Geotechnical Instrumentation News

John Dunnicliff

Introduction

This is the twenty-fifth episode of GIN. I'll look forward to all the silver presents that will arrive from you.

This episode contains a follow-up, an article by Gordon Green, and a discussion by Dave Druss.

More on Installation of Inclinometer Casing

The last episode of GIN included recommendations for overcoming buoyancy during installation of inclinometer casing. This focussed on the typical North American practice of using ABS casing, which is relatively light, and buoyancy forces can therefore be large. After publishing the article it was realized that PVC casing is used in many countries, and because PVC has a higher specific gravity than ABS, buoyancy forces are less. The "follow-up" that appears immediately after this column focuses on the buoyancy issue when PVC casing is used. Your attention is drawn to our two concerns about using PVC casing. First, the practice of using an unusually low-density grout to avoid the buoyancy issue, thereby perhaps creating inadequate backfill between the ground and the casing. We strongly recommend a grout with a minimum density of 80 pcf. Second, the lesser clearance between the probe and the inside of the casing.

More on Temperature Effects on Strut Load Measurements

The last episode of GIN also included an article by Storer Boone and Adrian Crawford, on the complexities of separating thermal effects from true external loads when making vibrating wire strain gage measurements on struts in braced excavations. The following discussion by Dave Druss, about experience with similar measurements on the Boston Central Artery/Tunnel Project, adds to the lessons learned.

What's New in 2000?

If you want to know, read Gordon Green's article. There's a wealth of information in here, made particularly useful by the inclusion of a comprehensive list of references. In the section "Instrument Installation", Gordon says, "It appears that there is great concern about allowing any grout between the porous piezometer element and the surrounding soil or rock. For many engineers and geologists, directly grouting in a diaphragm piezometer is simply not a thing they will do". I know some strong advocates of this practice, who are currently feeling the pain of my arm-twisting. I hope for a future article or discussion on this subject — watch this space!

The March 2001 Course in Florida

Details of the course are on page 25. Come and join us!

Birger Schmidt

A memorial to Birger Schmidt is on page 6. Birger was a good friend, and we worked and wrote together on many occasions since 1971. A significant part of my friendship with him was a 'fun' one, and I thought that it would be appropriate to reflect that side of his character in a few words here. Among many possible anecdotes, here are two. I know that Birger would be happy for me to "go public" with these, and his wife and daughter, Perla and Erika, have encouraged me to do so.

When co-authoring several reports on tunneling and high-level nuclear waste repositories for various US government agencies, Birger wrote the parts about which he knew something, and I did the same. That left the required parts about which we both knew nothing at all. "Okay, Birger, these are for you". And he wrote them — they appeared to be wise and impressive reading! We labeled those parts "the BS parts". What a talent!

Since he became unwell, we had regular e-mail exchanges, some serious and some flippant. About three months ago he said, "How about drafting my obit, and sending it to me for review? Just kidding!" I didn't take him up on it, and perhaps I should have done.

So much technical talent, and such a sparkling character! I'll miss him.

Regular readers of this column may remember that it was Birger who gave me a beer mat with toasts in many languages, and that I've been using these as closures to each column for the past six years. So, even though this is a repeat, this column closes with a toast in Birger's native language, Danish.

Closure

Please send contributions to this column, or an article for GIN, to me as an e-mail attachment in ms-word to *johndunnicliff@attglobal.net, or by fax or mail: Little Leat, Whisselwell, Bovey Tracey, Devon TQ13 9LA, England. Tel. +44-1626-836161, fax +44-1626-*832919.

Skål, Birger!

Overcoming Buoyancy During Installation of Inclinometer Casing — A Follow-up

John Dunnicliff
P. Erik Mikkelsen

Introduction

In the last episode of GIN (September 2000, pp. 19-20) we identified the need to overcome buoyancy of inclinometer casing during installation, and suggested appropriate methods. Tom Tonkins, Sales and Marketing Director, Geotechnical Instruments (UK) read what we had written and pointed out that our suggestions relate to use of ABS (acrylonitrile/butadiene/styrene) casing and not to PVC (polyvinylchloride). He's right. This follow-up will consider the buoyancy situation for PVC casing.

Comparison Between the Two Plastics

Almost all installations in North America use ABS casing. Almost all installations in England use PVC casing. Elsewhere both are used, the selection often depending on which manufacturer has the most influence. Fiberglass casing is also available.

The specific gravity of PVC is much greater than ABS, hence buoyancy forces are smaller. The two types are manufactured to different diameters. PVC tends to be more brittle than ABS, especially at low temperatures (we believe that this is reason why ABS has become the casing of choice in North America).

