Instrumentation

John Dunnicliff

Introduction

This is the thirteenth episode of GIN. My primary effort for this issue has been to assemble the article that follows this column — "No More Judgment in Geotechnical Engineering: The Professional Legacy of ASTM?".

Yes, I know that the title is provocative, but the present situation, as Ralph Peck says in the article, "threatens our profession, and it ought to be brought to resolution forthwith".

We wanted to get your attention with a zingy title. If you don't understand the link between the title and important recent history, see the box on this page.

Please read the article, and respond to the call for action. *(See fax form page 45).*

Conversion Factors

Those of us involved with instrumentation are usually called upon to report numerical values of data. To be politically correct, nowadays we report them either in SI units, or we provide both SI and "American" units.

I recently read a letter written to the editor of a technical magazine, who had changed the author's reported units by using a mathematically equivalent conversion. The letter woke me up to the importance of care when working with conversion factors. The following is an excerpt:

Engineering and scientific measurements are always reported in the units of the instrument by which they were measured. The unit itself, whether millimeters or light-years, is an important element of the measurement. It tells the reader something about the equipment used and the accuracy of that measure. If conversions to a common standard of measure are desired, they should follow in parentheses. The unit conversion it-

Judgment in Geotechnical Engineering: The Professional Legacy of Ralph B. Peck

The book was originally published by Wiley in 1984, and is now available from the publishers of this magazine, BiTech Publishers.

From the Preface:

Many geotechnical engineers have been neither students nor co-workers of Ralph Peck, and have not had the opportunity or motivation to seek out his professional papers....The original purpose of this book was to make such meaningful papers readily available, so that more could benefit from the philosophy and engineering judgment of Ralph Peck

Now that this book is complete, we can identify two audiences. First, Ralph Peck's colleagues, co-workers, and former students, for whom this book is a tribute to a man who played a profound role in developing their own senses of engineering judgment. Second those much less close to him, including current students, young practicing geotechnical engineers and engineering geologists, and young faculty members, for whom this book opens the door to a store of wisdom.

There's "a store of wisdom" in the book for the practitioner in field measurements, in fact one of the eight groups of papers is on this subject. If you think that you can't learn to develop your own sense of judgment, however old you are, read the book and change your mind! In these days, where analysis by computer is king, I believe that Peck's writings on this subject are required reading for us all.

Letter to the Editor

The following letter was published in the March 1996 issue of Geotechnical News:

Dear Editor:

In the December 1995 issue of Geotechnical News, John Dunnicliff in his section Geotechnical Instrumentation News commented on the book "Judgment in Geotechnical Engineering: The Professional Legacy of Ralph B. Peck", now available from BiTech Publishers.

Let me endorse his recommendations of this collection of papers by Ralph Peck. In my Terzaghi Lecture of 1993, "Lessons Learned from Missed Predictions" published in the ASCE Journal of Geotechnical Engineering in October 1994, I advised all young geotechnical engineers to read this book....It is a prerequisite to development of good judgment in this time when there is an over-reliance on the computer. It should be in every geotechnical engineer's library and be referred to frequently, not just by young engineers but by older ones as well.

I am pleased that your company decided to make it available to the profession.

Sincerely,
John A. Focht, Jr., P.E.

self creates another common pitfall—a failure to preserve the degree of accuracy implied. The accuracy of any measurement reported is understood to be within one-half of the smallest unit given. For example, if a distance of 5 mi is reported, it is understood to be within a ½ mi more or less. Similarly, if the same distance is reported as 5.0 mi, it is understood to be within 0.05 mi either way.

Although mathematically one could convert 5 mi to 26,400 ft, this would imply that the measurement was accurate to within 0.5 ft, or at least to within 50 ft. Actually, the accuracy remains what it was as measured: plus or minus ½ mi (mathematically 2,640 ft, but 2,600 ft is more correct). This conversion is therefore something like 26,400 ft plus or minus 2,600 ft, or somewhere between 23,800 and 29,000 ft. The same principles apply in converting centimeters to inches or whatever. You can see how this easily becomes a big mess, which is why unit conversion in technical publications should perhaps be done by persons with technical training.

The authors of the letter are Joyce Maxwell and Charles M. Fralinger, Albert A. Fralinger, Jr. P.A., Tel: (609) 451-2990, Fax: (609) 455-9702. If anyone wants to add anything to this wise advice, please contact the authors or me.

Forewarning of Landslides by Monitoring Rainfall

Our primary tools for monitoring the stability of cut and natural slopes in soil and rock give us information about horizontal deformation and groundwater pressure. However, if we hope to provide a forewarning of slope failure in situations where the failure would occur suddenly, these tools are of limited value.

While in Hong Kong recently I learned of methods used by the Geotechnical Engineering Office to provide a forewarning of landslides, based on the relationship between rainfall and landslide occurrence.

The following is abstracted from Brand et al (1984):

- Hong Kong's steep slopes of deeply weathered rocks are prone to landslides during heavy seasonal rainstorms.... An automatic rain gage system linked to a central microcomputer allowed continuous monitoring of these storm events and enabled correlations to be made between rainfall and the occurrence of landslides.
- The large majority of landslides are induced by localized short duration rainfalls of high intensity, and these landslides take place at about the same time as the peak hourly rainfall.
- A rainfall intensity at about 70 mm/hour appears to be the threshold value above which landslides occur. The number of landslides and the severity of the consequences increase dramatically as the hourly intensity increases above this level.
- The 24-hour rainfall usually reflects short duration rainfalls of high intensity, and can therefore be used as an indicator of the likelihood of landslides. A 24-hour rainfall of less than 100 mm is very unlikely to result in a major landslide event; this fact could form the basis of a satisfactory landslide warning system.
- These conclusions are thought to be of significance not only for Hong Kong but for other parts of the world which suffer from rain-induced landslides.

There are now 69 automatic rain gages in Hong Kong, recording rainfall at five minute intervals, and controlled by a central microcomputer. A landslide warning is issued at present when intense rain is forecast or more than 175 mm of rainfall is expected in 24 hours, based on measured 20 hour rainfall and forecast 4 hour rainfall.

The warning is broadcast on radio and television, and a brochure has been published to advise how people should protect themselves when a landslide warning has been issued. The brochure includes the following recommendations:

- You should cancel non-essential appointments, stay at home or remain in a safe shelter
- Pedestrians should avoid walking or standing close to a steep slope or retaining wall
- Motorists should avoid driving in hilly areas or on sections of road with...traffic warning signs [signs erected along roads with a history of landslides] until the rain has ceased.

Since 1984 the warning has been issued on average about three times per year, with a range of one to six per year.

For more information on the Hong Kong warning system, you can contact Dr. Richard Pang, Chief Engineer, Research Division, Geotechnical Engineering Office, Civil Engineering Building, 101 Princess Margaret Road, Kowloon, Hong Kong, Tel. 852-2762-5362, Fax 852-2714-0275, E-mail cgesp@netvigator.com.

For more details about Hong Kong's slope safety system, of which the warning system is a part, see Malone (1997).

References are:

- Brand, E.W., Premchitt, J. and Phillipson, H.B. (1984). "Relationship Between Rainfall and Landslides in Hong Kong." Proc. Fourth Int. Symp. on Landslides, Toronto, Vol. 1, pp 377-384.
- Malone, A.W., (1997). "Risk Management and Slope Safety in Hong Kong." In Slope Engineering in Hong Kong, Balkema, in press.

More on Electrolevels

The article on electrolevels by Storer Boone continues my ongoing efforts to publicize how this relatively new technology is working out, and how we can all learn from the experiences of others.

Temperature effects on in-place inclinometers with electrolevel transducers have caused significant concern on some projects in USA, England and Hong Kong, and efforts are underway to reduce temperature sensitivity. I will try to report on these in a later episode of GIN. If anyone has worthwhile information to report, I'd welcome it.

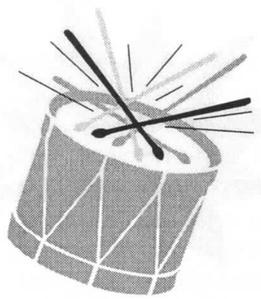
Closure

Please send contributions to this column, or a separate article for GIN, to me: 16 Whitridge Road, South Natick, MA 01760. Tel (508) 655-1775, fax (508) 655-1840. Kan Bei (China)

No More Judgment in Geotechnical Engineering: The Professional Legacy of ASTM?

