Geotechnical Instrumentation News

John Dunnicliff

Introduction

This is the forty-third episode of GIN. Three articles this time, and two discussions of one of them.

Measurement Uncertainty

Barrie Sellers was my primary helper when writing Chapter 7 of the red book, on *Measurement Uncertainty.* He's elaborated on the subject in the first article here. If you feel like checking yourself out, set up a target as in his Figure 2, and direct the darts, arrows or gunshots to try to create what you see in the figure.

Something doesn't seem fair! For Chapter 7, Barrie drew the two figures that are reproduced in his article, and here they're attributed to somebody else!

Erroneous Readings

The third article, by Gord McKenna, refers to "quirky instrument readings", and says *"Beware of quirky instrument readings. If you are getting odd readings from an instrument, even only some of the time, you need to decide formally whether you can rely on this instrument or if it needs to be abandoned or replaced. A purist might write off the instrument and perhaps its previous readings too …While quirky readings may indicate a new geotechnical phenomenon, the problem probably lies with the instrumentation. Confront the decision head on, and record your decision and rationale."*

This is excellent advice. I remember a case where a pneumatic piezometer suddenly changed from a steady positive reading to a reading of zero pore water pressure. All decided that it had died. Later there was a slope failure, and it was suspected that the piezometer was at or near the slip surface, which was in a dilative material. It was trying to tell us something! When faced with quirky readings after that experience, I've usually tried to get a group together to brainstorm. This has usually been over a brown bag lunch, and after explaining the issue, all are encouraged to suggest any possible causes of the quirkiness, however crazy the suggestion might first appear to be. Sometimes this has led to meaningful conclusions. Try it, you'll like it!

McKenna indicates that the two vibrating wire piezometer tips that he tested were from different manufacturers. I invited each of them to write a discussion, and these follow the article.

Research on Fibre Optic Sensors for Monitoring Deformation of Tunnels

In the June 2002 episode of GIN (Episode 31) I reported on a research program that had just started in England to develop fibre optic sensors for monitoring deformation in tunnels. The objective of the research, under the name 'OFSTUNN' (Optical Fibre System for Tunnelling), has been to design and manufacture an array of fibre optic sensors that can be fixed at discrete points to tunnel linings and that are able to measure accurately, reliably and economically tunnel strains and displacements associated with settlement, rotation and distortion. The research program was planned for three years. Participants have been University of Birmingham, Smart Fibres Ltd., London Underground Ltd. and SolData. I've just received the following update from Nicole Metje of University of Birmingham.

The OFSTUNN project is coming to a close later this year and significant progress has been made in understanding the behaviour of the fibre optic sensor system, termed Smart Rod. The Smart Rod consists of a square section fibreglass rod with optical fibres fixed into grooves running along the centre of each of the four faces. Fibre Bragg Gratings (FBGs) are located at discrete, pre-determined points along each of the optical fibres and measure strains at each location. The Smart Rod is fixed at discrete locations to the structure being monitored, such that the FBGs are positioned away from the fixing points, and structural beam theory can be used to back-analyse the strains in the rod, and hence the structure. The focus of this project is to install the Smart Rod in tunnel applications, and the laboratory tests have been set-up to represent the rod arrangement that is likely to be used in a tunnel, i.e. a longitudinal and circumferential set-up. Initial laboratory results show that temperature compensation can be applied successfully to the raw data, thus enabling the calculation of strain data unaffected by any change in ambient temperature. Further, it has been shown that lateral displacements of the fixing points of 0.1 mm and rotations of 0.5 deg can be resolved successfully. As a spin-off project, Smart Fibres and SolData have successfully installed the Smart Rod in a diaphragm wall and are getting encour-

aging agreement with inclinometers.

I'm hoping for more details soon, with a focus on applications for tunnels, and to include them in GIN later this year.

Rules for Authors and Editors

While interacting with Barrie Sellers before finalizing his two contributions to this episode he alerted me to two wise rules, put forward by Dr. Samuel Johnson. A Google search revealed:

On September 18, 1709, Dr. Samuel Johnson was born at Lichfield, Staffordshire, England. A giant in literary and cultural history, his 1755 "Dictionary of the English Language" was the first comprehensive dictionary ever published. While a voluminous writer himself, Johnson is known to the world primarily through the book of another man, Scottish writer James Boswell. In 1791, Boswell published the most famous biography ever written, "The Life of Samuel Johnson," in which he minutely detailed Johnson's verbal facility, trenchant wit, and storehouse of knowledge. The biography became so popular that Johnson's most frequently quoted words come from the biography and not from his own works. At one point, an aspiring (and apparently annoying) young writer pestered Johnson to read a first-draft of a novel he had written. Johnson finally relented, and then sent the man a note containing one of the most famous chiasmic put-downs in history:

"Your manuscript is both good and original; but the part that is good is not original, and the part that is original is not good."