Buoyancy

Tom Tonkins reports that frequent practice when installing PVC casing is to pre-grout the borehole and to lower the casing through the grout. He comments "when lowering through grout, quite often we do not have to fill the casing with water completely, as with the weight of the casing and water, this is enough to make it go down". The following table summarizes calculated buoyancy forces for the two types of casing, with two different grouts. Forces and weights are per 100 feet of depth.

Note also that the article in the last episode of GIN indicated that the typical density of grout used for this purpose is between 75 and 90 pcf (and we strongly prefer a grout that actually sets and remains volumetrically stable, with a minimum density of 80 pcf), and from the table it can be seen that it is necessary to use a grout with density 73 pcf or lower to overcome buoyancy when PVC casing is used. Also note that if a grout with a higher density that Grout 1 is used, the buoyancy force will be much larger than given in the table.

Finally, use of PVC casing creates a 10 mm annular clearance between the inclinometer probe and the casing. On the other hand, for the smaller of the above two diameters of ABS casing, this is 17 mm. The greater clearance allows for monitoring a greater displacement. In our view this is a significant issue in favor of selecting ABS casing.

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Casing Material	O.D. inches	I.D. inches	S.G. of Plastic	Weight of Casing lbs	Weight of Water lbs	Weight of Grout 1 (Density 80 pcf) lbs	Weight of Grout 2 (Density 73 pcf) lbs	Buoyancy Force with Grout 1 lbs	Buoyancy Force with Grout 2 lbs
PVC	2.40	1.93	1.50	104	127	251	229	20	-2
ABS	2.75	2.32	1.06	79	183	330	301	68	39
ABS	3.34	2.87	1.06	101	280	487	444	106	63

Notes:
1. *Uplift force acts on the bottom cap.*
2. *Casing is fully surrounded with grout on the outside.*
3. *Casing is entirely filled with water on the inside.*

Discussion:

"The Effects of Temperature and Use of Vibrating Wire Strain Gauges for Braced Excavations" by Storer J. Boone and Adrian M. Crawford

David L. Druss

The article on pages 24-28 in the September issue of GIN by Boone and Crawford was not only informative, but also timely with respect to our efforts on the Central Artery/Tunnel Project in Boston MA. The project recently reached the 90% excavation-completion mark, and we are continuing to evaluate the vibrating wire strain gage data for the more than two miles of internally braced excavations completed to date. The primary means of assessing performance as excavation progressed was through measurement of ground and building deformations.

We too have grappled with the complexities of separating thermal effects from true external loads (earth, hydrostatic, and surcharge) when making strain measurements on struts in braced excavations. The most notable and pertinent example is a 110-foot deep cut primarily in glacial till. The design groundwater level for temporary construction is approximately 5 feet below the ground surface. Control of deformation was critical at this location because the edge of the mat foundation for a 46-story building lies within 15 feet of the cut. The building is founded at a depth of approximately 35 feet. The bracing system consists of a 3-foot diameter concrete diaphragm wall reinforced by W36x300 soldier beams placed at 4-foot centers. There are eight levels of struts at the greatest depth of excavation. The largest strut consists of a bundled (flange to flange) trio of W36 x393 rolled sections, with a design load of 3,880 kips. To account for the many uncertainties in temporary underground construction, inclusive of thermal effects, the allowable stress in strut members is restricted by CA/T Project criteria to 12 ksi. Struts are preloaded to 50% of their design load. Note that the excavation had precast concrete decking over the entire width, thus controlling the difference in temperatures among struts.

The performance of the excavation support system exceeded expectations. An unconservative analysis conducted in 1994 in advance of construction, yielded a predicted value of approximately 1.2 inches of maximum lateral wall deformation. Actual deformation never exceeded approximately 0.3 inches. Much of the bracing had been installed in the fall and winter months of 1999/2000. In the summer of 2000, measurements of approximately 0.25 inches *into* the soil mass were recorded. The "negative" lateral deformations were attributable exclusively to thermal expansion of the strut members. However, even under conditions which would appear conducive to extreme thermally induced stresses (e.g. substantial strut cross sections, stiff walls and very stiff soils), all measured strut loads remained within design values.

