Instrumentation

John Dunnicliff

The goal of this column is to share useful (and perhaps sometimes more light-hearted and trivial) information relating to geotechnical instrumentation. Each part will be brief, and I intend to focus on performance of instruments. As a practitioner, I know how difficult it is to be confident that such-and-such an instrument will work well, and it seems to me that if we share performance information with each other, we will make this less difficult.

This is therefore not "my column," but "our column." Please let me have useful information, in the form "We're about to do...and will tell you how it worked out later," or "We've just learned...," or other material that you think will help others. If your material is other than brief, and I think it's worthwhile, I'll suggest that you flesh it out as a stand-alone article for this magazine.

Introduction

This is the third episode of GIN.

I've agreed on the following arrangement with the Managing Editor of GN: this column and any future articles, that are submitted to me and for which I act as editor, will appear in the magazine under the heading **Geotechnical Instrumentation News** (GIN). If anyone wants to submit an article without me acting as editor, he/she should submit it directly to GN.

This time I've solicited articles from four colleagues for inclusion under the GIN heading: two about electro-levels, by Arthur Penman and Eric Drooff, some elaboration by Gordon McKenna on the September 1994 article about slope monitoring, and a report by Bryan Sweeney on a recent convention session. I hope that other articles will come from you — I'll run out of colleagues who I can lean on sooner or later!

Electro-Levels

Perhaps the '90s will be remembered as the decade of the electro-level. Turn a stone, and there's another one! They appeared twice in GIN-1, in relation to an in-place inclinometer and to tests in a subway tunnel. There are two articles on electro-levels in this issue of GN (trust me when I promise you that it's a coincidence that both tell about a commercial source from across the big pond!).

I'm working on two projects that will include chains of electro-levels, to monitor deformation of existing facilities during construction of nearby tunnels. One will be an immersed tube tunnel constructed over an existing tunnel, with electro-levels in the existing tunnel. The other will be a jacked tunnel beneath several railroad tracks, with electro-levels alongside the tracks.

Both are in the design stage, and I hope to be able to report on details later. Because this is a relatively new technology and because, as Eric Drooff says at the end of his article: "our experience suggests room for an improved electro-level system", I'd welcome other articles that report on performance of electro-levels.

Liquid Level Gages

When we need to monitor deformation during tunneling, as in the four projects referred to above, should we consider multi-point liquid level gages (red book Figure 12.99) for the primary system or as a backup to chains of electro-levels?

I've tended to say no, because of possible problems associated with discontinuity in the liquid, temperature changes and differentials, and possible non-uniform air pressures. However, Eric Drooff raises the question, and it's an active issue for one of the projects with which I'm involved. A major disadvantage with chains of electro-levels is the reliance on **all** electro-levels: if one is faulty the entire chain is compromised, as with an open survey traverse. Also, any inaccuracy is magnified as levels are calculated further along the traverse, because the inaccurate angle rotates the entire remainder of the traverse.

As an aside, when we do this, we should create a closed traverse by tying into known levels (or benchmarks) at both ends. The liquid level gage does not suffer from these disadvantages and hence, in my current view, should be considered. The Interfels gage referred to by Eric Drooff is the type shown in red book Figure 12.99, and has performed very well in Germany.

However a better choice, which Shannon & Wilson is considering for the immersed tube tunnel constructed over an existing tunnel, may be a large diameter pipe, sealed and partially filled with a liquid, with liquid level sensors at intervals along the pipe. This arrangement should reduce concerns about the three possible problems identified above. As for electro-levels, I hope to be able to report on this development later.

Load Cell Calibrations

Barrie Sellers of Geokon has sent me a follow-up to his article on load cell calibration (*Geotechnical News, September 1994*):

I repeated the tests using vibrating wire load cells. In situations producing a 15 percent difference in the calibration constant with electrical resistance type load cells [difference between the underregistration and overregistration], the corresponding difference with a vibrating wire load cell was only ***one*** *percent. This is probably because the vibrating wire elements are located in the middle of the loaded annulus, so they don't suffer from bending the same way as the electrical resistance types, which are responding to the barreling out or pinching in of the mid-section. (The VW elements are on the neutral axis; they are not affected in the same way.) Another thing that amazed me was that the 15 percent effect was present with electrical resistance load cells even though I was using at least two-inch thick platens, top and bottom, and the size mismatch was not all that unusual.*

To name or not to name? ... two reactions

Unless others convince me that this information is misleading, I learn that I should lean towards using vibrating wire cells rather than electrical resistance load cells for load tests on driven piles and drilled shafts, and when I use load cells during testing of tiebacks.

FMGM 95 in Italy

If you're reading this in late March or early April, it's not too late to arrange to go to Italy to participate in the international symposium "Field Measurements in Geomechanics" in Bergamo, between April 10 and 12 (*Geotechnical News, December 1994, page 30*). I have a symposium program — let me know if you want one, or fax *Giorgio Pezzetti at ISMES, 39-35-211191* (note that this number is different from the one given in GN, December 1994).

Continuing Education Courses

A 2-day instrumentation course for September 23 & 24, 1995 in **Vancouver, British Columbia** is being planned. See page ?? for more details. The date for the proposed 3-day instrumentation course (*Geotechnical News, December 1994, page 30*) has been set for November 6-8, 1995 at **Cocoa Beach, Florida**. If anybody is interested, please call or fax me.

To Name or Not to Name?

In GIN-1 (*Geotechnical News, September 1994*), I wrote:

If your material is controversial, and in particular if you want to report on something with which an instrument manufacturer may disagree, I will contact all concerned and mediate as necessary. All references to manufactures and others in the first episode have been approved by the people referred to.

In GIN-2 (*Geotechnical News, December 1994*), I encouraged users to prepare a written performance assessment of instrumentation whenever possible, and share with manufacturers. I wrote:

There's a temptation to publish these assessments (which list both pros and cons), but I feel more comfortable with a "gently, gently catchee monkey" approach.

...potential users have a right to know...

I've had two reactions to the issue of naming manufacturers. The first, from Gordon Green (a user: name included at his request), contending that we **must** name names, as this is the only way that others can learn what's good and what's not good. Also that there should be no need to seek manufacturers' approval before naming. I'm concerned about that approach, fearing that it fosters the "them and us" atmosphere between users and manufacturers, which we must avoid.

The second reaction was from Barrie Sellers of Geokon (a manufacturer: name included with approval), who wrote:

Your "gently gently catchee monkey" approach is, I think, the best. Certainly we should avoid naming names in a negative way.