John Dunnicliff

Part 1 — Introduction



I feel that a drum roll or blaring trumpets are quite appropriate for the introduction to this article. However, if I know you're reading it with undivided attention, that will suffice.

I will start by telling the story in the order in which I heard it.

1. In 1992 I was contacted by a task group, formed by ASTM (American Society for Testing and Materials) Committee D-18 on Soil and Rock, which planned to develop a subcommittee on field instrumentation. The purposes of the subcommittee were stated as:
   - to promote education, research, and exchange of information regarding field instrumentation for soil and rock, and
   - to develop appropriate standards or guides for installation and monitoring of instrumentation.

   I responded by expressing excitement about the first purpose (not very different from my purpose as I churn out GIN every quarter!), but concerns about the second. Guides: yes, but standards: no. Gordon Green (see the end of this article for information about contributors) was also contacted, and he expressed his own reservations about the standards issue. Our reservations are outlined in Parts 4 and 5 of this article. In summary, we both recommended, very strongly, that standards would be detrimental to geotechnical field instrumentation practice.
2. About a year ago, having heard nothing about ASTM's plans since 1992, I received a "call for papers" for a Symposium on Field Instrumentation for Soil and Rock, to take place in Atlanta on June 18 & 19, 1998. The announcement said "ASTM Subcommittee D18.23 on Field Instrumentation is currently developing standard guides and practices for the selection, use, installation and recording of field instruments critical to the performance monitoring of soil, rock, and man-made [gotta change that word!] masses."

   The subcommittee and symposium co-chairmen are Gary Durham, president of Durham Geo-Enterprises, Stone Mountain, GA, and Allen Marr, president of Geocomp Corporation, Boxborough, MA. I was asked, by the co-chairmen, to make a presentation at the symposium. I again expressed my concerns about the plan for standards, and we agreed on an Atlanta presentation about these concerns.
3. In the December 1996 and June 1997 issues of *Geotechnical News* I read two articles about ASFE's (Professional Firms Practicing in the Geosciences) concerns about ASTM's establishment of prescriptive professional practice standards. This is a much broader issue than instrumentation, and until last December I hadn't realized that the broader issue existed. ASFE's views, and the views of eleven other professional organizations are included in Part 2 of this article — the concerns are major.
4. At GeoLogan in July this year I listened to Ralph Peck's lecture, during which he spoke about some of the problems that currently face our geotechnical community. He included, although not by name, ASTM's plans. The relevant part of Ralph Peck's lecture is included in Part 3 of this article.
5. Later in July I received a copy of ASTM's January 1997 draft of "Standard Test Method for Monitoring Ground Movement Using Probe-Type Inclinometers", with a request to comment. I did: see Part 4 of this article.
6. In August I received a "bootleg" copy of ASTM's first draft of "Standard Guide for Specifying Level of Accuracy for Field Instrumentation." I sent my comments to Allen Marr: see Part 4 of this article.

In my view the issues raised are of vital importance to our practice as environmental and geotechnical engineers. Focusing on my own practice, it is of vital importance to our practice of geotechnical instrumentation, and I am convinced that ASTM's efforts are counter-productive. Hence this article, in an attempt to move towards a reversal of what's going on. I've asked Gordon Green and Erik Mikkelsen, two primary practicing instrumentation professionals whose views should be heard, to contribute to this article. I've also asked Allen Marr and Gary Durham to respond on behalf of the ASTM subcommittee. We have all seen the entire text, so each has had an opportunity to amend his part in the light of words by others.

Several contributors to this article focus on the use and meaning of the word "Standard", and this is clearly a basic issue which has created disagreement. It seems appropriate to quote, directly from ASTM's statement of definitions:

"**Standard**" - A document that has been developed and established within the consensus principles of the Society and that meets the approval requirements of ASTM procedures and regulations."

ASTM has six types of "full consensus ASTM Standards", three of which are referred to by contributors to this article:

"**Guide**" - Offers a series of options or instructions, but does not recommend a specific course of action.

"**Practice**" - A definitive procedure for performing one or more specific operations or functions that does not produce a test result.

"**Test Method**" - A definitive procedure for the identification, measurement, and evaluation of one or more qualities, characteristics, or properties of a material, product, system, or service that produces a test result."

The next two parts of this article provide background information on the broad environmental and geotechnical issue. The final five parts focus on geotechnical instrumentation issues.

Part 2 — Views of Twelve Professional Associations

Introduction

This text is abstracted, with some editorial changes, from the first two issues of ASCE Geo-Institute's magazine *Core Bits* (Core Bits, 1997a and 1997b), with ASCE's permission. More background and detail of the views are in two articles in *Geotechnical News,* referenced as ASFE (1996 and 1997) at the end of this article, and in an article in *Foundation Drilling* (ADSC, 1997). I encourage you to read these articles. Also, look for David Thompson's Forum article in the December 1997 issue of ASCE's *Civil Engineering* magazine, titled "ASTM - A Good Thing Gone Astray?".

Coalition to Oppose ASTM's Actions

Twelve associations have formed a coalition to oppose further promulgation of prescriptive professional practice standards. Called *Advocates for Professional Judgment in Geoprofessional Practice (APJGP),* the coalition comprises:

- ACIL: Association of Independent Scientific Engineering & Testing Firms
- ADSC: The International Association of Foundation Drilling
- ASFE: Professional Firms Practicing in the Geosciences
- American Consulting Engineers Council
- American Engineering Alliance
- Geo-Institute of the American Society of Civil Engineers
- Association of American State Geologists

- Association of Engineering Geologists
- California Geotechnical Engineers Association
- DFI: Deep Foundations Institute
- Hazardous Waste Action Coalition
- The GeoCouncil (National Council for Geo-Engineering and Construction)

ASTM is developing more than 100 prescriptive professional practice standards, including many for environmental site characterization. Prescriptive professional practice standards are documents that set forth specific steps for engineering and environmental professionals to follow in order to perform certain services. The coalition does not object to such documents when they are issued as guidelines. However, when an organization refers to them as standards or even standard guidelines, non-professionals, juries, and others can be led to believe, erroneously, that any variance from them is equivalent to negligence.

APJGP have two main concerns with the development of ASTM standards, and would like to see ASTM make the following changes:

1. To alter the terminology used for Standard Guides to something that does not include the word "standard," e.g., Consensus Guides. [In your editor's opinion, "Practice Guides" would be a more appropriate title.]
2. To provide a caveat or user advisory in ASTM documents with instructions for proper/improper use of each document. Hopefully, this would keep documents from being mischaracterized in court.

ASCE also uses the term "Standard Guidelines" for some of its publications, hence there is also concern over ASCE's terminology, and this has been discussed by ASCE's Codes and Standards Activities Council (CSAC). They seem to recognize the concern and are considering such a change. ASCE already uses a caveat similar to that described in Item 2.

The Geo-Institute Task Force on Codes and Standards has discussed the overall place and need for codes and standards. The task force understands the concerns about poor practice and agrees that there is a place for standards, guidelines, and professional judgment, depending on the circumstances (e.g., standards for drilling and testing are very important and are certainly an appropriate and needed service from ASTM). However, good engineering and scientific judgment needs to come into play (versus prescriptive standards) when a standard test is not needed or available. The task force believes that professional judgment should be directed by guidelines and those are more appropriately developed by professional societies.

The task force also recognizes that some group (e.g., the Geo-Institute) should develop the standards and guides. The task force is currently developing a draft policy statement that states that the Geo-Institute will establish an organizational framework to identify needs for preparation of codes, standards, and guidelines, and to execute a consensus process with CSAC.

Representatives of APJGP met with the ASTM Board of Directors on October7, 997. The purpose of the session was to alert the ASTM Board to the serious concerns in the geoprofessions with regards to ASTM development of prescriptive standards of practice. As a result of the meeting, the ASTM Board agreed to participate in a joint task force to study the issue. The task force will consist of approximately four members from APJGP and four members from ASTM. The APJGP representatives expect to discuss their concerns with nomenclature and the need for a caveat concerning document usage. The goal of the task force is to report back to the ASTM Board at their January 1998 meeting.

Part 3 — Views of Ralph Peck

Introduction

The following text is abstracted, with his approval, from Ralph Peck's lecture on the state of the geotechnical industry, at GeoLogan in July this year. The text of the entire lecture is published on pages 3 through 5 of this issue of GN (part repeated here so that this article can stand alone).