The following are conclusions and lessons learned:

- Strain gage data may need to be evaluated by a structural engineer. In some cases, there could be complexities in the specific construction of the bracing system that could entail a more detailed evaluation when calculating stresses. Many geotechnical engineers do not have the structural expertise necessary to identify such conditions, let alone correctly determine the stress distribution.
- If attempting to make initial strain gages readings, prior to installing the strut in the excavation, to represent a "zero stress" condition, a heavy strut resting on intermittently spaced blocks may not represent the condition of true zero stress which will occur after installation of the strut.
- Making initial strain gage readings when the strut is deforming under its own weight in the excavation, and is assumed to be in an ideally simply supported condition, may not be valid if the member has stiffeners, or consists of coupled elements. The actual stress distribution across a strut may not be consistent with a simply supported beam. In such cases, knowledge of the position of the gage relative to connections may be critical to determining the stress.
- A more reliable means of initializing/confirming strain gages is during the preloading process. If the preload is properly measured, the accuracy of the gages can be determined by checking the change in load after preloading.
- Use conservative criteria for design of struts, to account for thermal effects and other uncertainties.
- To determine the external load component of the measured load when using strain gages, the axial end stiffness at the end of the strut must be known. The end stiffness is comprised of the combined stiffnesses of the retained soil, wall, wale, and connections. This parameter can be approximately determined by taking several strain gage readings on a strut over a period when the temperature varies, but the external load can be assumed to remain reasonably constant. At each strain reading, accurately measure strut elongation and calculate the change in load (as measured by the vibrating wire strain gages). The end stiffness is the change in length divided by the change in load. To determine the thermal component of total measured strut load, calculate the theoretical unrestrained thermal elongation of the strut and subtract from that value the measured change in strut length. Divide the difference thus obtained by the end stiffness to calculate the thermal component of the compressive strut load.
- Of course, the method recommended by Boone and Crawford is also appropriate.

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Geotechnical Instrumentation for Field Measurements

March 12-15, 2001
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This Course is Unique:

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Ralph Peck will present a lecture "Observation, Instrumentation, Action – Chicago in the 30s to San Francisco in the 90s". He will also participate in a discussion on "People Issues with Observation and Instrumentation".

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Instructors and Topics, March 12-14, 2001

John Dunnicliff, Course Director,
Geotechnical Instrumentation Consultant, England.

- Systematic Approach to Planning Monitoring Programs.
- Overview of Hardware.
- Contractual Arrangements.
- Instrumentation of Slopes, Embankments on Soft Ground, Deep Foundations, Earth Retaining Structures.
- Discussion on People Issues with Observation and Instrumentation. Co-moderator with Ralph Peck.

Ralph B. Peck,
Civil Engineer: Geotechnics.

- Observation, Instrumentation, Action – Chicago in the 30s to San Francisco in the 90s.
- Discussion on People Issues with Observation and Instrumentation. Co-moderator with John Dunnicliff.

Douglas G. Baker, British Columbia Hydro. Instrumentation of Embankment Dams

Jeffrey A. Behr, Orion Monitoring Systems, Inc. Global Positioning Systems.

Helmut Bock, Geotechnical Consultant, Germany. Instrumentation of Tunnels.

Boyd Bringhurst, Campbell Scientific, Inc. Automated Data Acquisition Systems.

Pierre Choquet, Roctest Ltd., St. Lambert, Quebec. Fiber Optic Sensors.

Gary R. Holzhausen, Applied Geomechanics Inc. Tilt Measurements.

William F. "Bubba" Knight, Florida DOT. Case Histories. Instrumentation of Geogrid Reinforced Embankment Over Soft Soils. Instrumentation of Deep Foundations for Static Load Testing.

Jean-Ghislain La Fonta, Sol Data, France. Case histories. Real-Time Monitoring of Railway Tracks and a Dam, Including Automatic Surveying. Amsterdam Metro.

Kevin O'Connor, GeoTDR, Inc. Time Domain Reflectometry.

Tony Simmonds, Geokon, Inc. Vibrating Wire Instruments for Unique and Custom Applications.

Robert M. Taylor, RST Instruments. Measurement of Negative Pore Water Pressure in Unsaturated Soils.

Hai-Tien Yu, Slope Indicator Co. Electrolevel Sensors and Automatic Data Acquisition Systems.

. Criteria and Case Histories.

Optional Fourth Day, March 15, 2001:

Discussion Among Attendees and Instructors of Various Topics, to be selected by Attendees. **Attendees are encouraged to send requested discussion topics to John Dunnicliff well before the course date.**

Textbook Included:

Geotechnical Instrumentation for Monitoring Field Performance, by John Dunnicliff, published by Wiley in 1988 & 1993, is a part of the course materials.

