GEOTECHNICAL INSTRUMENTATION NEWS

Introduction by John Dunnicliff, Editor

This is the seventy-fifth episode of GIN. Three quarters of a century! Two articles this time:

- "Automated MEMS-based In-place Inclinometers". Margaret Darrow reports on successful use of MEMS (Micro-Electro-Mechanical Systems)-based in-place inclinometers for monitoring a landslide in a remote location in northern Alaska. This article adds to our confidence in these recently developed instruments.
- The second article, anonymous at the author's request, is in response to my repeated plea, "Lessons learned. I need you". It provides more lessons learned from unexpected events in the field.

Discussions

In my earlier pleas for contributions to GIN I didn't mention discussions. I welcome discussions of articles previously published in GIN, and authors' replies will be included in the same episode. I have one of these in the pipeline for December GIN. **More please!**

Continuing my plea for contributions

If you've written a paper for a conference, journal or other publication that fits within the scope of GIN, please consider sending me a version that fits within the GIN guidelines. See http://www.geotechnicalnews.com/instrumentation_news.php, and click on "How to submit articles …". Minimum effort for you!

Continuing education courses

In the previous GIN I said that there will be no more of these courses in Florida, but perhaps elsewhere. Plans are now underway to start a new series in beautiful Tuscany, Italy, in June next year. The venue will be Poppi Castle, www.castellodipoppi.it. How's this for a contrast to Cocoa Beach? Good wine too! Details and a website later.

Important new publication about monitoring slope stability

Allen Marr of Geocomp Corporation, Acton, MA has written an outstanding state-of-the-art paper: Marr, W.A. (2013) Instrumentation and Monitoring of Slope Stability. Geo-Congress 2013: pp. 2224-2245. Here's the abstract:

> Instrumentation and monitoring of earth structures has experienced phenomenal change and growth since the last [ASCE] slope stability conference some twenty years ago. This paper gives an overview of the current state-of-practice of instrumentation and monitoring for slopes and embankments and other structures that involve global instability considerations. Reasons to monitor performance, technological revolutions in instrumentation and monitoring over the past 20 years and some recommended practices are presented and discussed. A principal theme of this paper is the important role of instrumentation and monitoring in helping to identify and manage risk. When considered as a part of a risk management program, the role and value of instrumentation

> and monitoring program becomes much clearer to all involved.

The full paper is copyrighted by ASCE, and can be downloaded for a fee of US$30, from http://ascelibrary.org/doi/abs/10.1061/9780784412787.222 Click on the Permalink, then the PDF tab, scroll to Download Options, Buy Now. Yes, I appreciate that $30 may seem a lot, but it's worth it!

An attitude worth repeating

I included this in GIN five years ago. Time for a reminder: the great jazz-master Humphrey Lyttleton (Humph) died recently. In his own words: "As we journey through life discarding baggage on the way, we should keep an iron grip, to the very end, on the capacity for silliness. It preserves the soul from desiccation". What a wonderful attitude!

Sheep for monitoring slope stability

During the few days before the disastrous landslide at Vaiont Dam in Italy in 1963, grazing animals apparently moved off the future landslide area. They knew something that humans didn't!

In the early 1990s, many large slow-moving potential landslides were discovered in the slopes around the future Clyde reservoir in New Zealand. At great expense, geotechnical monitoring was adopted as an early warning system for disaster risk reduction. However, New Zealand has an enormous number of sheep. I suggested fencing off the slopes, with a single small opening in each fence (ensuring that there were lots of sheep inside), and installing at each opening an instrument for counting the rate of flow of sheep, and automatic data acquisition systems transmitting to the office, with trigger levels.

Nobody took me seriously!

Closure

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

Cin Cin! (Italy)

Automated MEMS-based In-place Inclinometers

Margaret M. Darrow

Introduction

Inclinometers are used in geotechnical engineering to measure ground movement. A relatively new form of inclinometer instrumentation incorporates Micro-Electro-Mechanical Systems (MEMS) accelerometers. MEMS-based in-place inclinometers (M-IPIs) consist of a series of accelerometers that are connected with flexible joints and encased in a watertight housing. Although these devices have been evaluated previously in some areas of the contiguous US, the author evaluated two different M-IPIs for their applicability in frozen ground applications. The overall research project consisted of four different sites within Alaska. The M-IPI were installed both vertically and horizontally, and their measurements of ground movement and temperature

Figure 1. INC500 modules, staged with centralizers attached and ready for installation.