"Your manuscript is both good and original; but the part that is good is not original, and the part that is original is not good."

Another one:

"Read over your compositions, and wherever you meet with a passage which you think is particularly fine, strike it out."

Good stuff!

Florida Course

The 2005 instrumentation course in Florida is now history. It was remarkable for the record number of registrants – 96 – and for the breadth of countries from which they came. See the table.

Country	Number of Registrants
Australia	2
Canada	15
Colombia	1
Finland	1
France	3
Germany	1
Greece	1
Iran	1
Italy	1
New Zealand	1
Pakistan	1
Peru	4
Poland	1
Singapore	1
Sweden	1
USA	54
Venezuela	7

Ralph Peck was with us, and signed 55 copies of his book, *"Judgment in Geotechnical Engineering. The Professional Legacy of Ralph B. Peck"*.

We expect that the next course in Florida will be in March 2007. As before, I'll announce details in this magazine, and they will be on the course website *http://www.doce-conferences.ufl.edu/geotech.*

Closure

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

Genatz-et (Armenia)! "To your honor". Thanks to Vahan Tanal for this.

The Truth about Accuracy

Barrie Sellers

The concept of "accuracy" is a source of some confusion among users of geotechnical sensors, and of some frustration on the part of manufacturers. It is the intention of this monograph to eliminate problems caused by equating 'accuracy' with 'resolution', 'linearity' or 'precision' and to place 'accuracy' in its proper context, where it can be seen as just one desirable quality among others and not the *sine qua non* of sensor requirements.

Accuracy - Defined

Accuracy has been defined in many ways, sometimes many ways within the same publication. For example, from reference [1], accuracy is defined as:

> *"The degree of conformity of a measured or calculated value to its definition with respect to a standard reference."*

And somewhat less opaquely as:

> *"The correctness with which a measured value represents the true value."*

And yet again, more completely as:

> *"The degree to which the readings match an acceptable standard (absolute) value and includes the combined effects of all sources of measurement error. Accuracy is written as a +/- value of the full span, e.g., +/- 1% F.S. [Full Scale]. The accuracy specification indicates that the measured value will conform to the absolute values within the stated+/- limits over the full range of the specified operating conditions."*

There is a common human tendency among sensor users to suspect any unwelcome data as being the product of defective (inaccurate) equipment. So, a more cynical definition of accuracy, from a manufacturer's as opposed to a user's point of view, might be:

> *"How closely the measured values conform to predicted values and preconceived notions."*

Accuracy and Truth

Probably the best definition of accuracy is [2]:

> *"The maximum difference between a measured variable and its true value. Usually expressed as a % of the full-scale output. <u>In the strictest sense, accuracy is never known because the true value is never really known</u>."* (Emphasis added).

Accuracy and Traceability

The nearest approach to truth is achieved during calibration of the sensor, when the sensor output is compared against an input variable (measurand) of traceable accuracy. Which is to say, that the calibration equipment and reference standards used have themselves been tested directly (or indirectly through traceable intermediate standards) against the standards of length, mass and time, etc. Traceability is in the care of the appropriate national institute of standards (The National Institute of Standards and Technology, NIST, in the case of the USA). It is desirable, wherever possible, to use calibration standards whose accuracy is greater (preferably 10 times greater) than the sensors being calibrated.

So, one simple answer to the question, *"What is the accuracy of the sensor?"* is that it depends on the accuracy of the equipment used during calibration.

Accuracy and Linearity

But the simple answer is, of course, not enough. Granted that each datum point on the calibration chart is accurate to the degree permitted by the calibration equipment, yet it is an extremely common desire for these points to fall on a straight line in order that the relationship between measurand and sensor output can be characterized conveniently by a single number – the *linear calibration factor.* However, if the calibration datum points do not fall exactly on this straight line then this procedure introduces an error and accuracy suffers.

The accuracy to which the calibration data can be fitted to the best straight line, as determined by linear regression techniques, is called *linearity* (Figure 1). Again, it is usually specified as a % of the full scale. Thus a sensor whose linearity is better than +/-0.1% F.S. will yield output values, calculated using the linear calibration factor, that are in error by no more than +/-0.1% of the full range of the sensor.