Enrollment, Fees, and Registration:

The three-day registration fee (March 12-15, 2001) received by Feb. 16, 2001 is $1,075. Late registration (after Feb. 16, 2001) is $1,150. Including the optional fourth day, the fees are: by Feb. 16, 2001 $1,225; after Feb. 16, 2001 $1,300.
All the above fees include the textbook and break refreshments. If you have, and bring, the text, each fee is reduced by $50.

Accommodations:

The course will be held at the Holiday Inn Oceanfront Hotel, Cocoa Beach, Florida. Rates are $82+tax single/double. To make reservations, call (800) 206-2747, or (321) 783-2271 from outside the US, or fax (321) 407-8878. To ensure a room at this rate, make reservations by Feb. 11, 2001, and mention the Geotechnical Instrumentation for Field Measurements course.

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Geotechnical Field Instrumentation - What's New in 2000

Gordon E. Green

- **Robotic Optical Survey Systems (ROSS)**
- **Global Positioning Systems (GPS)**
- **Time Domain Reflectometry (TDR**
- **Fiberoptic Sensors**
- **Electrolytic Levels**
- **Vibrating Wire Tiltmeters**
- **Vibrating Wire Force Gages**
- **Digital Tape Extensometer**
- **Quick Connect Inclinometer Casing Couplings**
- **Instrument Installation**
- **Automated Data Acquisition Systems (ADAS)**

Introduction

Since the publication of Geotechnical Instrumentation for Monitoring Field Performance by John Dunnicliff (the red book) in 1988, a number of new technologies have appeared or have reached a more advanced stage than were hinted at twelve years ago. New geotechnical sensors, installation methods, data logging techniques and software packages are now, or are becoming, more available. Traditional survey systems are being replaced by high-accuracy electronics-driven systems which are capable of automation, and satellite-based global positioning systems can provide sub-centimeter accuracy, but all at a price. Features of some of these new technologies are described, together with their advantages and limitations.

Robotic Optical Survey Systems (ROSS)

Traditional survey methods require a human operator to move the level or theodolite from station to station and take periodic readings. Motorization and computer control provides more consistent manual operation together with remote automated reading capability and data transmission.

Motion-controlled digital levels are now available that can monitor settlement or heave over large areas to sub-millimeter accuracy. The level is programmed to sequentially read a series of permanently located bar-coded invar staffs fixed to the structure of interest. The system can be left unattended and data recorded at preset time intervals and transmitted by hard wire or telephone. Automated Leica levels have been used to monitor a large urban excavation (Naterop & Yeatman, 1995; Buchet, et al, 1999) and railway lines while tunneling below them (Naterop, 1998).

Motion-controlled total stations are also available and have been used to monitor building movements during tunneling as well as within existing tunnels to monitor movements caused by adjacent new construction. In one case (La Fonta & Person, 1999), a motorized Leica total station was mounted on a building roof to monitor about fifty measurement and reference prisms set on nearby structures. Three-dimensional deformations over a three-year period during shaft and tunnel construction were obtained and comparisons with traditional manual first order leveling were excellent. Motorized total stations have been successfully used in Singapore (Chua & Liew, 1999; Kimmance et al, 1999), mounted permanently on tunnel walls to sequentially sight a series of targets along the tunnel to measure both local convergence and vertical and horizontal displacements along the tunnel alignment.

The motorized survey instruments

can withstand direct exposure to weather but reflectors require cleaning, and damage by vandals must be guarded against. Space considerations in tunnels may be restrictive and clear sight lines are required.

Global Positioning Systems (GPS)

GPS is a satellite navigation system set up by the US military that can provide centimeter or even subcentimeter survey accuracy. It has been used to monitor displacements of dams, locks, bridges and landslides, but only to a limited extent so far, due to the newness of the technology, high cost and restricted availability, and perhaps a lack of understanding by geotechnical instrumentation program designers.

To achieve the deformation measurement accuracy desired, differential carrier phase GPS is needed. A base station is located at a nearby stable location and receiving stations are placed on the dam or landslide. Data are collected from both the base station and the various receiving stations. A line-of-sight VHF radio link may also be required. The receiving station may be a portable unit mounted on a tripod or survey pillar and read periodically at each station location. Alternatively permanently installed GPS receivers are available that can be remotely accessed and which provide higher accuracy and real-time displacement measurements. Depending on a site specific conditions and the equipment used subcentimeter accuracy for position and centimeter accuracy for heights can be achieved (Plant et al, 1998). Recently government restrictions on signal quality available to the private or non-military sector have been lifted so that the available accuracy should increase.