We had a bad experience many years ago with some instruments that malfunctioned. A report was published naming names. It was a black eye for us and, ever since then, this report has been used as a means to discredit our products with potential customers. (Note, I am not naming who is doing this, but they know who they are.) No manufacturer needs to be continually beaten over the head over problems which have long since been put right. Also, it is worth bearing in mind that instrument failures are not always brought about by faulty design or poor workmanship, but quite often by unforeseen and unforeseeable circumstances.

Certainly potential users have a right to know whether a particular manufacturer is reliable or not. They can always find out by asking for references and users' lists. Also, if they really want names, they can always contact the author of the article or report.

So — where am I now? I go with the manufacturer's view, modified by accepting use of names as in Eric Drooff's article. As users, we should recognize that manufacturers want to learn from our experience with their products, both good and less good, and I repeat the plea made in GIN-2: please adopt the approach of requiring a performance assessment whenever you can, and share with manufacturers.

Reactions to GIN-1 and 2

I've had several, and will share two:

The first, by Gordon Green: *The content of technical items is too superficial, and many items are too controversial and complex to be dealt with in this brief and dogmatic way. For example, you shouldn't tell about a preference for* *granular bentonite to seal piezometers without telling about the waiting time for swell before adding grout, about the method of grout injection to avoid jetting into the bentonite, the possibility of eliminating granular or pelletized bentonite entirely, the possibility of using granular bentonite in the entire borehole rather than granular bentonite followed by grout, etc.*

I suggested to this reader that he provides a discussion for publication, covering the missing points — it seems to me that this is the best way to overcome the apparent dilemma, because it certainly isn't my intent to mislead anyone, and I don't plan on writing lengthy contributions.

Second: *Your series of articles in the September GN was more informative, useful and entertaining than the last 10 years of the ASCE Geotechnical Journal. Keep up the good work, we look forward to future installments.*

Life would be dull if we all shared the same opinions, wouldn't it?

Contributions from Manufacturers

The first three episodes of GIN have referred to several manufacturers of geotechnical instrumentation. Some have been brief items written by me, some have been contributions by the manufacturers themselves. It has been pointed out to me that these references have been primarily to two manufacturers only, and that this "isn't right". I agree. I'll try to correct this in future episodes, but I'll need contributions from manufacturers to help me do this. Another plea for help!

Some Trivia: Bumper Stickers

- My old favorite: Vietnam, love it or leave it.
- Wife's old favorite: If they can send one man to the moon, why can't they send them all?
- Our favorite: It's never too late to have a happy childhood.

Closure

As said before, please send me discussions, new material, whatever you think may be useful, to 16 Whitridge Road, South Natick, MA 01760, Tel. (508) 655-1775, fax (508) 655-1840. Skål

Deformations Measured by Electro-Levels

Arthur D.M. Penman

Early Work

John Dunnicliff's remarks in GIN-1 (Geotechnical News, September 1994) about the new development by Slope Indicator Co. of an inclinometer with electrolytic sensors, reminded me that I tried out electro-levels more than 30 years ago at the Building Research Station (BRS), England. The one I tried was 6 inches long with four electrodes through the glass into the liquid, and was read by a Wheatstone's Bridge. It was extremely sensitive and would respond to the slightest movement, so much so that it seemed useless for measuring the types of deformations that interested the soil mechanics people of that time. Had it been stable, it could have been used to measure the deformations of buildings due to settlements, or movements caused by adjacent works, but it suffered terrible zero drift. The manufacturers proposed a way round this weakness by having a stable reference plane on which the instrument could be clamped to set a zero reading, immediately before taking a reading on a building, but this could be done more readily with a traditional spirit level: the beauty of the electrical part was the ability to read remotely. The trouble was caused mainly by the use of direct current, which caused electrolysis and the formation of bubbles around the electrodes.

More Recently

The method was abandoned for geotechnical uses, until about 20 years ago, Bob Cooke, working with Tom Whitaker on pile research at BRS, was seeking a method of measuring the small deformations of the ground at progressive distances from a pile as it is loaded. His idea was to level along a horizontal borehole radial to the pile and determine the settlement of the ground caused by pile loading from the change of level. The borehole inclinometers at that time were designed for vertical boreholes and in seeking a mechanism that would measure in a horizontal borehole, he came across a firm, Hamlin Inc. of Wisconsin, making electro-levels, so he tried them out. They were extremely sensitive instruments, as was the one I had tried out, with a range of only ±1° Bob got over the DC problem by using a portable commercial AC strain gauge bridge with a precision volt-meter which showed 100 divisions for only one second of arc movement of the electro-level. For practical use, he shunted the output with high stability resistors to reduce the response from 100 divisions to 2. He found the stability of the instrument to be within ±10 seconds of arc over a period of two weeks, and described the work in 1973. The electro-level continued to develop under the work of Bob Cooke and his new assistant, Gerwyn Price. After Bob retired, Gerwyn was joined by Irene Wardle, a computer wizard, and they soon had the electro-level as a very stable instrument, automatically recording the smallest changes of inclination.

Recently

A beauty of these modern electro-levels is their small size. The sealed glass tube is 30mm long and 6mm diameter, so that they can be mounted at any attitude in the measuring instrument. They were recently used to measure the deformations of an asphaltic upstream membrane on a dam with a slope of 1 on 2.25. The instrumentation consisted of a chain of box section tubes, 0.5 and then 1m long, each containing an electro-level. They were mounted so that they could be set level after installation, but before the hot asphaltic membrane was placed. The connecting wiring was run back into an inspection gallery to the readout equipment. Each unit had a range of ± 3°, i.e. a movement of ±52mm over a one metre length. Their long term accuracy was better than 50 seconds of arc, i.e. 0.25mm over the metre length. This work has been described by Tedd et al (1991). Current information from Gerwyn Price is that the evidence shows an accuracy of less than 1mm movement of beams 15m length in 5 years. He has several deep in the ground near Fenchurch Street, where it can be assumed that there is virtually no movement, that were installed more than 10 years ago. Their repeat readings have all been within 1 or 2 seconds of arc.