Text of Lecture

Another cloud is the ever-present consciousness, if not outright fear, of litigation.

I need not dwell on the reality of the threat. However, the geotechnical engineer's measures to attempt to avoid being sued all too often are detrimental to good engineering. One defense is compliance with accepted codes of practice and standards. Such codes and standards are useful in ensuring that unwarranted departures from general experience and practice are avoided, but we are dealing with geomaterials, materials made and arranged by Nature, and we are obliged to be on guard against Nature's whims. After a failure occurs, it may be some small comfort, and it may actually be a defense against liability, to be able to affirm that all the borings, tests, loading assumptions, and calculations were made in accordance with accepted standards. Yet, a failure actually did occur, perhaps because the geo-expert, concentrating on meeting the accepted standards, missed a crucial non-standard aberration in the rock or soil involved.

One of my father's favorite sayings was that if there is a controversy there are always two sides: they may be lopsided, but there are always at least two, and they both have to be taken into account. Unhappily, we are presently in such a controversy over standards and codes of practice. To oversimplify, there are two apparently contradictory statements that are often taken as axioms. The first axiom might be expressed as "No geo-engineer who makes borings, soil or rock tests, pore pressure observations — the whole range of geotechnical observations — can carry out these operations according to his or her personal whims, or else the results will be unintelligible to any other engineer, and furthermore they would be useless in attempting to develop correlations with the experience of engineers elsewhere; that is, there must be standards." Similar statements can be made about loads or stresses. The second axiom might be stated as "Nature did not follow standards in creating the mass of rock or soil in question; a defect or a field condition potentially fatal to the performance of the project may exist that escapes the standard investigation; experience leading to judgment is the best defense against the consequences of such a possibility; and the course of action leading to an appropriate solution will differ among individuals of different experience; that is, judgment is an essential ingredient in geo-engineering, and it cannot be standardized."

The unhappy situation in which we presently see two of our most respected geotechnical organizations [ASTM and ASFE] unable to come to terms with the realities of each other's concerns in this context is more than a cloud on the horizon. It actually threatens our profession, and it ought to be brought to resolution forthwith.

Part 4 — Views of John Dunnicliff

Introduction

The remainder of this article will focus on ASTM's work to "develop standard guides and practices for the selection, use, installation and recording of field instrumentation critical to the performance monitoring of soil, rock and man-made [Yes, I know!] masses."

When I was first contacted by the ASTM task group in 1992 I wrote:

> *"I've always believed, and still believe it strongly, that standards are inappropriate for most field geotechnical instrumentation. For such things as installation of strain gages on steel struts they might be useful (even though there would be a difficulty in coping with the differences between procedures for different manufacturers' gages), because we're dealing with a known material: steel. However installation of most instruments involves a marriage between the instrument and a hole in the ground, and every hole is different. I believe that standardization would be a retrograde step, and in nobody's interest. Each installation must be planned in relation to field specifics, and "tailored" to these. I faced this issue when writing parts of my instrumentation book, and realized that I*

should go no further than presenting the broadest of hand-holding guidelines. See, for example, the planning chapter (Chapter 4), Table 9.4 (Some Questions to be Answered when Selecting a Method for Installing Single Piezometers in Boreholes in Soil), and the sections in Chapter 17 on installation procedures."

For expressing such an opinion I was called a "curmudgeon" by the ASTM task group leader. In 1992 I discussed the issue with Gordon Green, Erik Mikkelsen, and some of the manufacturers of instrumentation, and found that I had several curmudgeonly companions.

In a letter to members of the task group, its leader wrote:

"When I was soliciting support for the formation of this subcommittee, several respected professionals expressed reservations regarding the development of standards for field instrumentation. In brief, they suggested that publication of standards might encourage an inappropriate "cookbook" approach to specification writing and discourage the thoughtful development of detailed custom designs prepared for the specific purposes and installation conditions of the project [This is a key *sentence: see Part 8]. An open discussion of this question will be part of the agenda for the organizational meeting."*

I don't know what discussion took place, hoped that it would all go away, and heard nothing for about four years.

ASTM's Draft Standard on Inclinometers

Before looking at any of the January 1997 draft in July this year I made a list of issues which, in my view, should be addressed in a practice guide (note these words) document about inclinometers. I considered equipment, installation, reading, calibration, maintenance and data. I listed 65 issues. I then summarized what was in Allen Marr's draft:

Adequate coverage: 26 issues
Some coverage, but insufficient: 9 issues
No coverage: 30 issues

Of course the draft could eventually be "fixed", given time and input of people with both adequate experience and willingness. But the overriding issue is the one discussed in Parts 2 and 3 of this article — that the document will be labelled "standard guide", not "practice guide", creating the unacceptable scenarios that are identified above.

When I consider the possible contents of guide documents for instruments that are installed in boreholes: equipment, installation, reading, calibration, maintenance and data, I conclude that inclinometers have less-than-average variations from site-to-site. Think of such a document for piezometers:

- About five different basic types of equipment
- Many variations among manufacturers' versions of each type
- A multitude of different "best" installation procedures, depending on many variables (e.g. the 29 questions in Table 9.4: see above introduction to Part 4)
- Numerous possible procedures for reading, calibration, maintenance and data

How could all this possibly fit into an ASTM format and have any value at all?

ASTM's Draft Standard on Specifying Level of Accuracy for Field Instrumentation

This document establishes three specific levels of accuracy which can be used to set the accuracy level for each type of measurement in a program. For each level, a numerical value is given for accuracy, for various measurement types. For example:

Measurement Type	First Order	Second Order	Third Order
Deformation, ft	0.001	0.004	0.01
Strain	10^{-5}	10^{-4}	10^{-3}
Stress	1 part in 1000	1 part in 400	1 part in 100

The document indicates "applications" for each level of accuracy. For example, the following indicates typical situations where first order accuracy may apply:

- Very high consequences of failure
- Geotechnical factor of safety below 1.3
- Situations where small changes in the measured quantity are of significant importance to the success of the project
- Situations where early warning of unexpected performance is required
- Situations with considerable uncertainty about some important geotechnical aspect of the project

Are you still sitting in your chair? In fairness, the covering memo says "The attached draft...is a first attempt to provide a guide (note this word) to help achieve a uniform level of accuracy in field measurements for a project. It represents the first efforts at trying to achieve a guide that most people believe would be useful. It undoubtedly has flaws and shortcomings."

My comments to the author (Allen Marr) included:

- I find the whole issue very puzzling. I have a great deal of respect for your abilities and, as you'll see from what follows, I wonder why our views are so divergent.
- I wonder whether you are perhaps influenced mostly by your lab testing experiences. With lab testing, we can and should specify measurement accuracy. We can and should calibrate our measuring devices, using systems traceable to the National Institute of Standards and Technology (NIST), hence we know "the actual value of the quantity being measured" (you use these words, correctly, in your definition of accuracy). I'm in complete agreement with the need for standards for

lab testing.

However, I believe that field instrumentation is an entirely different issue, because **we almost never know the actual value of the quantity being measured**. We can calibrate the hardware before installation, as we do for lab testing hardware, but this is usually a minor part of the ingredients of "accuracy." Accuracy of field instrumentation data is a composite of the hardware, the site geology and method of installation, and the method of reading, any one of which can dominate. Therefore a specification for accuracy is usually meaningless. In the real-world geotechnical practice of instrumentation, it is better to specify or approve "means and methods" for each specific application, and police those. Please consider:

- Slope Indicator Company's flyer on their total pressure cell says that accuracy is determined by the pressure gage and indicator. This has nothing to do with accuracy of field data, which is dominated by the inclusion effect, and may never be better than ±20% (or more) for the full-embedment case.
- The accuracy of open standpipe piezometers is dominated by response time issues.
- Accuracy of strain gage and tiltmeter data is greatly influenced by temperature changes and temperature transients.

I could go on. In how many of these cases do we know "the actual value of the quantity being measured?" Rarely.