Leading suppliers of GPS equipment include Trimble Navigation Ltd. (www.trimble.com) and Magellan Corporation (www.ashtech.com). These companies supply complete systems including computer software, e.g. Hydra 3-D by Magellan. Technical specifications and procedural guidelines are given in USCE, 2000. High accuracy permanently installed GPS systems for displacement measurements are relatively expensive at present, but presumably costs will decrease in the future and they will be used more often by geotechnical monitoring system designers.

Time Domain Reflectometry (TDR)

TDR is, in its most common form, a method of detecting the location of breaks or localized distortions in electrical cables by transmitting a pulsed signal and observing reflections. The time delay between the pulse and its reflection or a change in capacitance defines the fault location and detailed analysis of the reflection characteristics may indicate the magnitude of the distortion (O'Connor, 1996; O'Connor & Dowding, 1999). A coaxial cable is grouted into a borehole so that localized shear movements caused by a landslide or extension due to subsidence can be detected by periodic connection to a portable cable tester. More usefully a number of grouted-in TDR cables can be multiplexed to a data logger that can be accessed by cellular phone (Kane & Beck, 1996; Mikkelsen, 1996). Such a system provides an important early warning capability for a dormant landslide that can be reactivated by excessive rainfall. The grouted-in coaxial cable can be used to accurately locate the depth of a slide surface, but the ability of the system to measure the magnitude and rate of movement is presently fuzzy, despite claims made by some of its proponents. The interpretation of the cable deformation signature is dependent on grout properties and other site specific issues, all difficult to control and calibrate.

In my opinion, a TDR cable grouted in a separate borehole near to a probe inclinometer casing, may provide a valuable remotely accessible early warning system at significantly lower cost than an in-place inclinometer installation. When movement is indicated, probe inclinometer readings can provide accurate information about magnitude and rate of movement (Green & Mikkelsen, 1988) well beyond the capability of a TDR cable . Installing a TDR cable in the same borehole as the inclinometer casing is likely to degrade the TDR signature and seems best avoided. Surface surveys are normally much less accurate and are no substitute for probe inclinometer measurements, as is claimed by Kane & Beck, 1996.

In a different form, TDR can be used to measure moisture content changes in soils, such as below pavements or in agricultural studies or for irrigation control (O'Connor, 1996; O'Connor & Dowding, 1999). Changes in the dielectric properties of a small 3-prong probe embedded in the soil are remotely monitored and can be calibrated against soil moisture content. The TDR probe appears to be much more reliable than traditional moisture block techniques. Other applications, including monitoring structural deformation and retrofitting open standpipes, are described by O'Connor & Dowding, 1999.

Fiberoptic Sensors

Fiberoptic data transmission is now commonplace and a new type of fiberoptic geotechnical sensor is available from at least one supplier, Roctest (www.roctest.com). Fiberoptic sensors may in the future compete directly with vibrating wire sensors for measurement of strain, displacement, pressure and temperature, with the added advantage of being immune to radio and electromagnetic interference and a higher dynamic measurement capability.

The new Roctest sensors are designed around a Fabry-Perot white light interferometer (see Choquet et al, 1999, 2000, for more details). Light transmitted along a fiberoptic cable passes through two semi-reflective mirrors facing each other. A portion of the white light sent by the readout unit is reflected by the first mirror and another portion of the light is similarly reflected by the second mirror. The two returning portions of light interfere and this returning light signal is analyzed in the readout by a Fizeau interferometer and a linear CCD array. Changes in the distance between the two reflectors can be measured.

Sensors currently available include temperature probes, embedment, weldable or clampable strain gages, and displacement transducers. Limited data logging equipment is now available, as is data transmission through a phone line. At present field experience is limited and real in-service performance is unknown. In my opinion, the sensors, cables and connectors appear to be relatively fragile and may not perform well under typical field conditions.

Electrolytic Levels

A desire for real-time data together with concerns about unit sensor costs have resulted in renewed interest and developments in electrolytic level technology. Available for use for over thirty years, they were largely neglected by geotechnical engineers until ten years ago, when extensive use on UK tunnel projects began. The electrolytic level or electrolevel is similar to the traditional carpenters spirit level but with three electrodes extending into the glass vial containing an electrolyte. Tilt of the vial is measured by a Wheatstone bridge type circuit. Tilt ranges as large as 90 degrees and as small as 1 degree or less are available with a precision better than one arc second for small ranges. These small range, high precision sensors can be built into automated displacement monitoring systems, e.g., Slope Indicators EL beams and Bassett convergence system (Rasmussen, et al, 1995; Bassett, 1995). Major concerns remain about accuracy, long-term stability, temperature sensitivity, cross-sensitivity and optimum monitoring methods, and opinions are divided (Chan & Weeks, 1995; Spalton, 1995). Ceramic vials rather than glass are now available that are more consistent in manufacture and less temperature sensitive, as well as a greater variety of monitoring configurations. Relatively stable underground or downhole temperature environments are desirable for these sensors, and surface locations exposed to direct sunlight should be avoided.