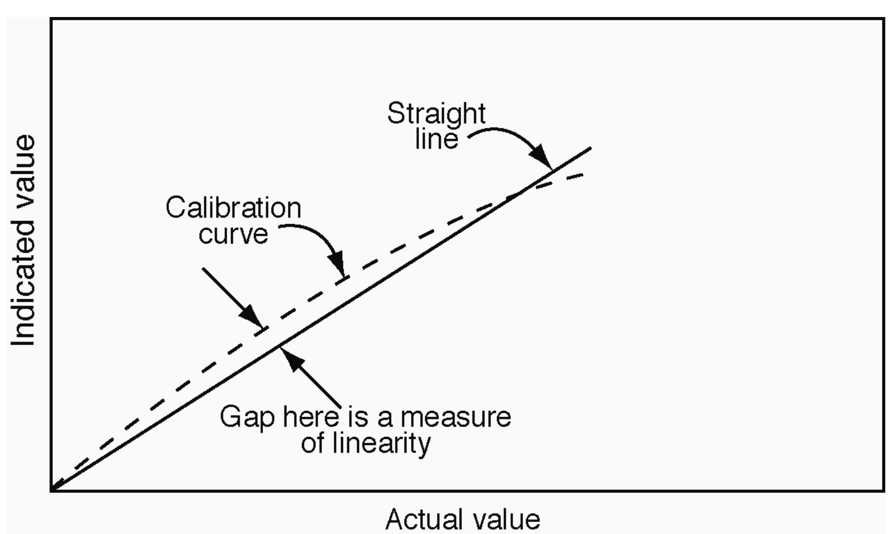

Figure 1. Linearity (Dunnicliff 1988, 1993)

But why should it be thought necessary to sacrifice accuracy on the altar of linearity? Surely it cannot be asking too much, in the day of computers, to fit the calibration datum points to a second order curve or, even a fifth order curve if this is what it takes to recapture the accuracy inherent in each datum point. Or if the highest attainable accuracy is important, why not perform a linear interpolation between the two calibration datum points that straddle the measurement point?

Accuracy and Precision

Other factors intrude upon the simple scenario thus far described. For instance, if the sensor has internal friction it may not yield the same output reading at the same value of the input, depending on whether the measurand is increasing or decreasing. In which case the sensor is said to exhibit *hysteresis.* Similarly, internal friction, viscosity, surface tension effects etc. can also give rise to a *dead band* in which small changes in the measurand are not detected by the sensor. The ability of a sensor to give repeatedly the same reading for the same measurand is termed *precision* or *repeatability.* The above assumes, rightly or wrongly, that the measurand itself can be precisely reproduced, i.e. that there is adequate precision within the calibration apparatus itself.

Precision is a very desirable attribute, especially where the absolute value of the measurand is not as important as the change in the measurand. This is very often the case in geotechnical applications. For instance, inclinometer probes measure changes in tilt along the length of an inclinometer casing, and from these changes the horizontal displacements of the casing are calculated. The absolute value of the inclination of the casing to the vertical is usually of little interest. Another example would be the measurement of roof/floor convergence in a mine opening where the distance between roof and floor is not significant. There are many other examples of a similar nature where high precision permits the detection and accurate measurement of small changes of the measurand, even where the sensor might be grossly inaccurate.

Figure 2 shows the true value of the measurand, represented by the bull's-eye, and three sets of three separate measurements of varying precision and accuracy.

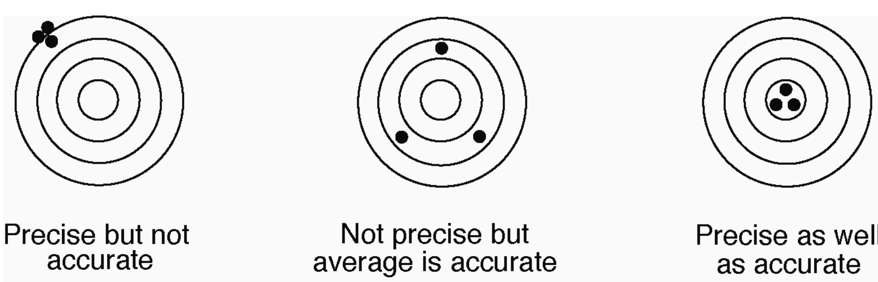

Figure 2. Accuracy and Precision (Dunnicliff 1988, 1993)

Accuracy and Resolution

The measurement of small changes of the measurand brings up another consideration: the *resolution* of the sensor. *Resolution* is the smallest change of the measurand that can be detected and displayed by the sensor and its associated readout equipment. It is frequently limited by the capability of the readout instrument. Resolution is often confused with accuracy in the sense that the question, *"What is the accuracy of the sensor?"* is often a question about what is the smallest change that can be measured. The resolution can be "infinite" in the sense that it is limited only by the capability of the readout instrument and by the fact that, at some point, the signal-to-noise ratio falls below a threshold at which the readout value is no longer steady.

Accuracy and Economics

Accuracy does not come without a price tag: a pressure gage with +/-5% F.S. accuracy might cost $4; one with +/-0.5% F.S. accuracy might cost $40; a test gage with +/-0.1% F.S. - $400; and a +/-0.01% F.S. pressure transducer might cost as high as $4000.