The Mansion House

The prestigious historic Mansion House in the middle of London suffered some cracking during tunnelling operations. When proposals were made for further tunnelling to extend the Docklands Light Railway to the Bank Underground Station, further detailed assessments were made of the probable effects on the Mansion House and it was agreed that the distortions and settlements of the structure should be accurately monitored by equipment that could give continued information about the movements occurring as tunnelling progressed. An electro-level monitoring system was installed by BRE (Station was changed to Establishment a few years ago) under the direction of Gerwyn Price. The system was in two parts, in boreholes under the Mansion House and within the basement of the House. The boreholes were fitted with standard 50mm diameter inclinometer tube grouted into place, and the electro-levels were mounted in spring loaded carriages at one or two metre intervals forming a chain that was passed into the tubes. Two of the holes were horizontal, two were vertical and one was inclined. Within the basement, settlements were measured by use of interconnected strings of beams each about 2m long, their ends attached to common pivot points drilled into the basement walls. An electro-level was fixed to each beam and the measured tilt gave the rise or fall of the beam ends relative to the ends of the adjacent beams, whose electro-levels showed their movements and so on, right round the building. This beam system was below floor level, so out of sight, allowing the normal use of the Mansion House, home of the Lord Mayor of London, to continue uninterrupted. Electro-levels were also used to monitor the tilt of some walls of the building.

The electro-levels, with other instrumentation, were connected to a specially designed modular data acquisition system which fed, via a telephone line, a modem and computer in a Croydon office. The software for the system consisted of a main control programme specially developed for the Mansion House instrumentation. This ran on a site computer continuously, checking time continuously and at predetermined times of usually an hour, taking sets of readings and storing them on a disc, sending the new information to the Croydon office at least once a day, over night, or on demand. In this way a constant check could be made on the effects of tunnelling as the work progressed. The system has been in use for more than three years.

Closure

The value of the electro-level in providing accurate, unobtrusive and continuous measurements of movements has put it in great demand. During the past four years, BRE has completed more than £3 million worth of commissioned work using the device. Gerwyn Price has now formed his own independent company called Construction Monitoring Control Systems (CMCS), to free himself of Civil Service restrictions and accountancy systems. CMCS can be contacted by phone and fax on + 44 923 673 804. The Mansion House work had been described by Price et al (1994).

Additional news about electro-levels became available just before the deadline for submission of this article to GN. Lives were saved by a settlement monitoring system, that included electro-levels, above the recent tunnel collapse at London's Heathrow airport. Around the entire Heathrow complex a £700,000 monitoring system had been set up to check on any settlements caused by tunnelling for the new high speed rail link from Paddington main line station to the airport. Readings were being taken continuously, as at Mansion House, as tunneling work proceeded. At about 1 a.m. on Friday 21st October 1994, it was seen that a depression was forming over the excavation of three parallel tunnels for two platforms and a central concourse, each 9m across and 8m high, with the rate of settlement accelerating. A warning was sent below ground and the 25 construction workers were hastily brought to the surface moments before the whole workings collapsed.

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Remote Monitoring Electro-levels for the New St. Clair Rail Tunnel

Eric R. Drooff

Introduction

The new St. Clair River Tunnel currently under construction is an 8.4 meter internal diameter tunnel driven with a full face earth pressure balanced tunnel boring machine (TBM) from Sarnia, Ontario under the St. Clair River to Port Huron, Michigan.

The tunnel is being constructed by CN North America to accommodate double stacked rail cars too large to fit through an older parallel tunnel originally constructed in 1890. Before the tunnel heads out underneath the St. Clair River, it passes underneath the Imperial Oil Refinery and, in particular, the main research building in that facility as well as several other process structures.

Passing approximately 10 meters below the foundations of this building, the design scenario predicted a maximum centerline settlement of 120mm. As such, the construction of the new tunnel had the potential to cause significant differential movement and damage to their 3-story reinforced concrete research building.

In May, 1993 Hayward Baker Inc. (HB), a specialty geotechnical contractor out of Odenton, Maryland, was selected as the prime contractor for settlement protection work of the Imperial Oil Research Building, as well as a number of other structures on the site. As part of a performance specification produced by the Owner's consultant, a joint venture of Hatch Associates Limited of Mississauga, Canada, and Mott MacDonald of Croyden, U.K., HB was charged with maintaining the level of the Imperial Oil Research Building, using the Soilfrac grouting method controlled through the use of a real time remote monitoring system mounted to the building (see Figure 1). Soilfrac grouting is the locally confined and controlled fracture of the soil structure using a fluid grout. This technique is used to both increase bearing capacity and shear resistance of soils as well as to induce heave to compensate against settlement.

Contract Requirements

The consultant's performance specification called for a structural monitoring system installed unobtrusively in the basement of the Imperial Oil Research Building. In addition, a second entirely independent system of electro-levels was required to be installed in the soils below the building's foundations in order to register ground movements before their effect on the building.

The system was to provide electronic data capture and remote reading facility of the Imperial Oil property, and was required to achieve sufficient accuracy to identify angular distortions of 1 in 2,500 between the main structural elements in two directions.

Review Of Prospective Systems Before Bid

1. Electro-levels

While the performance specification in the bidding documents clearly allowed for the proposal of any type of remote monitoring system, all the details and layout provided in the plans were based on an electro-level system. The use of an electro-level system was introduced by the consultant, who had just recently supervised the compensation grouting test program at Red Cross Way in London, in which electro-levels were tested for their compatibility in controlling the Soilfrac grouting anticipated for that work. In addition, the consultant had several other experiences with which HB was familiar, such as the Kingston Bridge in Scotland.

After some study, we found only two viable suppliers of electro-level systems. The first potential supplier considered, was Slope Indicator Company. Slope Indicator, through their supplier in the U.K., Brainard Kilman, Ltd. and Sinca in Canada, provided a rather expensive yet comprehensive package to supply the electro-level system. None of the two Slope Indicator suppliers