Figure 2. Installing the INC500 within the guide casing (photograph courtesy of J. Simpson).

were evaluated against those obtained using traditional instruments. This article presents the results of the fourth site, where an INC500 Series In-Place Inclinometer (INC500) from GEO-DAQ was installed vertically to obtain data from a landslide in a remote location along the Dalton Highway in northern Alaska.

Research site and installation

Geology and background

In recent years a new permafrost-related hazard has affected Alaska's Dalton Highway in the southern Brooks Range. Near Mile Post (MP) 219, an elongated lobe of frozen soil, rock, and debris – termed a frozen debris lobe (FDL) – is encroaching on the highway. Many FDLs are present within the Dalton Highway corridor; however, near MP 219, the critical FDL-A is less than 60 m from the highway shoulder. Analysis of remotely-sensed imagery indicated that FDL-A moved at an average rate of 1.0 cm per day between 1955 and 2008, and reconnaissance site visits suggested several movement mechanisms, such as permafrost creep, debris flows along the over-steepened toe, and basal sliding (Daanen et al., 2012). Prior to a 2012 field program, however, we did not know anything about the lobe's internal structure, nor did we have any in situ movement measurements. We also suspected that FDL-A might move quickly enough so as to make retrieval of the M-IPI device impossible. Thus, the reasons for this installation were 1) to collect important data to determine FDL-A's mode, location, and rate of movement, and 2) to determine how much movement the INC500 device could withstand before it no longer functioned.

Instrument installation

The author, working with colleagues from the Alaska Department of Transportation and Public Facilities

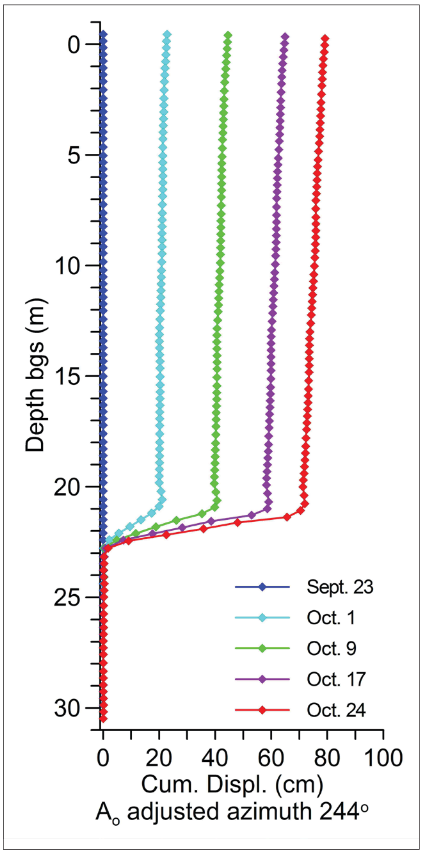

Figure 3. Cumulative displacement measurements for the boring through FDL-A until the INC500 began to demonstrate signs of failure.

(ADOT&PF) and the University of Alaska Fairbanks (UAF), installed the INC500 in September 2012. Where drilled, FDL-A was fairly homogeneous, mostly consisting of silty sand with gravel. The boring in which the INC500 was installed intercepted white mica schist bedrock at 26.4 m below ground surface (bgs). We attached two vibrating wire (VW) piezometers and a thermistor string to the outside of the guide casing, and backfilled the boring using cement-bentonite grout.