Accuracy and the Real World

In the geotechnical world, measurements are made because of the uncertain nature and random variability of both the material properties and the structure of the rock or soil encountered. There are no guarantees that the value of a parameter measured at one location is typical of the values of the same parameter only a short distance away. Nor can sampling, however closely spaced, entirely eliminate these uncertainties. Therefore, if the inherent uncertainty of the measurand is, say, 5 to 10%, there is no way that the measurements are going to be any more precise or accurate than this – even if taken with sensors of +/-0.1% F.S. accuracy. The *system accuracy*, i.e. the accuracy of the entire system of measurements, taking everything into account, needs to be kept in mind. For a description of the various types of errors that affect overall system accuracy see reference [3].

Micro-Measurements, the leading supplier of electrical resistance type strain gages, has this to say concerning a particular tabulation of accuracies of the various types of gages they manufacture [4]:

> *"It is inappropriate to quantify 'accuracy' as used in this table without consideration of various aspects of the actual test program and the instrumentation used. In general, 'moderate' accuracy for stress analysis purposes is in the 2 to 5% range,*

'high' accuracy in the 1 to 3% range, and 'very high' accuracy 1% or better."

And, bear in mind, these criteria apply to test programs on homogeneous materials whose properties are well known!

Accuracy and Reliability

So, if +/-0.1% F.S. accuracy is unattainable in the real world, why specify it in the first place? The argument must be that, in certain critical situations where questions of safety or economy are dependent on the correct interpretation of measurements made, there needs to be a high degree of confidence in the data and hence in the sensor. In these situations accuracy shades into *reliability* and the important questions to ask are those concerning: (a) robustness of design — *can the sensor survive in the environment to which it is subjected?*; (b) simplicity of design — *the simpler the design the less chance of anything going wrong;* (c) long-term stability — *will the sensor give the same reading next month or next year if the measured parameter does not change?*; (d) insensitivity to other changing parameters such as temperature, moisture, cable effects, lightning damage, electrical noise; (e) prior use — *does this sensor have a good track record in similar situations?* All these questions must be at least as important as *"How accurate is the sensor?"*

Accuracy Put in Perspective

To sum up the desirable properties of a sensor: **Linearity** is nice, but not essential; **Precision** is good, because it allows accurate measurement of small changes even where a sensor might be inaccurate (e.g. large zero offset); **Resolution** should be as high as possible, consistent with the necessity of providing sufficient range; **Reliability** is highly desirable, instilling confidence in the measurement data and a willingness to trust them even when they fly in the face of theory. And **Accuracy..**?

Accuracy is Truth, but—what is Truth?

References

[1]. ASCE (2000), Guidelines for instrumentation and measurements for monitoring dam performance / prepared by ASCE Task Committee on Instrumentation and Monitoring Dam Performance; ISBN 0-7844-0531-X

[2]. Nachtigal, Chester L. (1990). Instrumentation and Control; Fundamentals and Applications. John Wiley and Sons, Inc, ISBN 0-471-88045-0

[3].Dunnicliff, J. (1988,1993). Geotechnical Instrumentation for Monitoring Field Performance. (Chapter 7, Measurement Uncertainty). Wiley, New York, 577 pp.

[4]. Measurements Group, Micro-Measurements Division. Catalogue 500, Part B – Strain Gage Technical Data.

Barrie Sellers, President, Geokon Inc., 48 Spencer Street, Lebanon, NH 03766, Tel: 603- 448-1562, Fax: 603-448-3216, email: barrie@geokon.com

Reminiscences of a Director of Instrumentation Courses

John Dunnicliff

During the past thirty or so years I've been involved with about 100 instrumentation courses, lasting from one to five days. There have been ups and downs, excitements and agonies, satisfactions and frustrations, and I thought it was time to share some of these.

The Executive International Inn

For many years the University of Missouri – Rolla (UMR) organized a course near St. Louis airport. It was usually at the Executive International Inn, a name so impressive that I assumed people would register for the courses from far and wide, just to experience the assumed luxury. In fact it was the kind of hotel where discarded room service dinner trays tended to remain on the floor in the corridors until about lunchtime the next day. One year I tried three rooms before I found one in which the rain didn't come through the ceiling. Why did UMR continue with this place? It was convenient and cheap!

One year the course was in a large room directly across the corridor from another large room, in which was held the 'Southern Baptists' Convention'. After several unsuccessful attempts to make ourselves heard above the singing, we gave up – if you can't beat 'em , join 'em – we moved across the corridor and exercised our lungs in a different way!