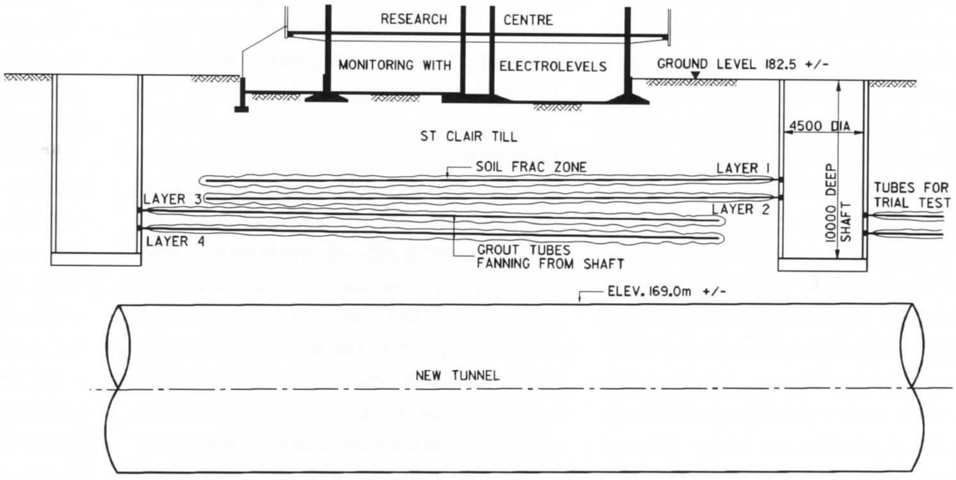

Figure 1. Section through research building showing frac-grouting shafts and tubes

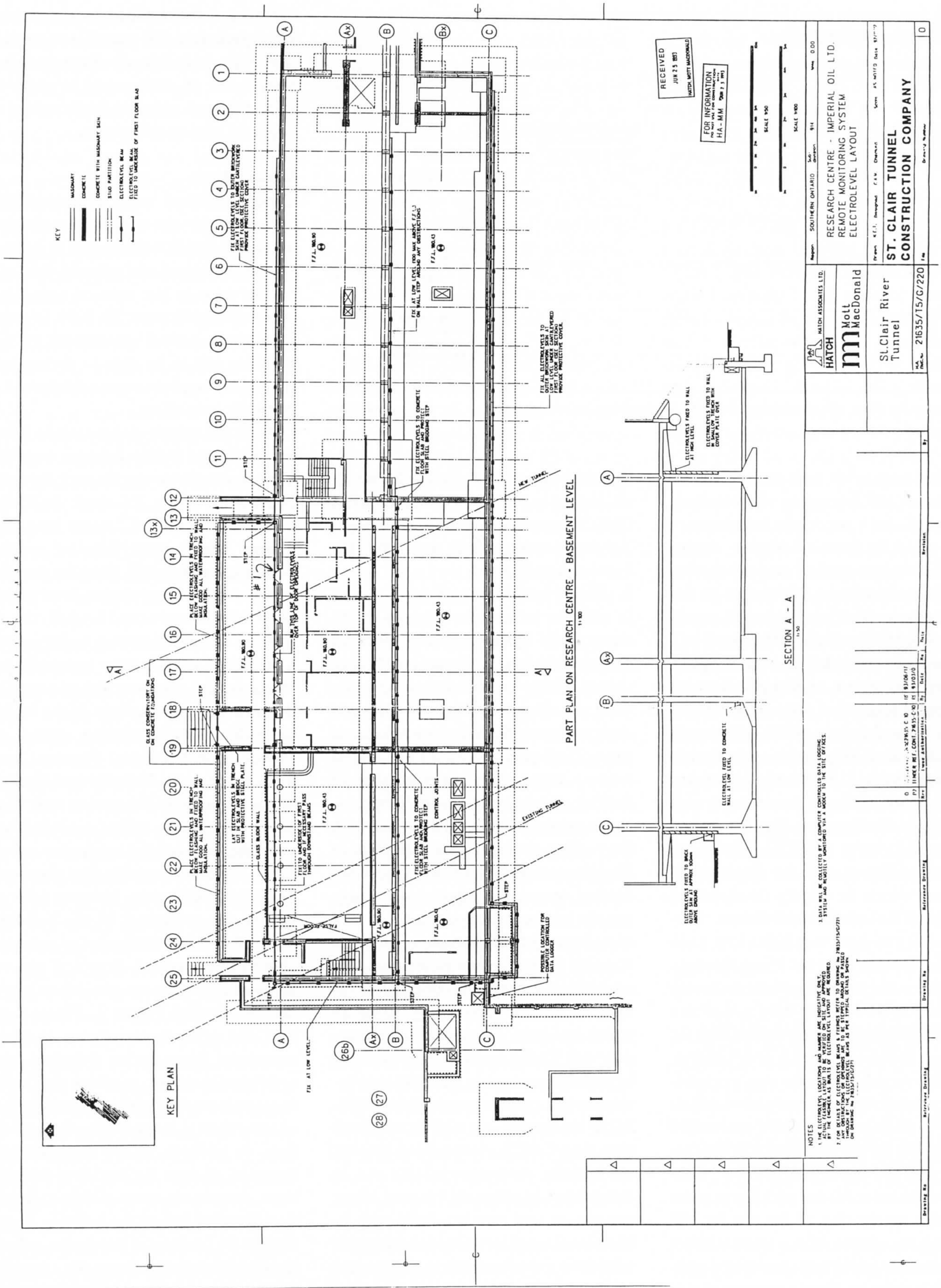

Figure 2. Electro-level layout in research building

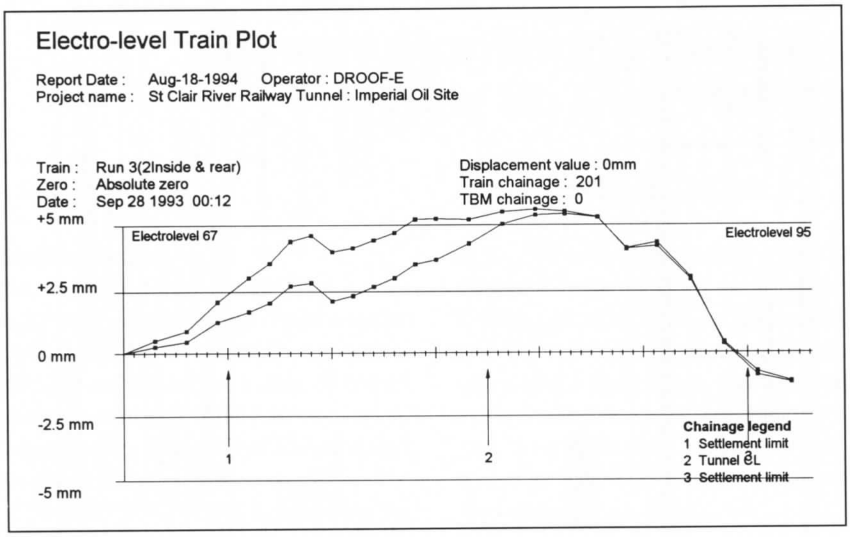

Figure 3 Plot of electrolevel train 3 showing movements due to pre-condition grouting