The INC500 device consists of 2.4-m long modules that contain a series of MEMS-based accelerometer sensors. In a standard module, these biaxial sensors are located every 30.5 cm, along with a temperature sensor that has a reported accuracy of ±1.7°C (GEODAQ, 2010) and is not calibrated unless specified by the customer. The modules are joined by underwater electrical connectors with connections that are stiffened by a coupler assembly to give the entire length a uniform rigidity. Additionally, three to four centralizers are mounted along the length of each module (see Figure 1). Each centralizer contains four stainless steel wheels that are designed to guide and orient the device within a slotted guide casing. Because of its modularity, an INC500 device can be lengthened or shortened to accommodate the geometry of a given installation.

For this installation, the INC500 device consisted of 12 modules and was installed to 30.5 m bgs (see Figure 2). Due to the difference between the casing and assembled M-IPI lengths, approximately 0.5 m of the uppermost INC500 module was above the ground surface within the casing. The guide casing was filled with propylene glycol to prevent freezing of any water that might accumulate due to condensation and/or leaks. All instruments were wired into an automated data acquisition system (ADAS) powered from a battery bank recharged by a solar panel. A data logger within the ADAS recorded measurements every six hours.

Results and Discussion

Figure 3 contains plots of cumulative displacement from the M-IPI device. The data were corrected using vector summation (Cornforth, 2005), and for the cumulative change in depth of the sensors. Originally at 0.5 m above the ground surface, horizontal movement within the shear zone pulled the M-IPI down within the casing to 0.1 m bgs, correlating well with visual observations. These adjusted readings indicated movement within a well-developed shear zone between 20.2 m and 22.8 m bgs. The M-IPI device recorded at total of 79.2 cm at the surface in 31 days.

On October 24, the M-IPI began to record apparent “retrograde motion” upslope between 20.4 m and 21.4 m bgs (see Figure 4a). Considering the

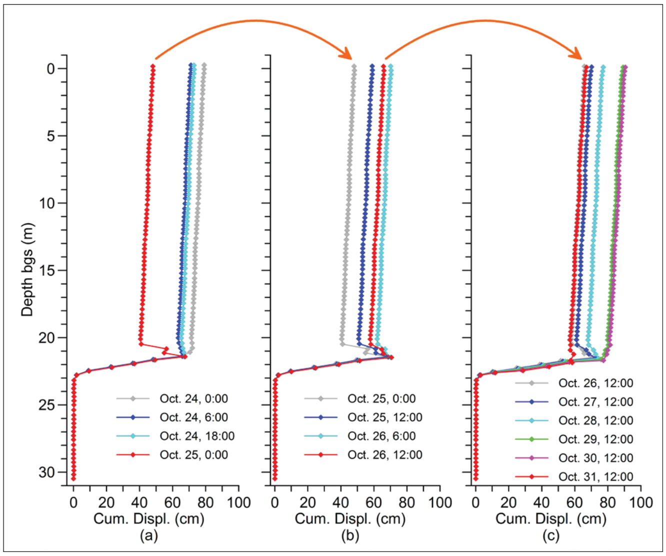

Figure 4. Evidence of failure of the INC500 at FDL-A. (a) Apparent “retrograde motion” began at 6:00 on October 24, with major “retrograde motion” at 0:00 on October 25. (b) The lobe above the shear zone continued to move downslope, with another episode of “retrograde motion” on October 26 at 12:00. (c) Final readings of the INC500 until failure of the lower modules after October 31 at 12:00. For each plot, the set of readings in gray represents the last reading from the previous plot (for (a), this is the last reading shown in Figure 3). The sequence of readings is given the same color scheme, with red indicating “retrograde motion”.