Vibrating Wire Tiltmeters

Vibrating wire tiltmeters have long been available but until recently were large bulky devices that found limited application. A new vibrating wire tiltmeter is available from Geokon (www.geokon.com) which is small enough that it can be used in an in-place inclinometer system installed in standard sized plastic inclinometer casing. It offers all the advantages of vibrating wire technology plus low thermal sensitivity, and appears to compete pricewise with electrolevel sensors. Ongoing developments have minimized the risk of shock damage prior to and during installation that is inherent in this type of sensor, unlike the electrolevel.

Vibrating Wire Force Gages

A vibrating wire force gage consists of a cylindrical weight partially submerged in water and suspended on a vibrating wire. As the water level changes the wire tension, and thus the resonant frequency, changes. This principle forms the basis of a high-precision water level sensor used for weir gaging as well as the very successful differential settlement open channel monitoring system used in the Red Line Tunnel in Boston (Feldman et al, 1999).

Digital Tape Extensometer

A new digital tape extensometer is available from P.J. Ealey (www.p-j-ealey.com) in the UK which provides a direct digital readout and appears to be easier to use than most others. It incorporates illuminated indicator lights rather than index marks to register correct tape tension. The digital unit should have a future potential for data recording on a separate portable logger.

Quick Connect Inclinometer Casing Couplings

Inclinometer casing assembly in the field traditionally employs rivets and/or solvent cement with the addition of tape and caulking compound for waterproofing in some cases, depending on the joint design. The ideal inclinometer casing joint should be easy to both assemble and disassemble, leak proof and sufficiently strong to withstand handling (including the inevitable mishandling) and external grout pressure during installation. Quick-connect couplings that snap together and incorporate O-ring seals are now available from four manufacturers (RST [www.rst-inst.com], Slope Indicator [www.slopeindicator.com], Phoenix Geometrix [www.phoenixgeometrix.com], and Roctest [www.roctest.com]) that appear to meet some or all of these design requirements. The quick connect casing method is attractive since it simplifies and speeds up field installation. Its acceptance and robustness has yet to be proven.

Instrument Installation

Significant new developments in instrument installation techniques are fewer and less obvious than in the instruments themselves. Grout mixes for borehole installation of instruments can be a source of problems. Traditional cement/bentonite or cement/lime mixes are being used successfully. The proportions, mixing sequence and mixing equipment (high speed or slow speed) all contribute to its pumpability down small diameter grout tubes and strength when set. The strength and stiffness of the set grout should generally match the soil or rock, particularly for some deformation monitoring instruments. Some instrument suppliers provide mix guidelines, others do not. Many users have a preferred grout mix which they use, otherwise the redbook contains some guidelines. Trial grout mixes using the actual field grout mixing equipment are often desirable but logistics can be awkward. Ideally a single dry component low permeability grout is desirable. Such sealing grouts are available and have their advocates. Their strength when fully set remains low. To some extent instrumentation grout mix design and implementation remains a black art and care and attention is required. Dont just leave it up to the driller.

Traditional piezometer installation in a borehole requires sequential placement of sand, bentonite, and grout. Installation can be problematic, time consuming and good practice limits the installation to one piezometer per borehole. Multilevel piezometers are available, e.g. Westbay and Waterloo systems, but are relatively complex, expensive and are only used in special circumstances. Alternatively a number of diaphragm piezometers can be suspended down a borehole and directly grouted in with a suitable low permeability grout without any sand or bentonite pellets/gravel being used. This technique was successfully used with small diameter standpipes in the UK in the mid-60s (Vaughan, 1969), but the idea remained dormant for 25 years until McKenna (1995) performed comparison tests on conventionally installed and fully grouted-in pneumatic piezometers at the Syncrude oil sands open-pit mine. These tests demonstrated that using a cement-bentonite grout the fully grouted pneumatic piezometers showed similar piezometric elevations as adjacent, conventionally installed pneumatic piezometers, as well as similar response times.