wished to provide firm pricing for installation and debugging of the system, but rather each provided a long menu of unit prices for technical support. At that time it was also unclear as to whether we would eventually be able to operate this system ourselves or whether its operation would be entirely at the mercy of a technician provided by the supplier. While the review of Slope Indicator's proposal proceeded, we contacted Gerwyn Price, formerly of the government funded Building Research Establishment in the U.K., who had just taken early retirement and founded his own company, Construction Monitoring and Control Systems (CMCS), in order to commercially market the electro-level system which he largely developed at Building Research Establishment. Gerwyn Price brought with him a long track record for using electro-levels throughout the world, including the monitoring of the Tower of Pisa in Italy as well as a great willingness to be involved with the project in order to start his new business. CMCS was able to offer very competitive pricing for the supply of materials and, in addition, provided a guaranteed lump sum for the installation of the system and the development of a "Windows" based software package in order for the monitoring to be run by HB during the course of the work without the need for additional specialized technical assistance. This arrangement was appealing to us because of Gerwyn's technical expertise, as well as his favorable pricing. However, despite CMCS's guarantees, there was no financial organization to back these up in the event of a problem.

2. Liquid Level Gauge System

In addition to our investigation of the electro-level system, we also pursued the use of the Interfels liquid level gauge system which had been used and partially developed by Hayward Baker's sister company, Keller, over a number of years. The liquid level gauge system had worked successfully on a number of Soilfrac grouting projects in Europe, including one system installed underneath the cooling tower of a nuclear plant in Neckerwestheim, Germany. Under the cooling tower, the liquid level gauge system had been in operation for over two years without disruption. Interfels was able to provide complete pricing for equipment supply and installation as well as remote monitoring software which had been developed in conjunction with Keller, and could be operated by technicians on-site who had not previously had experience with this system. While the system was a bit more expensive than CMCS electro-level system, we initially recommended it's use to Hatch Mott MacDonald because of our experience and comfort level with it. Mott MacDonald remained comfortable with their experience using electro-levels, so we decided to go with the electro-level system provided by CMCS. Working under a fairly loose partnership agreement, HB was able to participate fully in design, development, and installation of this system in order to minimize cost and gain the expertise to properly operate the system.

Installation

During the first week of July, 1993, set-up of the electro-level monitoring system began. It was our goal to get this system debugged and running at least a month prior to the start of tunnelling scheduled for October 23, 1993, in order to observe natural movements of the building and to be able to distinguish natural movement versus settlement induced by tunnelling.

Over the course of three weeks, Gerwyn Price and four technicians from the U.K. worked their way through the tight constraints of the Research Building. Continuous trains of 2 meter long aluminum beams were installed on the building wall footings. Each beam contained an individual electro-level with a range of ±3 degrees and a sensitivity of one arc second mounted to its center. The beams were simply supported by stainless steel reference pins mounted to the concrete wall footings of the building. The overall building system as shown on the attached Figure 2 was made up of over 120 individual electro-levels mounted in succession over four continuous trains which extended beyond the limits of the maximum anticipated settlement trough. By summing individual deflections between ends of beams, the settlement of the building across the tunnel settlement trough was able to be measured. A typical plot of measured building movements is shown on the attached Figure 3. Please note that the plot demonstrates upward movement taken during the grout preconditioning phase, in which the building was heaved slightly in anticipation of settlement to be caused by the tunnelling. In addition to the electro-levels mounted against the building foundations, a separate system of electro-levels was installed below the building foundations in horizontal boreholes radiating from two shafts diagonally opposite one another on either side of the building. It was believed that the electro-levels installed in the ground below the building footings would provide an early warning system for impending movement of the building.

Up to 16 individual electro-levels were connected to each multiplexer. Multiplexers were in turn operated by six controllers, each capable of independent data storage. Raw data from controllers were sent via hardwire to a jobsite computer for data processing and graphic representation. In addition, data were also sent via modem to the consultant's office. Raw data processing was achieved within the Windows environment by a custom application written in Visual Basic by Richard Savory, a programmer commissioned by CMCS. The Windows environment was considered ideal because of its multi-tasking abilities in which continuous monitoring of the building could be maintained during the analysis or transmission of data elsewhere. This was also a format which our jobsite technicians were previously accustomed to.

Performance

In general, the entire electro-level system was completely installed and operational within six weeks. This system was sensitive to movements of 1/200th of a millimeter and could scan and record data as quickly as every 15 seconds. The raw data in the form of electronic bits were converted to radians of arc by a unique calibration factor for every instrument. Radians of arc multiplied by beam length would yield vertical difference between the opposite ends of each beam.

The analysis software allowed infinite flexibility in viewing raw data or processed data over time, for complete electro-level trains or individual instruments. Each of these readouts could be in graphic format or in tabular format. The data could be sorted to look at any given time frame, be it one-half hour or three months. By allowing this type of flexibility in the analysis, investigation of anomalies was facilitated. For instance, when an unexpected plot of the building profile was produced, each individual instrument could be plotted on a graph of movement versus time, in which the precise moment when an instrument was disturbed could be pinpointed. That instrument could then be re-zeroed to bring it back in line with the rest of the train. Instruments could either by zeroed individually or entire trains could be zeroed to look at relative movement over different time references. Each of these features was vital to the success of the monitoring program. During the time after the monitoring system had been installed and before tunnelling under the building, we were able to understand many of the elements affecting the measurement of movement.

It became apparent that despite our efforts to protect each instrument, human curiosity or clumsiness resulted quite often in the bumping and/or movement of electro-levels. In addition to this, we were able to witness building movements related to temperature, spanning the change of seasons from summer to fall and later to winter, as well as those movements caused by the change in temperature between daytime and nighttime.

On the downside of all of the electronic wizardry involved, the project was plagued by persistent software problems, both in the analysis program and within the individual controllers. A great deal of time and effort was spent pursuing phantom problems with the system, generated by the analysis software. Total system shutdown was nearly a weekly occurrence due to corrupt data files. During the system shutdown, software had to be reloaded in both controllers and in the analysis computer. Fortunately, during the five day actual tunnel drive under the building, the system worked without mishap and compensation of building settlement was successfully achieved using Soilfrac. If, however, the system shut down during the critical stages of the work, scanning and recording of raw data could always be accomplished by down-loading to a notebook computer hardwired directly into a controller, after which a crude analysis could be performed using a Lotus spreadsheet.