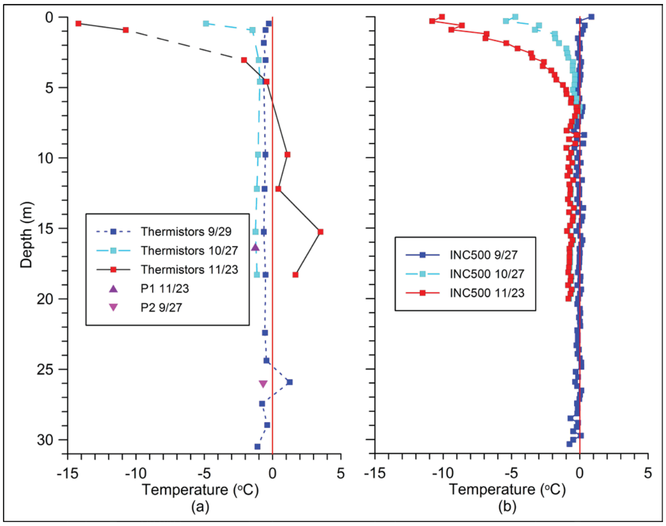

Figure 5. Temperature readings from the boring through FDL-A. (a) Temperature readings from the thermistor string and two VW piezometers attached to the outside of the casing; “P1” and “P2” are readings from the vibrating wire piezometers installed at 16.3 and 26.1 m bgs, respectively. (b) Temperature readings from the INC500. Nearest pairs of readings were averaged to reduce the scatter. For both plots, the phase-change temperature is indicated by the vertical red line.

failures of thermistors and a piezometer below this depth, we suspected that a few INC500 sensors were damaged in the shear zone. The manufacturer of the device agreed, indicating that the sensors "probably deformed or rotated within the housing" (J. Lemke, pers. comm., Nov. 2012). The M-IPI continued to record downslope motion above the shear zone, with episodes of "retrograde motion" intermixed (see Figures 4b and 4c). Then on October 31, the INC500 sensors below 20.2 m bgs ceased reporting data. The manufacturer suggested that either the cable was physically severed or that an underwater connector between modules pulled apart (J. Lemke, pers. comm., Dec. 2012). The sensors above the shear zone, however, continued to report movement and temperature data.

Scheduling allowed the author and colleagues to return to the site every two to three weeks for manual inclinometer probe measurements. Considering the movement rate, only one or two additional sets of readings would have been obtained before the inclinometer probe could no longer pass the shear zone. Thus, the M-IPI device at this site delivered much more data than we otherwise would have collected.

The M-IPI device provided additional data in another way. Figure 5a contains a temperature profile of the boring. Thermistor measurements collected on September 29 demonstrated elevated temperatures due to the drilling process (having not yet reached a pseudo-equilibrium). Most of these temperatures, however, fit the trend that developed with depth during the equilibrating process, with the exception of the malfunctioning thermistor at 25.9 m bgs. All thermistors and the VW piezometer below 18.3 m bgs failed on October 11 and October 26, respectively. Starting on November 9, the lowest remaining thermistors began reporting a steady increase in temperature resulting in above-freezing values, as indicated by the erratic temperature profile from November 23; yet the VW piezometer located at 16.3 m bgs (i.e., "P1") measured -1.3ºC, matching the previous temperature trend. Figure 5b is a plot of temperatures obtained from the M-IPI device. The M-IPI stopped reporting accurate temperatures below 20.0 m bgs on October 24; however, the data above this depth are sufficient to indicate below freezing temperatures. Thus, the M-IPI data confirmed that the thermistors below 4.6 m bgs began to malfunction on November 9, likely the result of propylene glycol entering the cable and affecting the measured resistance.

Conclusion

The in situ measurements from the Dalton Highway site indicated that FDL-A moved at approximately 2.5 cm per day during the measurement period, more than twice the historic rate. The M-IPI device continued to read during shearing and provided meaningful temperature data after shearing. Its presence in the continually moving landslide provided much more data than we otherwise would have collected due to the remoteness of the site. The M-IPI temperature readings served as a check of potentially faulty readings from other temperature sensors, an unexpected benefit of this device.

Acknowledgements

This project was jointly funded by ADOT&PF and the Alaska University Transportation Center. The author thanks her UAF colleagues and ADOT&PF personnel for their expertise, hard work in the field, and support; and J. Lemke for his willingness to address concerns and his patience with insistent questions.

References

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Lessons learned from unexpected events in the field

Anonymous

Introduction

This contribution is in response to John Dunnicliff's repeated plea, "Lessons learned. I need you".

Field monitoring may require special installations or simple visual inspections to determine whether specified criteria are met or there is need for corrective action. The examples of problems encountered with lightning and with inadequate planning of observations for a cofferdam on the foreshore of a lake are described. Some unusual water levels are noted.