Note that if pneumatic diaphragm piezometers are directly grouted in they should be encapsulated in a sand-filled porous PVC cylinder or equivalent device, to provide a large volume water filled cavity to reduce the likelihood of diaphragm displacements during reading affecting the measured pore water pressure. Such encapsulation was used at Syncrude. An enlarged water-filled porous cavity is not required for vibrating wire or other electrical diaphragm piezometers directly grouted in, clearly an advantage.

Theoretically a directly grouted-in, fully de-aired, stiff diaphragm piezometer surrounded by a low permeability ($k \leq 10^{-8}$ cm/sec) saturated grout cylinder should respond instantaneously to a pore water pressure change at the grout cylinder/soil boundary. The principle of effective stress and consolidation behavior of clays is well established. Tests by Penman (1961) demonstrated that a vibrating wire piezometer embedded in a remolded London clay ($k=3x10^{-8}$ cm/sec) cylinder 11 inches diameter showed 99% full pore pressure equalization in 20 seconds.

With a few notable exceptions, diaphragm piezometers are still being installed worldwide, one per borehole, by traditional methods. Why is this? It appears that there is great concern about allowing any grout between the porous piezometer element and the surrounding soil or rock. For many engineers and geologists, directly grouting in a diaphragm piezometer is simply not a thing they will do. Their concern, soundly based or not, may be allayed by using the spring-loaded multilevel piezometer available from Geokon (www.geokon.com). Two pads, one porous and connected to a vibrating wire piezometer, are held in a retracted position and released downhole by a reusable pneumatic actuator. A series of such piezometers are installed one by one from the bottom up, after which the borehole is finally grouted. Grouted-in spring loaded multilevel piezometers were successfully installed down to 500 ft deep in oil sands extraction tests (Laing et al, 1988). Direct contact between the porous piezometer element and the borehole wall eliminates users concerns about intervening grout and reduces the influence of imperfect initial de-airing of the piezometer cavity on the response time. Whichever method is used, grouted-in multilevel piezometers offer both great technical benefits and cost savings and can be expected to be used more frequently in the future.

Automated Data Acquisition Systems (ADAS)

Geotechnical instrumentation ADAS practice appears to be well established around either the Campbell Scientific CR10X MCU or the Geomation 2380 MCU. Limited software packages are available from instrument and ADAS manufacturers. Specialized software for a limited market is expensive, hard to justify, and has a limited useful life. The full potential of ADAS-based multi-sensor instrument systems cannot be realized unless comprehensive reliable software packages are available. Who will write these, the user of the instrument or ADAS suppliers? It can be difficult for many, e.g., geotechnical consultants or state highway departments, to maintain adequate in-house specialist expertise. This may lead to a new breed of system integration consultants of the type described by Buchet et al (1999).

Summary Comments

The geotechnical instrumentation and ADAS supply industry is maturing with a limited size market and relatively few players. It is becoming more and more a global business where sensors are manufactured and shipped around the world and then repackaged by local agents or suppliers. Who designed and manufactured what hardware becomes murky. The market is being driven by low-bid requirements for both instruments and services, which often results in too many layers of responsibility and marginal or often low quality data. A change in focus is sorely needed.

New technologies such as GPS, ROSS, TDR, and fiberoptics are becoming more available and ADAS are advancing to where true real-time data will be available to the engineer.

New instrumentation technologies should be carefully assessed, and adopted by both suppliers and users where likely to lead to real advantages or greater data reliability. The geotechnical instrumentation industry is sometimes criticized as being too conservative. Conservatism is to some extent a good thing in this business. However, lack of acceptance of new useful technologies is a hindrance to progress and unthinking adherence to established procedures without change is wasteful.

References

Bassett, R.H. (1995), "Deformation Monitoring in Association with Tunnel Work," Proc. Seminar on Instrumentation in Geotechnical Engineering, Hong Kong Institution of Engineers, pp 57-78.

Buchet, G., Soga, K., Gui, W-M., Bolton, M., J-P Hamelin (1999), "COSMUS: New Methods for Compensation Grouting," 5th Int. Conf. Field Measurements in Geomechanics, A.A. Balkema, Rotterdam, p 517-523.

Chan, C.H.F., R.C. Weeks (1995), "Electrolevels or Servoaccelerometers," Proc. Seminar on Instrumentation in Geotechnical Engineering, Hong Kong Institution of Engineers, pp 97-106.

Choquet, P., F. Juneau, F. Dadoun (1999), "New Generation of Fiber-Optic Sensors for Dam Monitoring," Proc. Int. Conf. Dam Safety and Monitoring, China.