Canada

In the early 1990s *Geotechnical News* sponsored a series of instrumentation courses in Canada and the West coast of USA. I well remember the hospitality of local hosts, and the striking difference between some Canadian and USA attitudes. I'll illustrate this with one tale. I was concerned that the lecture room should be locked overnight, because demonstration instruments were left inside. The local host looked me straight in the eye and said, "*John, you're in Canada now – don't worry about it"*!

One of the courses was to be in St. John's, Newfoundland, where I was told there was great interest in offshore oil-drilling platforms. I asked Elmo DiBiagio to join me, because he knows all about instrumentation for that application, and I know nothing. Three people registered, and we cancelled. I remember writing to Elmo, saying, *"Nobody loves us"*.

The Welcome Fight

During one of the four-day courses there was a man on the third row (as you'll see from what follows, the person was self-evidently male). For the first two days he continually added his own

opinion to mine, apparently on a major ego trip, and he was truly getting under my skin. But of course the golden rule of behavior for course directors is that they mustn't upset any attendee. I'd organized a workshop on planning monitoring programs, set the stage for this, divided the attendees into fours, and asked them to appoint a leader who would later come up to the front and present the opinions of the quartet. Of course the man elected himself as leader. After fifteen minutes or so there were loud words from that group and I saw a husky man punch the leader on the chest! Do you want to know how to cheer without letting it be shown? After that experience I used a different format for workshops.

Yawning

One evening before a two-day in-house course at the offices of an engineering company, we all went out 'on the town',

returning in the wee hours (that's Scottish, for those of you unfamiliar with the adjective). While giving the first lecture after lunch the next day, the yawn-frequency was on the rise, so in an attempt to liven things up I said, *"If I see one of you yawning again, something bad will happen to you"*. Very soon after that one person couldn't control a yawn, so: *"Don't you remember what I've just said?"* Another yawn, head well back – I pointed my finger at him and at that moment one of the legs of his chair fell off, and he was on the floor. The place broke up with laughter – yes, it was funny, but it wasn't **that** funny. Later I was told he was the boss! I hadn't remembered him from the night before.

The Smoking Dilemma

During one of the early courses in St. Louis there were several complaints on the evaluation forms about smoking (it was before the days of 'no smoking' arrangements). So the next time I arranged for the smokers to sit at the back. On the evaluation forms several smokers complained about discrimination because they were furthest away for the screen. What to do? The following time, right at the beginning, I told about these two previous experiences and asked the group to tell me what they'd like to do. One person stood up and said in a loud voice, "*Throw the [expletive deleted] out*!" And the course hadn't even started!

A Series of Courses Sponsored by a US Government Agency

Two of us taught more than fifteen three-day courses over a two year period, each in a different State Capital. On waking up, "*Where am I **this** week?"* Attendees came because they were **told** to attend – a very unwelcome situation (but the money was good!). It was usually possible to tell, by body language before the first lecture, what we were in for. Too often one of us said to the other, *"They've emptied the lab out on us again"*, and we'd struggle through the same old stuff. I have many memories, both bad and good – one will be enough.

Somewhere in the Midwest we asked, as we usually did at the end of the first day, *"Where do we go for a good dinner?"* We needed one (and felt that we deserved one!). Various recommendations were given, and we asked again at the hotel, eventually following their recommendation to go to a steakhouse about four miles out of town. The following morning, *"Where did you go to dinner yesterday evening?"* We told them. *"You went all the way out **there**?"*

Volume Discounts

A very important part of these courses is to have demonstration instruments available for attendees to see, touch and talk about. In the early years I invited manufacturers to come and display, but didn't give them time at the podium. What a foolish mistake! It created a *'them and us'* atmosphere, which is nonsense. **We're all in this together.** Have any of you ever read the dedication page in the red book? *"To the manufacturers of geotechnical instruments, without whom there would be no geotechnical instrumentation for monitoring field performance"*. And if you **have** read it, did you notice the double meaning? This is all leading up to a tale about the manufacturer who selected his hot-shot salesman to have the firm's half hour at the podium. I'd just given a lecture about vibrating wire strain gages, and immediately after that he arrived, in an anxious state because his plane had been delayed. He walked into the room with his suitcase, placed it on the podium, opened the top, took out a vibrating wire strain gage and held it out, *"This is a vibrating wire strain gage. Its uses are … Each one costs ..dollars. But if you want more than twenty I can give you a discount of … %. ... ...".*

Greeting card design supplied by courtesy of Rainbow Cards Ltd., England

That reminds me, one of the course sponsors once said to me that I should always make sure that one of the lecturers is bad, so that the rest of us look good by comparison! No – I don't do that!