- The above bullet presents **my** basic issue. Most colleagues who have talked with me about the draft have focussed on concerns relating to the linkage between factor of safety and accuracy, which they consider entirely inappropriate.
- You say "...a guide that most people believe would be useful." Who? Those who have expressed an opinion to me so far don't see it that way.
- I'm chagrined that we (you, me and others) are spending our valuable professional time on all this. Throughout my professional life I've tried to guard and uphold the quality of work products in my chosen area of interest and, apart from my June 1998 ASTM symposium assignment in Atlanta, that's the only reason for spending my time on this now. I don't want to spend any time, and I don't want to be confrontational, but I can't discipline myself to sit back and let things like this flow by.
- To summarize, I don't understand where you're coming from, and I worry that your effort is talking us backwards. How can we come to a meeting of minds?

Part 5 — Views of Gordon Green

Introduction

As indicated by John Dunnicliff in Part I, I was contacted by the ASTM task group in 1992. My 1992 response (edited and updated) included the following questions and comments:

- What is the purpose of an ASTM Standard for field instrumentation? What would they be used for? Why do we need them? Who would write them? Would potential writers be adequately qualified? What are acceptable standards for the Standard?
- If such Standards existed, what would the benefits be? Would they be misused and by whom and with what result? Would the disadvantages outweigh the benefits?
- Can useful Standards be written for most instruments or are the subject matter and current state of practice such that it would be very difficult or impossible to write suitable documents?
- Would the profession be better served with "Suggested Methods" as written by ISRM (International Society for Rock Mechanics) or "Codes of Practice" as used in Britain when "British Standards" would be too specific, or a "Practice Guide" perhaps? I believe the answer to this question is a firm yes.
- Two ASTM field instrumentation standards are currently in print: D4403-84 (Reapproved 1989), Standard Practice for Extensometers Used in Rock, and D4622-86, Standard Test Method for Rock Mass Monitoring Using Inclinometers. Neither of these documents appears to me to be well written and they both contain much material that was out of date at the time of initial publication. If they represent the quality of product that would be produced in new standards for other instruments, then the profession does not need them in my view. (They are still in print in 1997).
- Writing adequate new standards will be a great amount of work and will require suitably experienced persons to develop technically correct, well-written and useful documents. I doubt you'll find sufficiently qualified people in the US able to give sufficient, unpaid time to the task.
- I spent a great amount of time to support John Dunnicliff in his writing of what is considered to be the definitive textbook on field instrumentation (the Red Book). Much of what you need to know (unfortunately not all) can be found in that textbook, including the admonition that it should not be used as a cookbook and that intelligent thought is required to develop and successfully implement worthwhile instrumentation programs. The book contains the views, wisdom and opinions of many of the leading suppliers and users from many countries (see list of acknowledgments). I have great difficulty in seeing how ASTM Standards would improve on what's already available in that book.
- The potential for misuse of the proposed ASTM Standards is great, in my opinion. At present users, and

specification writers in particular, often do a poor job of designing instrumentation systems, specifying instruments, installing and monitoring. This may be due to a lack of knowledge or understanding, laziness, and thinking that instrumentation is simple and can be left to technicians or less well qualified firms. The existence of ASTM Standards will encourage this. For example: "Furnish and install 6 MPBXs in accordance with ASTM D4403-84" inserted in construction specifications. Any encouragement of this attitude would be very detrimental and unlikely to generate reliable measurements.

- There seems to be a mentality that says we can solve our problems by passing more laws and more written rules and writing more "Standard Test Methods." I do not believe this is correct. We need more intelligent engineering thinking geared to the specific needs of the job, geological conditions, drilling methods, and requirements of the specific instrument selected for the job.
- I think it is essential to prepare a written justification document that addresses the issues raised here. This document should be circulated for review to see if there is a consensus that ASTM instrumentation standards are required, will be useful, and can be written.
- I am an independent consultant with a limited budget for this type of subcommittee activity. I'm not a big committee person and am not prepared to give a lot of time to an activity I don't believe will be useful to the profession. My present thinking is that ASTM Standards are not the answer but I'm certainly open to hearing others' views and to seeing a detailed case made for these standards in a written statement.

I never received any response from ASTM to these comments and questions. In the interim I wrongly assumed that the issue of writing ASTM Standards on field instrumentation would die and that the two Standards then (and still) in print would somehow go away. It did not.

1997 Draft Standard on Inclinometers

Four years after it was formally established, the D18.23 subcommittee produced the new draft "Standard Test Method for Monitoring Ground Movement Using Probe-Type Inclinometers" written by its co-chairman Allen Marr. What the other 79 people who attended the first subcommittee meeting (see Part 7) had been doing since 1993 is unclear.

The new draft is a poorly written document that does not represent current good inclinometer practice. It includes a large number of specific inaccuracies and omissions which I have detailed in a letter to the author. They include:

- Anything with the word "Standard" in the title is a potential legal trap. Little if anything is "Standard" about trying to make good quality field measurements. Good field instrumentation practice is constantly evolving. Only a "Practice Guide" or "Suggested Method" is appropriate and acceptable.
- Existing published documents are readily available concerning inclinometers and include:
  - ISRM Suggested Method for Inclinometers (1977) in Rock Mechanics, Springer-Verlag
  - Green & Mikkelsen (1986) TRB paper in Transportation Research Record 1169
  - Dunnicliff (1988) textbook (the Red Book)
  - Mikkelsen (1996) chapter for TRB Special Report 247, Landslides
  - Current Slope Indicator Co. inclinometer manuals

  I find little or no evidence that the writer of the Jan 10, 1997 draft has read or understood the important issues contained in these documents.
- A figure illustrating inclinometer equipment is 9 years old and shows Slope's portable manual indicator rather than the current DataMate intelligent readout that records and stores data. The existence of an intelligent readout is never mentioned in the draft standard. It should be discussed as it's the best tool for field data collection. It's been available since 1994 when it replaced the then 10-year-old RPP (Recorder-Processor- Printer) intelligent readout.
- The section concerned with data analysis is woefully inadequate. Too many impressive mathematical equations and insufficient good example figures showing data formats and plots. The use of a PC to process the voluminous data is never even mentioned. This is 1997 and commercial programs are readily available, e.g., Digi-Pro from Slope Indicator Co., that are far more efficient than user-developed primitive spreadsheet methods (see back cover of this issue of GN). Twenty years ago the 1977 ISRM Suggested Method recognized computer analysis.
- Draft figures showing examples of data tabulation and plots are improperly formatted, show poor scale selection and reflect bad inclinometer casing installation practice. They are misleading and a far cry from time-proven data formats contained in Digi-Pro type software that are infinitely more powerful in diagnosing problems and leading to correct data interpretation.

1997 Draft Standard on Accuracy

The second product of the four-year-old committee is a draft "Standard Guide for Specifying Level of Accuracy for Field Instrumentation." It is a bizarre document:

- The simplistic approach embodied in this draft standard is fatally flawed. In contrast to the laboratory the actual value of the field parameter is largely unknown and the manufacturer's stated accuracy of the instrument is usually much higher than the measurement result from an installed instrument.
- Specification of the required accuracy of a measurement result is generally meaningless, contractually unenforceable and its determination comes too late in the instrumentation program, when instrument revisions are impossible.
- In general instrument selection is

based on what's available from suppliers, and program designers work around this. Instrument manufacturers generally are marketing the best instrument of a particular type that the individual manufacturer is able to produce.

- Some of the levels of accuracy listed are totally unrealistic. For example the first order accuracy required for force, stress, velocity and acceleration is stated as 1 part in 1000. Measurement of tieback load to an accuracy better than ±5 percent of the measured value, i.e. 1 in 20, is realistically impossible. Measurement of insitu total stress in soil or rock is often no better than ±20 percent. There is absolutely no need to measure the velocity or acceleration of a landslide to anything like 0.1 percent accuracy. Does ASTM understand the difference between accuracy and precision of a measurement?
- The direct link established in the draft standard between level of measurement accuracy required and specific factors of safety is entirely inappropriate. The draft standard suggests that slope stabilization projects with a calculated factor of safety less than 1.3, a common situation, need first order level measurements, i.e. pore water pressures to ±0.1 percent accuracy and deformation to 0.001 ft accuracy. Wishful thinking indeed!
- Examples are given of how to specify levels of accuracy. The simplistic statements that follow would be extremely difficult to implement, in some cases contractually unenforceable and would not improve geotechnical instrumentation practice.
- The draft standard on accuracy is best summed up in John Dunnicliff's words to me –"mind boggling".

Where Do We Go From Here?

I see no need for ASTM "Standards" for field instrumentation and see no evidence that Subcommittee D18.23 is capable of producing acceptable documents. The recent alarming revelations by ASFE in the December 1996 and June 1997 issues of *GN* strongly reinforce my view that standards would be detrimental to good geotechnical engineering practice.