There were three main factors which we feel caused these software problems. First, the custom software developed specifically for use on the project had never been sufficiently debugged and, at this time, we understand it has been scrapped in favor of a newer program by CMCS. The second factor we believe is an inherent problem of the Windows operating system while performing multiple tasks involving communications via modem.

Finally, the third and most pronounced problem of the system, was in communication between the six controllers. We believe communications were interrupted and random access data corrupted by the internal timers of each controller running out of synchronization. Being geotechnical engineers, and not experts in electronics, we are unable to provide any further insight into the controller problem.

As far as we know CMCS does not yet fully understand the problem. As a consequence of these problems, the monitoring system was never able to reliably monitor the building without full-time, on-site maintenance. As a result, we would be apprehensive to recommend this system for the purpose of long-term monitoring for periods greater than a week. If we are ever given the opportunity, we would like to contrast our experience with electro-levels using a liquid level gauge system.

While there have been many reported successes on other projects by both CMCS and Slope Indicator, our experience suggests room for an improved electro-level system and the consideration of other monitoring systems.

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Advances in Slope-monitoring Instrumentation at Syncrude Canada Ltd. - a Follow-up

Gord McKenna

Introduction

John Dunnicliff has asked me to elaborate on two points raised in the above article (Geotechnical News, September 1994, page 66-69).

Piezometers in Boreholes with Slope Inclinometers

John asked for information on diameters of inclinometer casing, sand-filled slotted casing and boreholes, commenting that the combination is practical only if the borehole diameter is substantial.

Syncrude routinely installs piezometers in boreholes alongside slope inclinometers (SI's). This is made possible by the fact that Syncrude drills relatively large-diameter boreholes for installation of all SI's - our typical tricone borehole diameter is 5 7/8 inches (150mm), the SI casing is one of 2.75 inches (outside) (70mm) diameter or 3.34 inches (outside) (85mm) diameter. The slotted PVC casing, which houses the piezometer tip, is 2 inches (50mm) diameter. The combination of a piezometer and 85mm-diameter SI casing is a snug fit in a borehole, so for these installations, a sand-filled cloth bag is used instead of the slotted PVC casing.

Syncrude installs up to two grouted-in piezometer tips with an SI (Figure 1) and three in a borehole without an SI. If one were to use more than these number of tips, there would be too great a chance for a hydraulic short-circuit along the length of the borehole which could lead to faulty pore-water pressure readings.

We have found that we must keep the piezometer tip at least 24 inches (600mm) from an SI casing connection. If the tip is placed too close to the connection, the connection develops a kink which can affect the SI readings.

One must also consider the fact that a piezometer installed near a shear zone in a borehole with an SI will be situated in ground which will deform and that the grout seal may be locally fractured

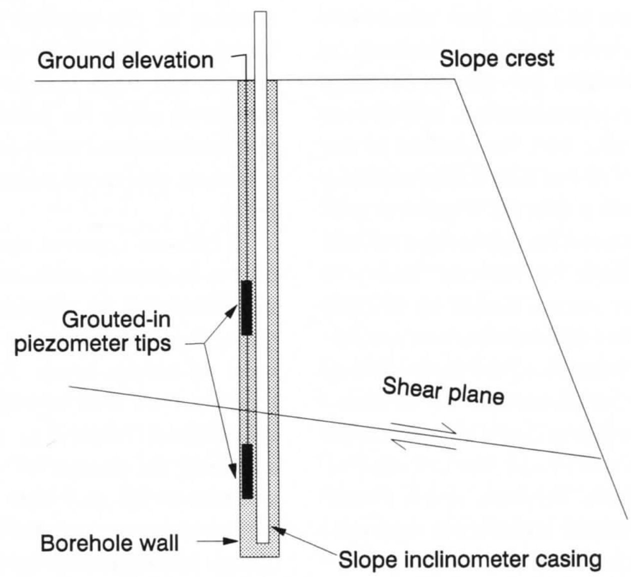

Figure 1. Cross-sectional view of grouted piezometers installed with slope inclinometer casing in the same borehole.

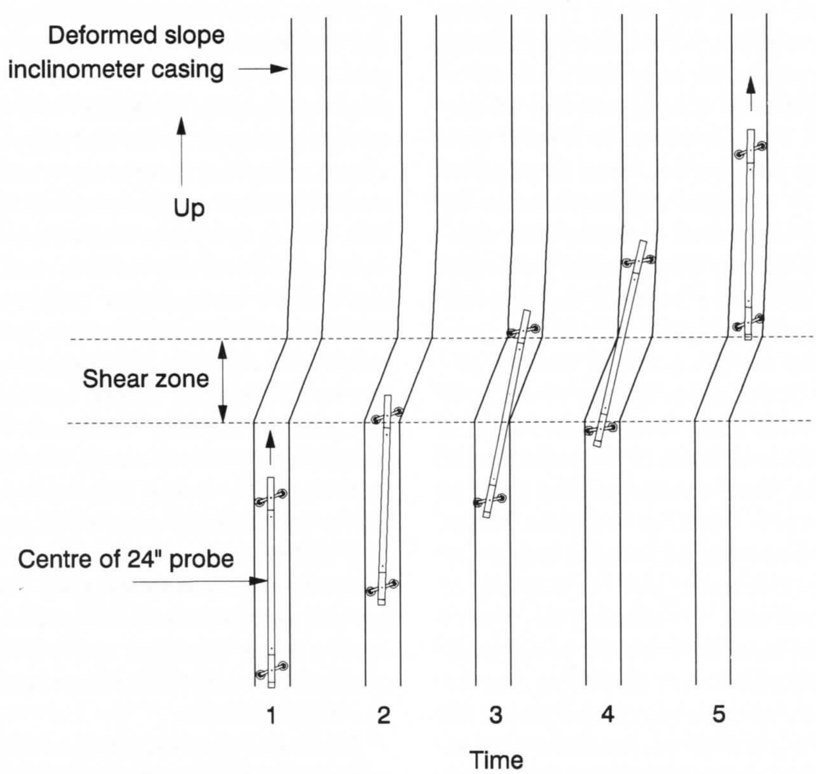

Figure 2. Path of a slope inclinometer probe through a double shear zone.