As the Scottish poet Robert (Robbie) Burns wrote, “The best laid schemes o’ mice an’ men gang aft a-gley [often go awry]”!

These examples have been derived from the experience of working with supervisors, associates and other colleagues in an organization which was closed around 1999.

These cases are being written with their contributions in mind from which the writer has benefited. Some are no longer with us. Others are retired. The writer has therefore requested his name to be withheld from publication.

Lightning and destruction of electronics

A chimney, about 100 m high, had been planned for construction on a very dense till deposit about 9 m thick over relatively flat bedrock. Tests on soil samples in the laboratory had been carried out to determine the usual parameters and also the response to cyclic loading related to wind effects.

The expected behaviour of the foundations suggested no long term consolidation settlement of the structure would occur and the calculated lateral forces would not result in a cumulative tilt. This project provided an opportunity to observe and document the data which could be compared with the assumptions used in the design and a proposal for instrumentation was approved.

During construction, within the area to be covered by the foundation, pressure pads were installed on the surface of the soil. An anemometer was located at the top of the chimney. Initial readings indicated that the installations were functional.

Soon after, there was a storm with severe lightning. The electronics installed for data collection were zapped and destroyed. No repair was possible and none was attempted.

Lessons learned

In retrospect, the disruption by lightning was a likely occurrence against which the protection provided at that time, four decades ago, was not effective. The increase in use of electronics in many applications has probably resulted in improvements in shielding for preventing damage by lightning. Specialists in this field should be consulted.

A cofferdam on the foreshore of a lake

A docking area was to be constructed on the foreshore of a lake where the bedrock surface was visible in shallow water at the shoreline and the overburden was about 2 m thick. The bedrock surface sloped gently away from the shoreline and soundings had reported negligible overburden. Bedrock was described as a shaley limestone.

The depth of water to be provided for the equipment for docking was about 4 m. To facilitate excavation of the rock for the for the docking area, a cofferdam was constructed to enclose a rectangular area extending 150 m along the shore and about 100 m into the water where the depth was about 5 m.

First, a rockfill embankment was built on the three sides of the perimeter of the area, extending into the water with material from excavations in bedrock for foundations for other structures at the site. The impervious till material from the overburden was then dumped on the inner slope of the rockfill and spread with a bulldozer to a top width of about 5 m and a freeboard about 1 m above the lake water level.

It was the practice to observe the abutments and downstream areas of dams, during the first flooding of a reservoir, for evidence of seepage or any unusual conditions while the water level is rising. The monitoring is continued for some time after the maximum operating level is reached. Lowering of the water level in an area enclosed by a cofferdam creates a comparable situation but the project had arranged only for the checks on the water levels during the pumping. The opportunity to detect, by inspection of the cofferdam, any location where a leak may have occurred was missed.

It was reported that the pumping for dewatering had started and progressed very well on the first day when the submerged inner soil slope was partly visible and appeared intact. Pumping continued, but on the second day the water surface had started to rise. Additional pumping did not produce any decrease in the water level.

The geotechnical engineering department was called in to investigate and find a solution. It was early winter. A diver was sent down to inspect the areas near the toe of the impervious fill for any unusual signs of leakage. He described observing possible movement of material from crevices in the rock surface where characteristic ridges caused by piping were noted on the rock surface near the toe of the impervious fill. In one location, he was able to insert a piece of wood about 50 mm thick which was secured as a marker by covering with small boulders.

It is likely that if observations had been made during the initial pumping, the locations of the piping would have been noticed, and time would have been saved.

A bedrock grouting program was initiated with priority where the diver had noted major crevices near the toe of the fill. Check grouting was carried out in the remaining sections.

Standpipe piezometers were installed in the impervious fill at several locations for checking the water levels during the resumption of pumping.