ASTM appears currently to be committed to including the offending word "Standard" in all of its documents, even though ASTM's definition differs from the dictionary definition. If "Standard" is included in a title, it is questionable whether inclusion of a caveat or user-advisory will prevent mischaracterization in court.

Technically correct, well written, up-to-date "Practice Guides" prepared under the leadership of qualified and experienced persons would clearly be of great benefit to the geotechnical profession. Preparation and regular updating of such guides would be a daunting task. Circulation of incomplete, out-of-date, low-grade drafts for committee review and several rewrites is inefficient, will take too long and is unlikely to produce a worthwhile up-to-date guide.

Part 6 — Views of Erik Mikkelsen

ASTM Field Instrumentation Standards: A Hazard for Geotechnical Engineers?

I'm getting "involved" because of what I have learned about the current and draft ASTM standards for field instrumentation, particularly "standards" for inclinometers. Based on my nearly 30-year detailed experience with inclinometers, I believe the assumption that such "standards" can be written to promote good engineering practice is flawed. ASTM standards for inclinometers and other field instrumentation could have very undesirable effects on our profession. In some instances, such standards would be a hazard to geotechnical engineers.

The Legal Issue

The first issue, as I see it, has to do with the US legal system. Field instrumentation is being used in two major "industries": construction claims and construction defect litigation. Lawyers for claimants and plaintiffs in both "fields" are going to have another tool in their kit for helping to discredit professionals and expert witnesses.

Field instrumentation has to be installed according to actual conditions encountered in the field. Conditions in the field are often different from what designers perceived them to be. Practices in drilling and construction vary from site to site, and from one side of the country to the other. Results from instrumentation programs are subject to interpretation and judgment. When disputes and claims march on to court, professionals involved will be grilled about their conformance to ASTM standards, whether they are relevant or not. A jury or a judge would be hard pressed to understand why a professional deviated from the "standard" and used judgment to deal with less-than-perfect field conditions. It certainly would be another excellent target for non-engineers and lawyers to shoot at.

Specifications

The second issue is specifications. Good field instrumentation practices are tied intimately to project-specific needs. Based on my experiences on both sides of the fence of the designer/installer issue, project-specific specifications are often woefully inadequate to serve the intended measurement task. Ill-conceived applications, boiler-plating from other projects and lack of practical experience in the designer's office already contribute to field installation and monitoring nightmares. ASTM standards would further promote boiler-plating and simplistic specification writing. Cookbook specifications are counter-productive to a good field instrumentation measurement program.

Where Do We Go From Here?

I see too many negatives at this point to offer constructive steps in helping with the subcommittee's self-appointed task. I know the people involved are earnestly trying to create "something" for field instrumentation under the philosophy of ASTM standardization, but I do not know how we can create a useful product in this case without setting booby traps for our engineers. A watered-down version of a standard could probably be launched, but how useful would that be?

Part 7 — Views of Allen Marr and Gary Durham

Introduction

As members of ASTM Subcommittee D18.23 on "Field Instrumentation," it was our initial understanding that we were invited to submit our position in regard to developing ASTM Standards for geotechnical instrumentation. With the exchange of early drafts and follow-up discussions, we became aware that Dunnicliff's focus included the broader topic of ASTM's standards development in certain areas of geotechnical and geo-environmental engineering, felt by some to be detrimental to professional practice.

Our comments are directed only to the activities of Subcommittee D18.23, as we are not privy to many of the details surrounding the broader disagreement between ASTM and ASFE. Further, it would not be appropriate for us to serve as spokespersons for either Committee D18 or ASTM. The chairman of D18, Terry Hawk; D18 Staff Manager, Robert Morgan; and ASTM President, James A. Thomas; would be the proper channels in soliciting ASTM's position regarding ASFE's position.

Background

ASTM Subcommittee D18.23 on Field Instrumentation was formed in 1993 to explore the needs for standards for geotechnical instrumentation. Over 80 people attended the first subcommittee meeting and participated in a lively discussion of the pros and cons of "standardization." It was obvious at this first meeting that some people held strong opinions against standardization of any aspect of field instrumentation. Similar arguments have been expressed ever since D-18 started its standardization efforts in 1936. However, many practicing professionals recognize the benefits of consensus standards. Had those arguments prevailed we would not today have the many benefits of over 200 standards covering many aspects of geotechnical testing and investigation.

ASTM's Standard Process

A well-written standard adopted through the open consensus process benefits the profession as long as it (1) represents current practice, (2) permits professional judgment and innovative technology, (3) does not promote a special interest, and (4) is user-friendly. A well-written standard uses a common methodology to obtain a result that is efficiently communicated to others. Standards remove the need to document and explain routine aspects of the task at hand; thereby allowing the professional to spend more time focused on the problem requiring his expertise.

The word "Standard" is often misunderstood. In ASTM, Standard refers to the consensus method of developing documents in an open forum with rigid voting rules to ensure that viewpoints from all quarters are considered. Standard is not a synonym for rigid specifications that dictate professional practice nor is a standard intended to replace the application of engineering expertise and judgment. Most standards do establish a minimum set of activities or actions acceptable to the prevailing practice, not unlike ASCE's Standards, e.g."Standard Guidelines for the Design and Installation of Pile Foundations".

ASTM provides several types of standards, including Terminology, Test Methods, Practices, and Guides. Standards provide us with a common ground for exchange of information and work product. They save us time and help us develop comparable data upon which we can act. A standard should never stand in the way of the application of professional judgment or the development of better ways to accomplish the work.

ASTM has become the most prominent standards organization in geotechnical engineering in recent years. Some governmental agencies have adopted ASTM standards rather than continue their own parallel efforts. The international use of ASTM standards is growing.

Standards for Field Instrumentation

In field instrumentation practice, the alternatives to standards are: (1) to have someone develop a set of specifications for each instrument on each project, or (2) to have an instrumentation specialist oversee the selection and installation of equipment, or (3) to do nothing and hope that whoever installs the equipment knows what they are doing. Is it really in the project's best interest to start from ground zero to develop a set of specifications for each instrument? Will selection and installation of equipment occur under the oversight of an instrumentation specialist? Is such work getting the best use from the professionals working on the project? Why not relegate those aspects of instrumentation that are common to all installations to one or more ASTM standards? Then the project team can focus on what specific requirements or differences from the instrumentation standard are necessary for the particular circumstances and needs of the project?

Draft Standard on Inclinometers

Subcommittee D18.23 is currently working on a draft standard for installing and monitoring slope inclinometer systems. This device has been in use for more than 25 years. It is now routinely used to monitor horizontal movements in many types of earthen masses, including slopes, excavations, dams and landfills. Inclinometers are frequently used to give advanced warning of potentially hazardous slides, events which may endanger life and/or property. Equipment is readily available from several suppliers. Most drillers will install inclinometer casing. Most consulting firms, including many general civil firms, will undertake the reading, data reduction and interpretation of data from slope inclinometers. Many of these activities follow the past experiences of those doing the work - experiences which may be good or bad, correct or wrong. These are all conditions favoring the development of a standard to establish a common ground of practice, a standard that if followed will improve the reliability and quality of the resulting data.

The draft standard for inclinometers will be developed as a "Standard Guide." In addition, the following language will be added to the standard: "This Guide offers an organized collection of information or series of options and does not recommend a specific course of action in all cases. This document cannot replace education and experience and should be used in conjunction with professional judgment. The word "Standard" as used in this document means that the document has been approved through the ASTM consensus process."

The draft inclinometer standard is drawing criticism from some who oppose standardization. Many of their points made known to this subcommittee will be incorporated into the standard. That is exactly how the ASTM standards development process works - someone makes a start by preparing a draft. That document may then go through several rewrites within subcommittee before it ever reaches the ASTM main committee. Those rewrites incorporate the contributions of specialists, users, suppliers and other interested parties, all of whom volunteer their professional time to this effort. The ASTM main committee balloting process reaches the entire geotechnical community. A single unresolved negative vote can stop final publication of a standard. This process results in standards which reflect the consensus of professional opinion on the accepted way to do a particular thing. Adopted standards must be reballoted by the entire voting community every 5 years or risk being dropped from the Book of Standards. This review process provides the opportunity to correct deficiencies and improve existing standards on a relatively frequent basis.