Inexperienced Lecturer

One lecturer hadn't had much experience of lecturing, so began with limited self-confidence. Early on, as he was explaining a point, he stumbled over words, then went on and on, trying to make it okay. After a while he stopped and said, "*You know, sometimes when you're up here you say something stupid. You try to get out of it. But instead you start digging a hole. You dig, and dig, and dig, making it worse and worse. So you have to stop digging. And I've now stopped, and I'm climbing out of the hole. And I'll start again*". And off he went. Superb! What a wonderful lesson for us all! His confidence rose after that, and he became **very** good.

A Biting Question

During question time after a one-day course in England, someone asked, *"How did you get into such a boring speciality as instrumentation?"* I stumbled over a foolish response, knowing very well that what he **really** meant was that he was bored stiff by my lectures.

Far Away from Home

Hong Kong. During the first lecture, someone's cell phone rang. This was before the time when it became the norm to switch them off in such situations. A shouted conversation followed, and I had to stop and wait for it to end about four minutes later. I seemed to be the only one who was affected by this, perhaps because Hong Kong is such a noisy go-go place (I can say this from experience, as I lived there for four years).

Japan. There was simultaneous translation into Japanese. I spent some time with the bilingual organizer and the translators beforehand (two of them, because they took it in ten-minute turns to do the translation), to go through some technical terms. The body language among attendees didn't look comfortable during the first lecture. During a break immediately afterwards one of the translators came up to me and asked, very diffidently, *"Do you speak Japanese?"* I don't! They were having significant problems with translation of our technology. In the end I spoke more slowly and stopped after every sentence. The bilingual organizer was in the translator's booth with a microphone, and we moved along. But of course it played havoc with the schedule! And in such situations the lecturer has no idea what's being said about him in the other language!

New Zealand. I'd been there several times to work on the same project, and thought I knew them all. Several asked for a signature in a book, so I used the normal format, and for one of them wrote, *"To Chris, with best wishes, signature, date"*. He looked at me and said, *"That's very nice, but my name isn't Chris"*. Fortunately there **was** a Chris in the line, but this taught me a lesson. **Always** be sure to have the name right before starting to write!

A Developing Country. After two days of a 3-day in-house course I'd had enough of wearing the required suit and tie. I knew they were building several large dams and pleaded for a field trip, re-scheduling the final day of the course on return. "*Okay*", they said. So I left with my guide by plane the next morning to the first site – a high masonry dam, just stones and mortar, and lots of people. No motorized equipment. The quality control criterion for the work of the masons was a limit on the ratio of volume of mortar to weight of stone – this ensured maximum jig-sawing of the stones into place. Fascinating! Then by dusty and bumpy road to another site, then another. At about seven in the evening I was taken to an office block, tired, dirty and hungry, and shown through a door through what I expected was — dinner. But no! 300 people waiting for my lecture!

We Were the Best

Two of us were asked to give a one-day course on rock mechanics instrumentation to an in-house group of people who worked for the US government and who, we were told, were involved with nuclear waste disposal. There were about 30 people in the room. My colleague started. After a while one person got up and left. Then another. It's very unnerving when someone leaves in the middle of a lecture – "*What am I doing* *wrong?"* My turn next. More leavings, and so on and so on. In the end we had **seven** people left. In his vote of thanks the person who'd asked us to give the course congratulated us on having so many left at the end!! It turned out that they had a one-day course on something every month, that there were about 30 in the whole office, with many different professions. They'd all show up at the beginning of each, and leave as soon as they realized that they weren't really interested in the subject. Why didn't they warn us?

Evaluations

Course attendees are usually asked to complete course evaluation forms, which I take very seriously, and over the years they've been extremely helpful in learning what needs to be changed – the

lecturers, the topics, the marketing, the logistics – whatever attendees want to say.

It's normal to find that comments on these forms oppose each other – of course – we all want different things and life would be dull if we all wanted the same. *"Don't start the course on a Sunday"*; *"It was great that you started the course on a Sunday because this helped to get my boss's support for me to come"*. *"The hotel was excellent"*; *"Don't use this hotel next time"*. *"Delete topic x from future courses"*; *"Topic x was great"*. And so on. The trick is to take action on any comments that are made by three or more people.

Sometimes the comments are positive (and usually signed), but not infrequently they sting (rarely signed)! And of course if a lecturer is stung, that's a **real** learning experience. I'll tell you about a memorable one of those. I was asked to give several lectures during a course at the office of a government agency, one topic being contract practices for instrumentation hardware and for field instrumentation services. I was on my way home from a field assignment in Honolulu, and was in an easy-going relaxed Hawaii mood. I talked about the options for contract practices, made a strong recommendation for the *professional* ones, and damned the *low-bid* ones – not thinking through the consequences. The agency's practice was always to low bid, so feathers were ruffled. One of the evaluations – *"Don't invite that bum back next time"*. Ouch! Lesson learned!