After some weeks of grouting operations, pumping was resumed. At this time the condition of the inside slope during the drawdown of the water level in the enclosed area was frequently checked. The area was dewatered, and the inner slope of the impervious zone was intact. The water levels in the standpipes were generally below lake level except for one case where the water in the standpipe was higher than lake level. The small ridge-like features where piping had occurred and where grout intrusion into the crevices had taken place to seal these openings were clearly visible. Minor seepage from joints which could be tolerated was recorded.

Lessons learned

Information on the geology of the bedrock and any relevant case histories in a location could be of much help in the planning and design of a water retaining structure.

Unless the bedrock surface at the location of a proposed water retaining structure can be thoroughly examined and, if necessary, treated, the presence of joints or fissures should be expected. Grouting should be included in the planning, scheduling and costing.

Scheduling of the project should try to avoid winter conditions for grouting to achieve savings in the cost. A list of contacts for resources which may be needed at short notice may be useful.

Unusual water levels

Many projects are concerned with the water levels or pressures in specific locations, and use observation wells or piezometers for measurements. Unusual water levels noted in three locations are described.

In the dumped impervious fill described in the above section 'A cofferdam on the foreshore of a lake', observation wells were installed in drilled boreholes from the crest of the fill with the bottom of the pipes estimated to be close to the bedrock surface. In all but one case, the water levels observed were below the lake level, which was about 1m below the crest elevation. The tops of the pipes were about 1 m above the crest. In one pipe, the water level was higher than the crest and more than 1 m above the lake water level. The cofferdam was removed after the dock was completed.

On another site, observation wells were installed in boreholes for exploration of the site on the bank of a lake where an extensive excavation of the approximately 30 m thick overburden to the limestone bedrock was planned for site preparation. The groundwater profile was fairly consistent with a gradient toward the lake but in a few wells in which the bottom of the pipes was close to the bedrock surface, the water levels were some 2 m above the groundwater profile. Almost all of the observation wells were destroyed when the extensive excavation of the overburden to bedrock was completed.

The third example is a location on high ground on the bank of a river on which a generating station was built. The reservoir associated with the station necessitated the construction of a relatively low earth dam over a depression and a small stream which flowed into the river. The embankment, about 200 m long, was built on the surface of a deep deposit of sensitive clay. The structure had been monitored for settlement of the crest and water levels were determined in open standpipe piezometers installed from the crest of the dam. The depths of the piezometer tips ranged between 15 m and 25 m below the crest. There was no problem with the rate and amount of settlement because the freeboard adopted about 3 m, was adequate. The tops of standpipes were about 1 m above the crest and protected by a larger diameter pipe with a cover for each standpipe. Although the water levels in most of the standpipes had stabilized at around elevations which could be related to the reservoir level, water could be observed at a few locations slowly flowing over the tops of the standpipes. Monitoring of the dam over a period of many years had shown that the settlement, stability and routine maintenance of the dam were all satisfactory.

Lessons learned

These examples of unusual water levels remain unexplained puzzles. Other than notes for the records, no investigation to seek an explanation had been carried out. *[But perhaps the lesson learned is to delve deeper at the time so that explanations are found – JD].*

IN MEMORIAM

Earle J. Klohn 1927-2013

Earle J. Klohn passed away on July 22, 2013 in his 86th year surrounded by his family. In the mid-1950s, Earle was one of the founders of Ripley, Klohn and Leonoff in Vancouver. He was a pioneer of geotechnical engineering in Western Canada. Earle obtained a Bachelor's Degree in Civil Engineering with Distinction in 1950 and a Master's Degree in 1952 both from the University of Alberta where he was taught soil mechanics by the late Dr. Robert Hardy. Earle's skills encompassed the full range of geotechnical engineering from foundations to embankments to tailings dam engineering. He won many awards for his contributions to our field including the Leggett Award in 1990 which was presented to him by Dr. Leggett personally. Earle took his experience in designing dams in the steep, wet and seismic terrain of British Columbia to many projects around the world. He served on boards of review in virtually every province and territory in Canada and in many countries. He authored over 60 technical papers and delivered many state-of-the-practice lectures on the analysis, design, and construction of building foundations and large dams. Earle inspired several generations of civil engineers and influenced the design of thousands of projects in Canada and abroad in his 46 years of professional life.