Specifying Accuracy for Field Instrumentation

This crude draft arose from Marr's efforts to deal with a problem he frequently encountered on field instrumentation projects — a great deal of effort expended to obtain some measurements to a high degree of accuracy, little effort expended to obtain other measurements with any consideration of accuracy, and no effort given to determining the actual accuracy required for the project. It seemed attractive conceptually to develop a framework within which an engineer could specify a level of accuracy appropriate to the project. The basic idea was that a First Order level would be the best accuracy available, a Second Order would be more like conventional practice, and a Third Order would be for preliminary or approximate work of low cost. The standard would reflect the profession's opinion about what levels of accuracy could be expected for different instrument types and degrees of effort.

The draft was circulated specifically to draw comments. Several comments were received. Most of them question how this document can be completed in a way that applies universally. This draft standard may die on the vine because a consensus view does not develop.

Closure

Members of D18.23 believe that the profession will benefit from having ASTM standard guides and practices for field instrumentation, including inclinometers, piezometers, settlement plates and points, strain gauges and force transducers. Such standards would cover the instrument, its installation, the readout equipment, and reduction and reporting of data. We believe the need for and benefits from such standards will increase as the use of field instrumentation grows. We foresee substantial growth resulting from the increase in variety of equipment, decrease in cost of equipment, decrease in cost of data collection and processing, and increase in use of field instrumentation to avoid costly damage and litigation from construction activities.

However, for these standards to appear, we need the help and support of the professional community. We need your help to get draft standards that are complete and useful. We need your support through affirmative votes during the ASTM balloting process. We welcome your comments. Direct them to either author, or to Bob Morgan, Director Technical Committee Operations, ASTM, Tel. 610-832-9500, FAX 610-832-9555.

Part 8 — Closure and Call for Action by John Dunnicliff

Use of the Word "Standard"

This is clearly a major sticking point. ASTM's definition is given in Part 1 of this article, and various contributors have expressed their views on the use of the word. In a letter to me Allen Marr wrote (quoted with his approval):

> *There seems to be a lot of concern with the word "standard." ASTM has a specific definition for the word as used in its documents. We don't have the ability to alter ASTM's definition but we can try to be clearer about the purpose and appropriate use of ASTM documents.*

I'd like to be optimistic and hope that "we **do** have the ability...." Some of us have great concerns that the word will be interpreted by jurors and others to mean that professionals **must** practice in a "standard" way, and that any caveat intended to dilute this message will be lost. Others do not see this as a concern, for example in Part 7, Marr and Durham say "a standard should never stand in the way of the application of professional judgment."

Is there a possible contradiction in that quote? What are **your** views?

ASCE's "Standard Guidelines"

Parts 2 and 7 refer to ASCE's preparation of Standard Guidelines. I don't want to give the impression that I favor ASCE's use of the term while opposing ASTM's use. I don't. As indicated in Part 2, ASCE seems to recognize the concern and are considering a change in terminology.

Where Are We Going?

Democracy is at work! Part 7 calls for your vote, as also does a later section in Part 8. As another indication of the merit of open discussion rather than confrontation, I was gratified to read the following in a recent letter from Allen Marr (quoted with his approval):

> *As far as changing direction, I think your efforts will have a substantial impact on the activities of D18.23. If we go forward, the inclinometer standard will be substantially revised to consider the many comments offered by you, Erik and Gordon. Whether we go forward will depend on the subcommittee's assessment of the likelihood of obtaining consensus on a revised draft that incorporates your comments and comments of those who reviewed the draft document. Since the burden of doing this work will fall largely on my shoulders, and since I have many other things to do with my time, I intend to give the issue considerable deliberation before moving ahead.*

Call For Action

What can **you** do? Some suggestions:

- If you care about the broad issue (Parts 2 and 3, and, to be blunt, you should: it's **your** profession), contact: Advocates for Professional Judgment in Geoprofessional Practice, c/o ASFE, 8811 Colesville Road, G106, Silver Spring, MD 20910. Tel: (301) 565-2733; Fax: (301) 589-2107; E-mail: ASFE@aol.com. Also, visit ASFE's home page: http://www.asfe.org. ASFE will let you know how to get involved.
- Join ASTM, and become a member of Committee D-18, and Subcommittee D18.23. Contact ASTM, membership department, Tel: (610) 832-9500, Fax: (610) 832-9555, E-mail: service@local.astm.org. Annual membership costs $65 and entitles you to a copy of the current annual book of relevant standards, i.e. Vol. 04.08 Soil and Rock (1): D420-D4914. Subcommittee membership provides a voice and a vote.
- If you care about the instrumentation issue, send a fax to both Allen Marr and me, with your views. Include a completed questionnaire (see page 45). If appropriate, views and questionnaire responses can form the basis of a follow-up article in this magazine. If you want to see the two instrumentation drafts, ask Allen Marr or Gary Durham.

I acknowledge that the individuals working on these standards are well intentioned people, trying to contribute to their profession. However, I believe that many of them have not been exposed to "the big picture". This article is an attempt to paint the big picture. If we call these things practice guides, and if they are written in a style of "when you face this task, you should think about the following things", and if they are written by folks who know their stuff, we don't have a problem. How do we get there?

In closure, let's go to someone much better at writing closures than I (from a recent fax, with the author's approval):

> *Many years ago I was an expert witness in a lawsuit in which the opposition cited an ASTM Standard that to me was clearly inapplicable, in fact, erroneous in the context of the case. I explained why to our lawyer, a very sagacious fellow. His comment was something like this, "Dr. Peck, what are you going to answer when the opposing lawyer asks, Are you telling this court that you know more than the American Society for Testing and Materials? " In a nutshell, that's the danger.*

References

ADSC (1997), "Concerns of Environmental and Geotechnical Professionals Regarding Development of Prescriptive Professional Practice Standards", Foundation Drilling, ADSC, August, pp. 36, 37.

ASFE (1996), "ASFE White Paper. ASTM's Establishment of Prescriptive Professional Standards", Geotechnical News, Vol. 14, No. 4, December, pp. 21-26.

ASFE (1997), "Concerns of Environmental and Geotechnical Professionals Regarding Development of Prescriptive Professional Practice Standards", Geotechnical News, Vol. 15, No. 1, June, pp. 17-21.

Core Bits (1997a), "Eleven [now Twelve] Associations Form Coalition to Oppose Prescriptive Professional Practice Standards", Core Bits, Geo-Institute of ASCE, Vol. 1, No. 1, Summer, p. 7.

Core Bits (1997b), "Geo-Institute Continues to Support Coalition on ASTM Concerns", Core Bits, Geo-Institute of ASCE, Vol. 1, No. 2, Fall, p. 6.

Contributors to this Article

John Dunnicliff, Geotechnical Instrumentation Consultant, 16 Whitridge Road, South Natick, MA 01760. Tel: (508)655-1775; Fax: (508)655-1840.

Gary Durham, Durham Geo-Enterprises, Inc., P. O. Box 870907, Stone Mountain, GA 30087. Tel: (770)978-7895; Fax: (770)465-7447.

Gordon E. Green, Geotechnical Engineering and Instrumentation Consultant, 9835 41st Ave. NE, Seattle, WA 98115. Tel: (206)527-2742; Fax: (206)367-8570.

W. Allen Marr, President, Geocomp Corporation, 1145 Massachusetts Avenue, Boxborough, MA 01719. Tel: (508)635-0012; Fax: (508)635-0266.

P. Erik Mikkelsen, Principal, Cornforth Consultants, Inc., Ste. 111, 10250 S.W. Greenburg Road, Portland, OR 97223. Tel: (503)452-1100; Fax: (503)452-1528.

Ralph B. Peck, Civil Engineer: Geotechnics, 1101 Warm Sands Drive, S.E., Albuquerque, NM 87123. Tel: (505)293-2484.

Automated Electrolevel Monitoring Systems

Storer J. Boone

Introduction

Tunnelling for a sewer relocation project passed 5 m beneath the Toronto Transit Commission's Spadina subway line and settlement of the subway was controlled using compensation grouting. Trains in the existing subway carry passengers for about 20 hours of each day on 2 minute to 6 minute intervals in each direction. It was essential to protect the subway from damage as well as maintain the operating schedule and safety of the trains. Access to the subway tunnel was severely limited and automated systems had to be installed to monitor ground and subway movements during construction. This article summarizes results of the monitoring with a focus on the performance of the automated monitoring systems. Descriptions of the project associated with this work can be found in Boone and Heenan (1997) and Boone et. al (1997).