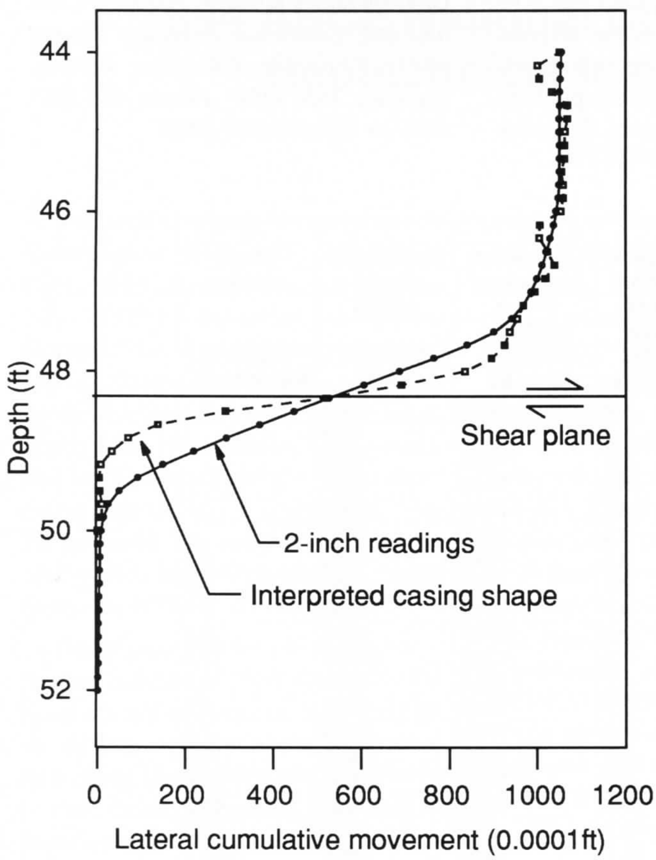

Figure 3. Cumulative 2-inch (50mm) SI readings through a shear zone.

if the grout is too brittle. To date, we have not seen any evidence of erroneous piezometer readings in movement zones, but we tend to install piezometer tips away from the zones of most intense movement or use a conventional piezometer installation (with sand and bentonite chips in its own borehole) to monitor pressures within shear zones.

A technical note which details the field performance and laboratory testing of the grouted-in piezometer installation method at Syncrude has been accepted for publication in the Canadian Geotechnical Journal in 1995.

Arithmetic Manipulation of SI Data Read at 2-inch (50mm) Depth Intervals

John has asked for clarification of the arithmetic manipulation to obtain the plotted points in Figure 3 of the original article for "interpreted casing shape" from the "2-inch readings" points.

The method of manipulating the SI data read at 2-inch (50mm) intervals is relatively straightforward, but to provide the formulae is too cumbersome for this article. Interested people are encouraged to contact me directly at the address listed below. Here is a brief summary of the method.

Once the readings are taken at the desired interval, import or keypunch the data into a spreadsheet as shown in Table 1. Column 1 shows the probe depth and Column 2 shows the present set of readings (A-axis). Column 3 shows the initialization readings (Set 1). If the initialization set is not read at the 2-inch (50mm) interval, one must interpolate between the readings. This can be done with a linear interpolation, but a cubic-spline or hand-drawn interpolation will be more accurate. Column 4 shows the incremental readings as measured over the 24-inch (600mm) probe length. Column 5 shows this same data normalized to 2-inch (50mm) intervals by dividing the values in Column 6 by 24"/2"=12. Column 6 shows this 2-inch (50mm) normalized reading cumulated from the bottom of the reading zone. This column then represents the usual way to present cumulated SI data, except with a shorter reading interval.

Reading at 2-inch (50mm) depth intervals with a 24-inch (600mm) long wheel-base can results in some loss of accuracy in determining the detailed shape of the casing. Figure 2 shows the stages of SI probe position as the probe is raised up the borehole through a shear zone. The reading elevation is referenced to the centre of the probe, but as the probe is drawn through the shear zone, the top wheels will "feel" the bottom of the shear zone and the probe will start to tilt. Eventually, the bottom wheels will also enter the shear zone, the top wheels will leave the shear zone, and last, the bottom wheels will leave the shear zone. (If the shear zone is thin, the top wheels will leave the zone before the bottom ones enter it as shown in Figure 2.) An increase in accuracy in determining the shape of the casing can be regained from the 2-inch readings using the following method.

Column 7 is the cumulative model casing shape that is input by trial and error from the bottom up, so that the Check Column (Column 8) matches Column 5. Column 8 provides the mathematically derived 2-inch (50mm) incremental reading that a 24-inch (600mm) long probe would read if Column 7 represented the true shape of the SI casing. When the bottom-to-top trial-and-error process is finished, Column 7 then represents a much more accurate shape of the SI casing than the original Column 6. Column 7 thus represents the "interpreted casing shape" from Figure 2 of the original article. I should note that the total displacement across the shear zone is the same for both methods, but the shape of the curves differ considerably. A similar construction can be done for the B-axis data.

Alternatively, it is easy to formulate an algebraic formula that takes the recorded data and calculates the model borehole. This second method is more accurate and a little simpler that the more manual method detailed above. It seems likely that this arithmetic method of calculating the profile of the SI casing is analogous to routine processing down-hole geophysical data.

I should note that this method of taking closely spaced SI readings was tried at Syncrude and the results were initially encouraging. However, it was shown that a discrete shear plane along a thin clay layer generally causes the SI casing to shear over a 600mm vertical zone. The increased accuracy in determining the casing shape has little practical significance to our present slope-monitoring programs. Correlating the increased accuracy with the geology from cores was also difficult due to inaccuracies in precisely determining the depths of geological units from core. Perhaps there are other applications, however, that can benefit from this reading method.