Choquet, P., M. Quirion, F. Juneau (2000), "Advances in Fabry-Perot Fiber Optic Sensors and Instruments for Geotechnical Monitoring," Geotechnical News, Vol 18, No 1, March, pp 35-40.

Chua, T.S., M. Liew (1999), "Development of Automatic Tunnel Monitoring System in Singapore," Proc 5th Int. Symp. Field Measurements in Geomechanics, A.A. Balkema, Rotterdam, pp 157-162.

Dunnicliff, J. (1988, 1993), "Geotechnical Instrumentation for Monitoring Field Performance," J. Wiley, New York, 577 p.

Feldman, A.I., Buechel, G.J., Ellis, H.L., Kucker, M.S., J.B. McRae (1999), "Instrumentation Program for Red Line Subway Tunnel," Proc. 5th Int. Symp. Field Measurements in Geomechanics, A.A. Balkema, Rotterdam, pp 95-100.

Green, G.E., P.E. Mikkelsen (1988), "Deformation Measurements with Inclinometers," Transportation Research Record 1169, TRB, National Research Council, Washington, D.C., pp 1-15.

Kane, W.F., T.J. Beck (1996), "An Alternative Monitoring System for Unstable Slopes," Geotechnical News, Vol 14, No 3, September, pp 29-31.

Kimmance, J.P., N.H. Osborne, M.R. May (1999), "The Design, Application and Performance of In-Tunnel Monitoring Systems," Proc 5th Int. Symp. Field Measurements in Geomechanics, A.A. Balkema, Rotterdam, pp 401-406.

La Fonta, J-G., T. Person (1999), "Puerto Rico Real-Time Control of Compensation Grouting with the Cyclops System," Geotechnical News, Vol 17, No 2, June, pp 27-32.

Laing, J.M., Scott, J.D., Stokes, A.W., Suggett, J.D., D.F. Wood (1988), "Geotechnical Instrumentation of the AOSTRA Mine-assisted Underground Steaming Trial," 4th Unitar-UNDP Conf. on Heavy Crude and Tar Sands, Paper 112, pp 17-32.

McKenna, G.T. (1995), "Grouted-in Installation of Piezometers in Boreholes," Canadian Geot. Jour., Vol 32, pp 355-363.

Mikkelsen, P.E. (1996), "Field Instrumentation, Chapter 11 in Landslides: Investigation and Mitigation," SR 247 Transportation Research Board, National Research Council, Washington D.C., pp 278-316.

Naterop, D., R. Yeatman (1995), "Automatic Measuring System for Permanent Monitoring: Solexperts Geomonitor," 4th Int. Conf. Field Measurements in Geomechanics, SGEditorali, Padova, Italy, p. 417-424.

Naterop, D. (1998), "Automatic Control and Data Acquisition for Optical Digital Levels and Motorized Total Stations," Geotechnical News, Vol 16, No 4, December, pp 29-34.

O'Connor, K.M. (1996) "Geotechnical, Environmental and Infrastructure Applications of Metallic TDR," Geotechnical News, Vol 14, No 2, June, pp 37-40.

O'Connor, K.M., C.H. Dowding (1999), "Geomeasurements by Pulsing TDR Cables and Probes," CRC Press, New York, 402 pp.

Penman, A.D.M., (1961), "A Study of the Response Time of Various Types of Piezometers, Pore Pressure and Suction in Soils," Butterworths, London, pp 53-58.

Plant, G.W., C.S. Covil, R.A. Hughes, Edits. (1998), "Site Preparation for the New Hong Kong International Airport," Thomas Telford, London, Chapter 14, Surveying, pp 387-416.

Rasmussen, C., E.P.W. Wong, W.R. Wood (1995), "Deformation Measurements using Electrolevel Sensors, Proc. Seminar on Instrumentation in Geotechnical Engineering," Hong Kong Institution of Engineers, pp 169-182.

Spalton, C. (1995), "Electrolevels-A Practical Solution or a Numeric Nightmare," Proc. Seminar on Instrumentation in Geotechnical Engineering, Hong Kong Institution of Engineers, pp 35-42.

USCE (2000), "NAVSTAR Global Positioning System Surveying," Technical Engineering and Design Guides as Adopted from the U.S. Army Corps of Engineers, No 28, ASCE Press, 336 pp.

Vaughan, P.R. (1969), "A Note on Sealing Piezometers in Bore Holes," Geotechnique, Vol 19, No 3, pp 405-413.

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