Monitoring Systems

To provide nearly continuous settlement monitoring, three arrays of beam electrolevels were installed on the subway walls (Figs. 1, 2 and 3). Each array included ten to eleven 2 m long beam-type electrolevels (Sinco EL Beams) installed end-to-end and connected to a Campbell CR10 data logger. The CR10 was programmed to collect and process sensor output, and store deflection data every two minutes. Long distances and limited access prohibited connecting the CR10 directly to a computer. Stray electrical currents in the subway tunnel also prohibited radio telemetry. Therefore, the CR10 was connected to internal subway telephone lines and accessed via modem. A remote computer located in the site office was initially set to download the deflection data every ten minutes with record storage to occur once per hour while tunnelling and grouting were underway. Plotting of the data was accomplished using conventional spreadsheet software.

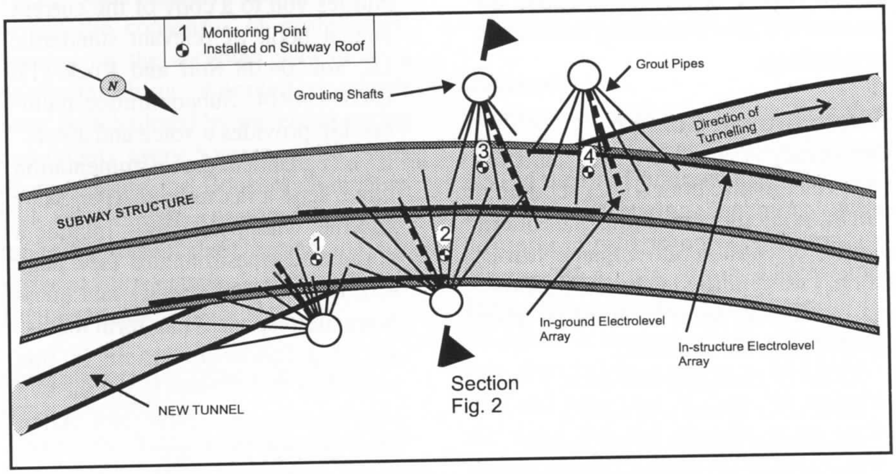


Figure 1. Plan of grouting and electrolevel systems.

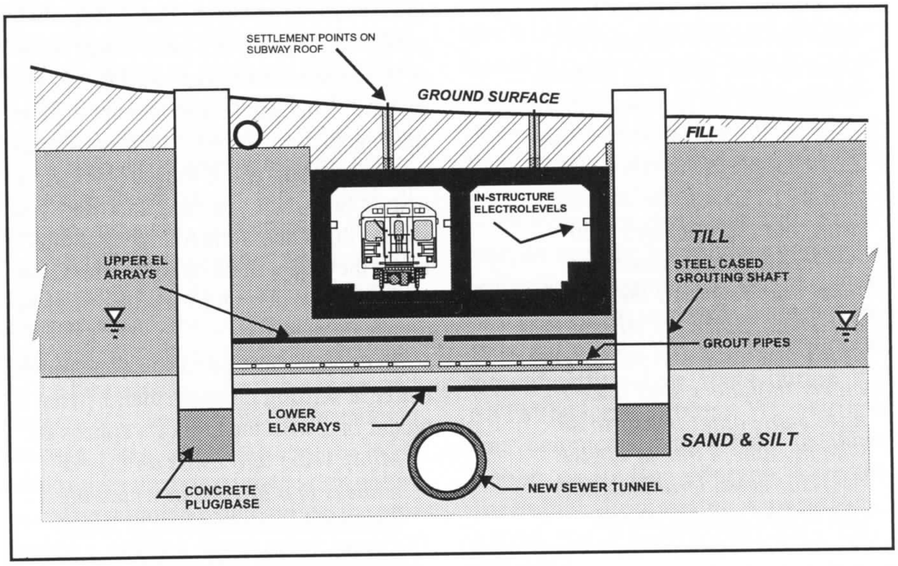


Figure 2. Cross-section of grouting and electrolevel systems.

Movement in the ground caused by tunnelling and grouting was monitored using four dual arrays of in-ground electrolevels (Sinco EL In-Place Inclinometers) as shown on Figs. 1 and 2. Each array location consisted of two inclinometer casings: one installed above the grout pipes; and one below. It was expected that as the ground deformed from the tunnelling, and grout was injected, the lower four electrolevels would drop to match the induced settlement. The electrolevels in the upper array were expected to indicate possible heave or settlement that could propagate upward toward the subway. All sensors were connected to another Campbell CR10 data logger for initial data processing and storage and a second computer for visual presentation of movements and record data storage. Data was collected and updated on the screen about once per minute and stored to files about three times per shift.

Measured Movements

During grouting, the in-structure electrolevels indicated relatively minor daily movements (Fig. 4a). Selected data from the in-ground electrolevel arrays is shown in Fig. 4b. A comparison of the movement patterns of the in-structure and in-ground electrolevels for one area is shown in Fig. 5. Although the compensation grouting was largely successful, its long-term performance was considered somewhat uncertain for a variety of reasons, one of which was that the in-ground instrumentation indicated continued deformation above the tunnel. A localized settlement of about 40 mm was measured by an in-ground electrolevel array after production grouting even though no structure movement was observed. A two-stage follow-up grouting program was then successfully completed to halt further movements. At the conclusion of the project it was determined that the subway had moved no more than about 4 mm. The in-structure electrolevels demonstrated that movements were characterized by relative rotations of the subway structure at construction joints (as shown in Fig. 4).

Figure 3. Array of electrolevels installed on subway wall (photo courtesy of Toronto Transit Commission Photographic Services).

Problems and Solutions

Before installing the in-structure electrolevel system, the arrays were all electronically connected to the data logger and remote computer so that full testing could be carried out. Each beam was tilted by hand and the computer output was compared to the physical movements; however, other problems developed later that were not evident during these initial tests.

After field installation, cumulative movements of about 12 mm were indicated by the electrolevels while the grout pipes were being installed. These movements were unusual considering the construction progress, and therefore the monitoring system was checked for errors before relying on the movement data. The CR10 programming included calibration factors for each beam sensor. To modify data collection intervals, the CR10 required reprogramming. It was found that if the program was downloaded from the CR10, modified, and sent back to the CR10, the communications software truncated the calibration factors from a six decimal place number to two decimal places; this factor truncation, however, was not readily apparent. The combined effect of truncated factors in the calibration polynomial and summation of subsequent deflections had produced the erroneous information. This problem was overcome by sending new programming code, including all calibration factors, to the CR10 each time logging frequencies were altered.

Because of noise in the poorly shielded subway telephone lines, modem connections were also interrupted at random intervals and it was necessary to redial and reconnect after each interruption. By checking the electrolevel data many times, both by remote computer and with hand-held readouts (during subway off-hours), it was demonstrated that, while the interruptions were annoying and caused delays, the transmitted data was not affected.

It was intended that the in-ground electrolevels would provide a "real-time" view of in-ground movements as grout was injected. The in-ground system functioned well in as much as initial ground movements were detected so that grout could be directed to the appropriate area. Because of the project schedule, however, there was little time for in-place or laboratory testing of the entire system and a variety of difficulties with the system were experienced. The visual computer display was not set to accommodate the large movements actually observed and its nearly continuous visual output was of limited use during grouting. After grouting was completed careful notes were taken of the orientation of the sensors and all electronic connections during system disassembly. It was determined that during installation, grouting, and settlement, several of the sensor assemblies became misaligned. After reconstructing and testing the physical and electronic array arrangements in the laboratory, one sensor was also found to