Please contact me if you desire additional information about these items or other items mentioned in the original article. Please note that the contact address has changed from the one published with the original article. The new address is:

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1	2	3	4	5	6	7	8
Probe depth	2-inch present set raw readings	2-inch interpolated initial set readings	Incremental readings over 24 inches	Incremental normalized to 2-inch intervals	Cumulative normalized 2-inch readings	Cumulative model casing	Check column
(ft)	(0.0001ft)	(0.0001ft)	(0.0001ft)	(0.0001ft)	(0.0001ft)	(0.0001ft)	(0.0001ft)
MATH--->			#2-#3	#4/(24"/2")	Sum #5	INPUT	Match to #6
44.00	-534	-517.0	-17	-1.4	-1052	**-1048**	
44.17	-531	-517.2	-13	-1.1	-1051	**-998**	
44.33	-528	-517.5	-10	-0.8	-1050	**-1002**	
44.50	-525	-517.8	-7	-0.6	-1049	**-1031**	
44.67	-520	-518.2	-2	-0.2	-1049	**-1067**	
44.83	-521	-518.6	-2	-0.2	-1048	**-1067**	
45.00	-515	-519.2	4	0.3	-1048	**-1061**	0.3
45.17	-514	-519.8	6	0.5	-1049	**-1060**	0.5
45.33	-520	-520.6	1	0.1	-1049	**-1060**	0.1
45.50	-531	-521.4	-10	-0.8	-1049	**-1053**	-0.8
45.67	-553	-522.5	-31	-2.5	-1048	**-1058**	-2.5
45.83	-574	-523.7	-50	-4.2	-1046	**-1058**	-4.2
46.00	-593	-525.0	-68	-5.7	-1042	**-1052**	-5.7
46.17	-620	-526.5	-93	-7.7	-1036	**-1004**	-7.8
46.33	-636	-528.1	-107	-8.9	-1028	**-1003**	-8.9
46.50	-648	-529.8	-118	-9.8	-1019	**-1022**	-9.8
46.67	-665	-531.5	-134	-11.1	-1009	**-1037**	-11.2
46.83	-698	-533.0	-165	-13.7	-998	**-1017**	-13.7
47.00	-752	-534.4	-218	-18.1	-985	**-993**	-18.2
47.17	-850	-535.5	-314	-26.2	-966	**-967**	-26.2
47.33	-1022	-536.3	-485	-40.4	-940	**-953**	-40.4
47.50	-1269	-536.7	-732	-61.0	-900	**-935**	-61.0
47.67	-1437	-536.7	-900	-75.0	-839	**-924**	-75.0
47.83	-1484	-536.1	-948	-79.0	-764	**-894**	-79.0
48.00	-1496	-535.0	-961	-80.1	-685	**-834**	-80.1
48.17	-1493	-533.2	-960	-80.0	-605	**-690**	-80.0
48.33	-1480	-530.9	-949	-79.1	-525	**-518**	-79.1
48.50	-1459	-528.0	-930	-77.5	-446	**-290**	-77.5
48.67	-1440	-524.8	-915	-76.3	-368	**-137**	-76.3
48.83	-1407	-521.2	-886	-73.8	-292	**-69**	-73.8
49.00	-1353	-517.4	-835	-69.6	-218	**-32**	-69.6
49.17	-1204	-513.5	-690	-57.5	-149	**-7**	-57.5
49.33	-1024	-509.5	-514	-42.9	-91	**-4**	-42.9
49.50	-793	-505.6	-287	-23.9	-48	**-5**	-23.9
49.67	-636	-501.8	-134	-11.2	-24	**-9**	-11.2
49.83	-563	-498.3	-65	-5.4	-13	**-8**	-5.4
50.00	-524	-495.0	-29	-2.4	-8	**1**	-2.4
50.17	-500	-492.1	-7	-0.6	-5	**0**	-0.6
50.33	-494	-489.6	-4	-0.4	-5	**-3**	-0.3
50.50	-493	-487.5	-6	-0.5	-4	**-3**	-0.4
50.67	-495	-485.6	-9	-0.7	-4	**-3**	-0.8
50.83	-493	-484.1	-8	-0.7	-3	**-4**	-0.7
51.00	-491	-482.9	-8	-0.6	-2	**-3**	
51.17	-486	-481.9	-4	-0.3	-2	**0**	
51.33	-484	-481.1	-3	-0.2	-1	**0**	
51.50	-484	-480.6	-3	-0.3	-1	**0**	
51.67	-483	-480.2	-3	-0.2	-1	**0**	
51.83	-485	-480.1	-4	-0.4	-1	**0**	
52.00	-483	-480.0	-3	-0.3	-0	**0**	

Table 1. Arithmetic manipulation of SI data from readings taken at 2-inch (50mm) depth intervals with a 24-inch (600mm) probe. Column 7 represents the interpreted shape of the SI casing through a shear zone. The readings are shown in Sinco RPP units (0.0001ft). To convert readings to millimetres, divide by 32.8.

1994 ASCE National Convention, Atlanta, Georgia Geotechnical Instrumentation Session

Bryan P. Sweeney

A successful panel discussion on Geotechnical Instrumentation related topics was recently conducted at the 1994 ASCE Convention in Atlanta, Georgia. This session consisted of several informative and brief presentations by the five panelists (Bob Leary, Steve Hunt, John Dunnicliff, Charles Ladd, and Mo Hosseini) and also some interesting and forthright discussions with the audience. The panel discussion was coordinated and moderated by Bryan Sweeney, of Haley & Aldrich, Inc.

The approximately 2 hour long session included brief presentations by the panelists and subsequent, more lengthy discussions with the audience. Several interesting discussions ensued relative to the current practice of geotechnical instrumentation programs and the commonly referred to "Observational Approach."

Mr. Bob Leary, from the Federal Highway Administration, discussed the need and purpose of geotechnical instrumentation programs. Some simple guidelines concerning the objectives and means of conducting these programs were also presented. Bob also supported the relevance of several opinions that were expressed by Dr. Ralph Peck almost 25 years ago. This was followed by a brief discussion on instrumentation devices and recording by Mr. Steven Hunt, of STS Consultants Ltd. Relational database systems were discussed along with the need for redundant readings and manual versus electronic data gathering.

Several informative opinions were provided by Mr. John Dunnicliff concerning geotechnical instrumentation and contract documents. The need for these documents was supported and several key steps to follow in developing a successful monitoring program were listed. In addition, an interesting discussion followed on the need and purpose of hazard warning levels for various construction situations. Subsequently, Professor Charles C. Ladd (MIT) presented a brief discussion on reduction, evaluation, and reporting of instrumentation data. Several case history examples were utilized to convey the need to document the field conditions (e.g., excavation depth) at the time the data are gathered, and also to identify the construction sequence.

A contractor's view on geotechnical instrumentation was presented by Mr. Mo Hosseini, of The George Hyman Construction Company. Some of the major disadvantages encountered on public and private projects were identified and several remedies were discussed. Insufficient planning, too much data, communication breakdowns and inadequate data reduction and reporting were listed as several primary disadvantages. To avoid these and other areas of dispute, several keys issues were identified that need to be addressed before construction. These issues included the need to verify the accuracy of the data, establishing contingency plans, clearly stating who pays for remedial actions, and defining when the monitoring stops in active and inactive areas of construction.

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