There's a sequel to this. At a UMR course shortly afterwards, I told that story when handing out blank evaluation forms near the beginning, to get a laugh and to show that it was okay for people to be as honest as they wished. One of the lecturers described earth pressure cells (he made them), and then went on to give a case history about measurement of total stress in the sandy clay core of an embankment dam. He showed calibration data for the cells, the results of finite element predictions of total stress, and plots of measurements. The predictions exactly agreed with the measurements! During question time someone was brave enough to ask, *"Is this a coincidence? Is it possible that both are wrong?"* (I'd wanted to ask the same question, because I know that we can't make accurate measurements of total stress in that application, but a course director must be careful not to upset others). The reply made it clear that both were right. On one evaluation form somebody wrote, *"Don't invite that bum back next time"*.

And now to the comment that made my week after the recent course in Florida, and kept the motivation flowing – *"Please don't take the constructive criticisms (from the evaluations) the wrong way. When something is very good, it generally tends to draw more criticism than if it was very poor – so keep up the great work and don't change too much"*. Thank you, Randy Divito!

Erroneous Readings from a Vibrating Wire Piezometer With a Broken Signal Wire

Gord McKenna

Introduction

A few years ago, a salesperson explained that vibrating wire piezometers (VWPs) are so robust that they can still work even when one of the signal wires is broken. While testing this claim, I learned that such a break can cause intermittent erroneous "ghost" readings which are sometimes observed in field installations too. But the deeper lesson involves a warning regarding quirky instrument readings.

Some Background

VWPs are routinely used to measure pore water pressures below the water table. Made by numerous manufacturers, VWPs consist of a tip with a pressure transducer, attached to an electrical signal cable that can be connected to a VW readout box. The frequency of the vibrating wire in the tip is transmitted by the signal cable to the readout box and is and converted to a pore water pressure reading. The first choice among most of today's practitioners, VWPs are generally very reliable and the measured frequency is independent of lead length, reading proto-

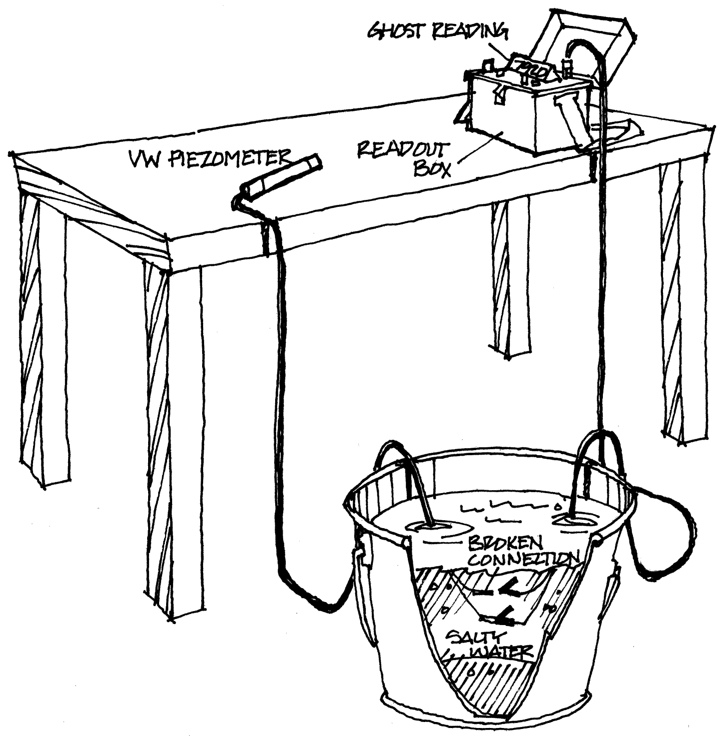

Figure 1. "The myth is busted."

col, and operator skill. *But do they still work when a signal wire is broken?*

The Myth is Busted...

Curious, I filled a pail with tap water and placed it next to two VWP tips (each from a different manufacturer) and a VW readout box. Next, I connected the box's alligator clips to the leads from the first VW tip and recorded the base reading. Leaving everything connected, I submerged the connection in the water and took the next reading (see Figure 1). No change – nice to see that the water didn't short out the signal. Next, keeping the setup underwater, I disconnected one of the alligator clips. The signal was lost, even if the clip was held a fraction of a millimetre from the cable wire – the readout box read zero. In the words of the heroes of the new Discovery Channel show, "The myth is busted!" No connection, no reading.

But what if the groundwater were more conductive than tap water? I dissolved salt in the water and repeated the experiment. Readings underwater with both leads connected were fine as before, but now a gap in a connection of less than half a millimetre caused wildly fluctuating readings. I used electrical tape to keep the gap constant – now the readings fluctuated between the "right" reading and one or two erroneous "ghost" readings. The tip from the second manufacturer gave the same results. The conclusion - bad connection means ghost readings.