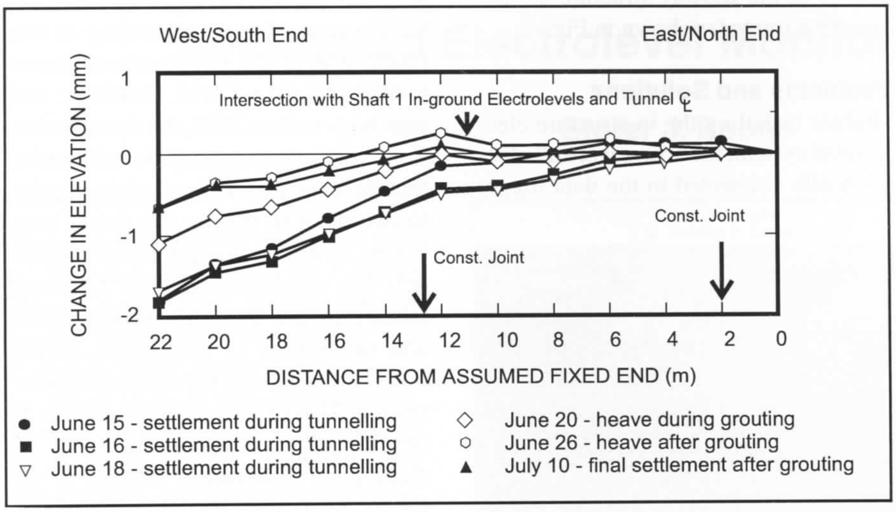


Figure 4. Electrolevel readings during and after production grouting: a) in-structure electrolevels at Array 1;

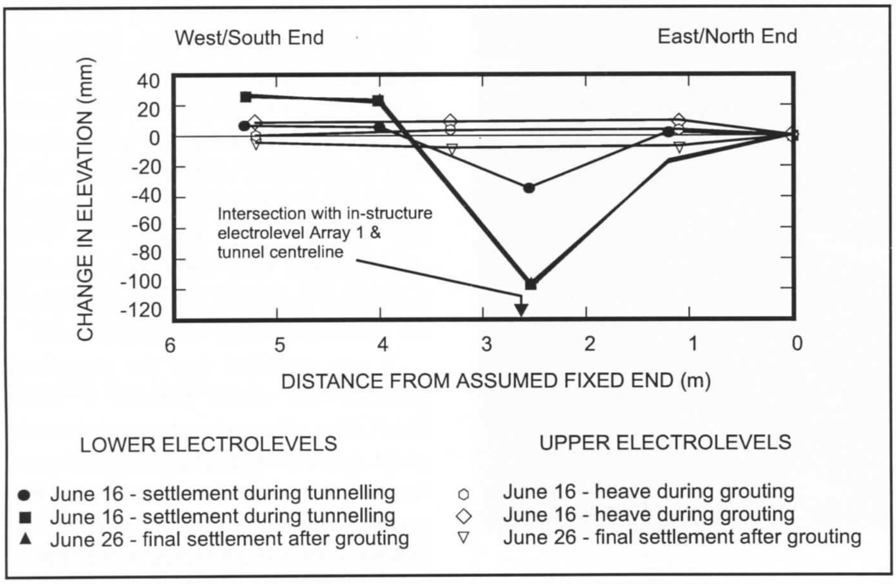


Figure 4. Electrolevel readings during and after production grouting: b) in-ground electrolevels at Shaft 1.

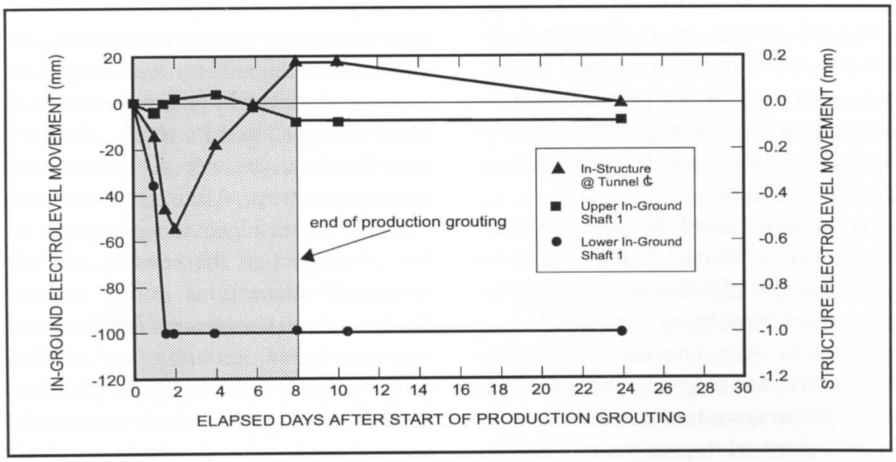


Figure 5. Comparison of in-structure and in-ground electrolevel movements at tunnel centreline.

be improperly oriented within its housing (resulting in reported deflections that were opposite in direction). A thorough review of the data logger programming revealed that one of the minor calibration factors was also assigned the wrong sign (- instead of +); although the incorrect calibration factor had an insignificant effect on data because temperatures were relatively stable. These difficulties, however, did not hinder the use of the sensors for their initial function - indicating where and when the grout should be injected. After review of the data processing and storage programming, the reevaluated information provided useful comparisons for assessing the success of the compensation grouting program.

Conclusions

From the work carried out on this project, a number of simple, but important, lessons for using automated monitoring systems were reinforced:

1. Test the full system in a controlled environment to check the physical relevance of measurement and computer output, sensor orientation, and the basic system programming.
2. Test the full system in the field under actual-use conditions prior to the activities for which measurements are to be taken.
3. Collect and store raw sensor data only; i.e. leave processing and record data storage to the remote computer. If problems are discovered later, the data can then be reliably re-evaluated.
4. Check all components of the system during disassembly.

Automated electrolevel systems could be a "numerical nightmare," as perceived by many engineers (Spalton 1995). With sufficient physical testing of the entire system and careful data management, however, they were a "practical solution" in this case. Although a number of difficulties arose with each of the automated systems, in most cases the problems were overcome and the systems provided essential information, unobtainable by other means.

References

Boone, S.J., Heenan, D. and Pennington,

B. 1997. Monitoring systems for compensation grouting. *Grouting: Compaction, Remediation, and Testing, Geotechnical Special Publication No. 66*, C. Vipulanandan, ed., ASCE, pp. 101 - 117.

Boone, S.J. and Heenan, D. 1997. Compensation Grouting. *Civil Engineering*, ASCE, January, pp. 39 - 41.

Spalton, C. (1995). "Electrolevels. A Practical Solution or Numeric Nightmare?" *Proc. of the Hong Kong Inst. of Engrs Seminar, Instrumentation in Geotechn. Engrg.*, May 10 1995, pp. 35 - 42.

Storer J. Boone is a Senior Geotechnical Engineer in the Mississauga office of Golder Associates Ltd., 2180 Meadowvale Blvd. Mississauga, Ontario, Canada, L5N 5S3. Tel.: (905) 567-4444, Fax: (905)567-6561.

Please photocopy, complete and forward the following questionnaire in response to the call for action (see page 29).

FAX TRANSMITTAL (Number of pages in this fax: ______) Date: ________________

To: John Dunnicliff, (c/o BiTech) fax (604) 277-8125
Allen Marr fax (508) 635-0266

From: Name: ______________________________

Affiliation: ______________________________

Fax No.: ______________________________

Re: ASTM Subcommittee D 18.23's Preparation of Standards for Field Instrumentation

My views on preparation of standards for field instrumentation are on the attached page(s).

The following are my responses to the questionnaire
(note that the scope of this questionnaire is limited to field instrumentation).

		YES	NO
1.	Are you a member of ASTM Committee D-18?		
2.	Are you a member of ASTM Subcommittee D18.23?		
3.	Do you think that our profession would benefit from having guide documents?		
4.	Is a document with "standard" in the title likely to stand in the way of engineering judgment?		
5.	If a document has the word "standard" in its title, do you think that a juror will pay attention to a caveat which permits use of engineering judgment?		
6.	Do you believe that publication of documents with "standard" in the title would encourage an inappropriate "cookbook" approach to specification writing, and discourage the thoughtful development of detailed custom designs prepared for the specific purposes and installation conditions of the project?		
7.	Do you believe that, as suggested in Part 7, there are sufficient "aspects of instrumentation that are common to all installations" to merit standardization?		
8.	Do you believe that we should work towards removing "standard" from titles, and use a term such as "practice guide"?		
9.	If you answer "yes" to question 8, and if "we don't have the ability to alter ASTM's definition" (part 7), do you believe that another professional organization, e.g. ASCE's Geo-Institute should develop guides? (This is suggested in Part 2).		
10.	Do you recommend that ASTM Subcommittee D18.23 limits its activities to "promote education, research, and exchange of information regarding field instrumentation for soil and rock?" (see item 1 in Part 1).		