments are seldom really giving "wrong" data.

I have put together a few ideas that I found helpful in understanding strange data, and to guide methods of interpretation and therefore to guide decision making. I have also included a few unusual situations where the instrument was assumed to be at fault, but was not.

### Evaluation ideas

- Get good baseline data before you are at a critical stage of decision making. Take readings hourly, daily, or by the minute, not just at prescribed periods. Find out how the instrument responds. What are daily fluctuations due to variations in temperature, rain, batteries, different readers, etc.? How does it respond to adjacent activities?
- Take very frequent readings at the first construction activity that would influence the instrument. Evaluate the data for trends, delays, quantification of first readings, etc. Use the data to plan the appropriate reading and evaluation schedules. Plan when the frequent readings need to be repeated to reevaluate responses.
- Evaluate the quality of the data at landmark happenings. For example, start or stop of construction, rain, freezing, atmospheric pressure changes, hot or dry spells, adjacent

activities.)

- Make sure that support data are adequately gathered and included with the instrument data. For example, time of day; quantification of construction in the immediate and adjacent areas; temperature/atmospheric pressure information; unusual happenings like stockpiling, change of equipment, loss of electric power, etc.
- Look for trends. There are many trends for different instruments and situations, e.g. temperature, tidal fluctuations, battery performance, system response time, plus site response trends. As examples, one piezometer may be nearer a permeable layer or zone than another, and construction processes or geometry may encourage arching or stress concentrations.

#### Examples of Situations where Instruments were First Blamed for Strange Readings

- On one project, the electrical instrumentation responded to airplane traffic, apparently the radio contact with the airport. One was influenced by overhead high tension wires.
- Standpipe piezometers on projects were not believed to be responding properly. I ran falling head and rising head tests on them to evaluate response time, leaks, permeability, and get a reasonably accurate value at the time of readings. Some said a rising head couldn't be done, but I have done them to 100 feet by using air pressure in a smaller diameter tube to pump the water out of the standpipe. I put a ¼-inch tube in the exhaust pipe of my old car with some rags, and pumped out 40 feet of water from a ½-inch poly tube standpipe by submerging it inches at a time.
- I found that the response time for piezometer readings to reflect real pore pressures was not considered on some projects. Sometimes the pore pressure dissipation is similar to the response time curve, causing the user to believe there has been no response from the piezometer. Putting a rod or closed tube into a standpipe provides a quicker response time to get better information. You may need special reading equipment if the piezometric level is not above ground surface. Believing the instrument to have failed leads the user to not consider important data when perhaps something major is happening.
- Natural underground drainage paths are sometimes not consistent, or as expected. Data from one project was following a normal top and bottom drainage model under first loading. Then it changed to single upward model. Further study showed the gravel layer below the clay was in a rock basin and sealed so that after the whole layer was pressurized, it no longer would drain downward. Another project was expected to perform like a top, bottom and both side drainage model. Piezometer data showed that it would not drain sideways toward an area that had been heavily loaded by an old railroad embankment. The soil under the old embankment was later shown to have a lower lateral permeability.
- Settlement, as measured with settlement platforms, stopped on many projects during hard freeze months and resumed the original trends in the spring. It was initially blamed on the instruments (pipe being frozen into surface soil), but later platforms fitted with manometers verified the same trends.
- I visited the site of an embankment failure on Sunday. The project staff had looked at the prior week's piezometer data and concluded the observed erratic data were wrong (instrument failure) and that there was no need to take any action. Therefore they sent me the data in Friday's mail. The embankment dropped 8 feet on Saturday and I finally got a call. The previous Tuesday's data showed unusual changes in pore pressure, indicating that a failure was imminent. The pore pressure had gone up faster than the fill was placed, and as displacements became larger (inches to a foot) the pore pressure then dropped down below the zero readings and was followed by an 8 foot embankment drop.

We often create opportunities for poor response by using poor installation details and techniques. Read and understand the red book.

*Verne C. McGuffey, NYS DOT retired, 22 Lombard St., Schenectady, NY 12304, email: GEO96POP@aol.com*

do not print key lines

frame is 42 x 13,7