Three conditions are needed to produce ghost readings: a break in the signal wire, conductive water must enter the gap, and the broken wires need to be just the right distance apart. I checked with the manufacturer of the readout box – they had already noted this problem, and new updates to the readout box firmware are available to fix the problem, but many older boxes have not been updated yet.

Field staff confirmed that some vibrating wire tips sometimes provide readings that alternate between two readings. Typically both frequencies are recorded on the data sheet and the "right" one is put into the database. Choosing the right reading is usually easy, but not always. It raises a more general question of how to deal with quirky instruments and odd readings – a question that arises on just about every large job, and the subject of lesson #3 below.

Three Lessons Learned

1. You can learn a lot by experimenting. Quick and dirty experiments can be used to verify or falsify theories or claims, often more quickly and cheaply than arguing. Look for opportunities to experiment – you can learn a lot in a few minutes.
2. An erroneous reading is worse than no reading. Instruments and protocols need to be designed to avoid creating erroneous readings.
3. Beware of quirky instrument readings. If you are getting odd readings from an instrument, even only some of the time, you need to decide formally whether you can rely on this instrument or if it needs to be abandoned or replaced. A purist might write off the instrument and perhaps its previous readings too. Most practitioners will try to interpret the readings, try a different readout box, and replace the tip if practicable– in some cases the money spent on redrilling will be less than that spent trying to explain quirky readings. While quirky readings may indicate a new geotechnical phenomenon, the problem probably lies with the instrumentation. Confront the decision head on, and record your decision and rationale.

Gord McKenna, Senior Geotechnical Engineer, Norwest Corporation, #830-1066 West Hastings Street, Vancouver, BC Canada V6E 3X2, Phone 604-602-8992, Fax 604-602-895, e-mail: gmckenna@norwestcorp.com

Discussions of "Erroneous Readings from a Vibrating Wire Piezometer With a Broken Signal Wire"

Gord McKenna

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Simon Cornwallace

The signal in a vibrating wire instrument system is very robust, but two wires are needed.

In our experience the most common reason for "ghost" reading is a count error cause by either excessive noise on the line or the incorrect range having been selected, manually or automatically. Routines were written into firmware some years ago to identify count errors and show no reading or a flashing reading if the signal is marginal. Other circumstances may cause this phenomenon and with careful feedback from users (like Gord McKenna) they can be dealt with.

Gord's three points at the end of his article are especially useful. Designing experiments to learn the capability and limits of an instrument before installation or burial to confirm suitability can be a useful tool. We would agree with point two but we would often rely on user input to outline problem circumstances we had not previously identified. Intermittent erroneous readings taken in ill-defined circumstances can be very difficult to process out but a reproducible one is not. User feedback is one of the instrument manufacturers' most valuable tools, so please include us in discussions of "quirky" readings. If it's been seen before we may be able to help you. If it's not been seen before, you may help us and other users in the geotechnical community.

Simon Cornwallace, Operations Manager, Durham Geo Slope Indicator, 12123 Harbour Reach Drive, Mulkiteo, WA 98275, Tel. 800-331-0703, email: scornwallace@slope.com

Barrie Sellers

It appears that someone either told an untruth or perhaps Gord misunderstood, because of course it would be impossible to read a vibrating wire sensor through one wire: you need two wires to have a circuit so that you can send current pulses out, to get the wire vibrating, and to get the sinusoidal alternating current signals back for analysis.

Output frequency signal from a vibrating wire sensor is not degraded by high circuit resistances in the same way as an output voltage or current signal would be. The frequency signal may be attenuated but is not altered and may still be readable, and I think that Gord's experiment confirms this.

The phenomenon of 'ghosting' is something that we have noticed on occasions ourselves and is a bit of a puzzle. The only explanation I can think of for the frequencies to jump in discrete quanta is that another extraneous frequency, of a constant nature, is periodically being superimposed on top of the resonant vibrating wire frequency. Where this extraneous frequency comes from is not clear: it may be due to energy radiated from power lines, fluorescent lights, radio interference, etc. It gets on to the output signal through the high resistance leakage to ground at the point where the cable insulation has been breached. As Gord says, the ghosting is usually intermittent so that the basic resonant frequency can usually be seen by inspecting a plot of the output signal with time.

We at Geokon will perform some experiments along the lines that Gord has described, in order to learn more about this 'ghosting' phenomenon, and to what extent it can be eliminated by digital signal processing. If we learn something worthwhile, we will submit it for publishing in GIN.

I do think that Gord's experiment shows how the single wire myth (if one indeed exists) might have arisen, and also why vibrating wire sensors are remarkable in that they can still be read even though there may be a very high resistance in the output circuit.

Barrie Sellers, President, Geokon Inc.